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Water Storage Potential of Two Different Dry Dipterocarp Forest Sites in Northern Thailand

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ABSTRACT

This research aimed to compare the water storage in the dry dipterocarp forest (DDF) at two sites located in Chiang Mai province, northern Thailand. Vegetation survey was carried out in the forest using a 40 × 40 m^2 plot, with 12 and 15 plots in Site 1 and Site 2, respectively. Plant data were obtained by measuring the stem girths at 1.3 m above ground and heights of trees with a height greater than1.5 m. Plant characteristics, biomass, and stored amounts of water were measured. The DDF at Site 1 was divided into four stands based on the most dominant tree species, which were *Shorea obtusa*, *Shorea siamensis*, *Dipterocapus obtusifolius*, and *Dipterocarpus tuberculatus*. The DDF composed of 60 species (50 genera and 31 families) and had a plant biomass of 91.99±11.44 Mg ha^{-1}, with 100.70±9.91 m^3 ha^{-1} as the contained amount of water. The maximum water holding capacity (MWHC) of the soil was estimated to be about 1,837.21±96.35 m^3 ha^{-1}. The amount of water in the soil during the winter (December 23, 2015) and the rainy season (July 26, 2016) was estimated at 330.83±102.37 m^3 ha^{-1} (18.0% of MWHC) and 1,072.46±18.93 m^3 ha^{-1} (58.37%), respectively. The DDF at Site 2 was composed of five stands, which included the *Pinus merkusii* stand. Its species richness (83 species, 69 genera, 42 families), plant biomass (125.49±53.61 Mg ha^{-1}), and amount of water (124.55±45.40 m^3 ha^{-1}) was higher than that of Site 1. The soil under the *D. obtusifolius* stand was deep and was able to store the maximum amount of water at 4,981.57±132 m^3 ha^{-1}, with the amount of water at the end of the rainy season (October 12, 2014) calculated to be around 783.58±21.00 m^3 ha^{-1} (15.72%). Thus, the DDF at Site 1 had a lower potential for water storage than the DDF at Site 2.

Keywords: biomass water, dry dipterocarp forest, plant biomass, soil water, water storage

INTRODUCTION

Water is the most important factor for survival for all living organisms on Earth. Plants, animals, and microbes have a water demand throughout their live cycle. In tropical countries such as Thailand, rainfall is the only source of water supply to watersheds and all ecosystems. Forest ecosystems have the functional role of being a channel for the hydrological cycle through many related processes (Landberg and Gower, 1997; Waring and Running, 1998; Kimmins, 2004; Chang, 2006) including interception, through fall, stem flow, surface and sub-surface runoffs, infiltration into the soil, stream flow, evaporation, transpiration, etc. However, these processes vary greatly between forests. In northern Thailand, five typical forests are found in the different altitudinal ranges: the dry dipterocarp forest (DDF), between elevations of 50 m to 1,300 m above sea level (a.s.l); the mixed deciduous forest (MDF), between 50 m to 800 m a.s.l; the dry evergreen forest (DEF), between 50 m to 1,000 m a.s.l; the pine-dry dipterocarp forest (pine-DDF), between 500 m to 1,300 m a.s.l; the pine-lower montane forest (pine-LMF), between 1,000 m to 1,900 m a.s.l; and the montane forest (MF), between 1,000 m to 2,580 m a.s.l (Smitinand *et al*., 1980, Santisuk, 1988; Khamyong *et al*., 2014a). The two deciduous forest types (DDF and MDF), including, pine-DDF and pine-LMF usually have forest fires during summer, while the evergreen broad-leaved forests (DEF and MF) normally have no forest fires. Most previous studies have focussed on inputs such as precipitation in the forest ecosystems and the movement of water through many processes, particularly interception–evaporation by the forest canopy, throughfall, stemflow, plant uptake, transpiration, water flow through the vegetation, evaporation from the soil, infiltration into the soil, drainage and runoff, stream flow, etc. However, very few data sources are available for the quantity of water stored as plant biomass in such forests. Khamyong *et al*. (2014b) performed a pioneer work on water storage in plants and soil in two community montane forests of the Karen tribe in northern Thailand. To examine and evaluate the role of plantation forests in watershed hydrology, the water storage potential of a 22-year-old teak and three needle pine plantations was investigated by Khamyong *et al.* (2014c) and Summanochitraporn (2014a).

This research paper aimed to assess the water storage potential of the plants and soil in the dry dipterocarp forest at two sites located in Chiang Mai province, northern Thailand. The results can provide useful information forest conservation and watershed management.

MATERIALS AND METHODS

1. Study areas

Site 1: Huai Hong Khrai Royal Development Study (HHKRDS) Center

The HHKRDS Center was established in 1982 in the Huai Hong Khrai small watershed, Doi Saket district, Chiang Mai province. It is about 27 km north of Chiang Mai city, on the road from Chiang Mai province to Chiang Rai province. The establishment of the Center was initiated by the King (Rama 9), and it was meant to be a center of study about integrated watershed management, forestry at the upstream, fishery at the downstream, and agriculture in the in-between areas for the people in the north. It covers an area of about 1,360 ha with an altitude ranging between 350 m and 591 m a.s.l. As a part of extension in the Center, many activities related to forest and wildlife management, agriculture, and fishery are demonstrated to the officers and people. Foreign visitors come here for learning as well.

Meteorological data measured using the instruments at the Center for the years between 1985 and 2011 are available and recorded the following parameters: average annual rainfall, 1,328.9 mm; average maximum and minimum air temperatures, 32.2°C and 18.9°C; and average water evaporation, 1,222.6 mm per year (Khamyong *et al*., 2016). The two deciduous forests, the DDF and MDF, are distributed in most of the area around the Center. The DDF is located on volcanic rocks and covers the eastern part of the Center, whereas the MDF is located on sandstone and is found in the western part.

Site 2: Mae Tha Sub district Community Forest

The community forest of the Mae Tha subdistrict located in the Mae On district, Chiang Mai province, was established in 1989 and covers an area having an altitude range between 480 m and 1200 m a.s.l. It is different from other community forests in that it is united at the subdistrict level and does not belong to a single village. Seven villages in the Mae Tha subdistrict are engaged in mutual forest management with the Mae Tha Subdistrict Administrative Organization. During the years 1901 to 1969, the forest concessions were given to private companies for timber, especially teak, wood railway sleepers, and firewood to supply to a tobacco factory. These activities resulted in forest degradation and there were occurrences of critical drought in 1991 and 1992. Therefore, the villagers in the Mae Tha subdistrict organized to work closely with the Mae Tha Subdistrict Administrative Organization. They set rules and regulations for the management of natural resources and the community forest (Phongkhamphanh, 2015). The management by this subdistrict office is recognized by the Royal Forestry Department, and recently, the government has begun issuing right certificates of the community land to people living in the subdistrict. Forest clearing and illegal tree cutting is strictly prohibited according to the rules and is done under inspection. However, the villagers can use some standing dead trees in the forest for fuel as per the regulations.

2. Plant community study

Field vegetation survey of the forests was carried out using the method of plant community analysis. The sampling plot was $40 \times 40\ m^2$ in size, and the number of plots used in the forests at Site 1 and 2 were 12 and 15, respectively. These were located randomly in the forest area and were chosen based on different topographic conditions such as altitude, slope aspect, position, and gradient. Stem girths at breast height (gbh, 1.3 m above ground) and tree heights, of all species with height above 1.5 m, were measured. All plots were located using the global positioning system (GPS). The field plant data were later calculated for species diversity (Krebs, 1985) and forest condition index (FCI), based on an equation reported by Seeloy-ounkeaw *et al.* (2014)

$$FCI = \sum n_1.10^{-4} + n_2.10^{-3} + n_3.10^{-2} + n_4.10^{-1} + 1(n_5) + 2(n_6)$$

where n_1 = number of individual trees having GBH <25 cm

n_2 = number of individual trees having GBH 25 to <50 cm,

n_3 = number of individual trees having GBH 50 to <75 cm,

n_4 = number of individual trees having GBH 75 to <100 cm,

n_5 = number of individual trees having GBH 100 to <200 cm, and

n_6 = number of individual trees having GBH 200 to <300 cm.

3. Estimation of plant biomass

The standing biomass contained in the stem, branch, leaf, and root organs was calculated using allometric equations obtained for deciduous forests in Thailand by Ogino *et al.* (1967) as

$$W_S = 189\,(D^2H)^{0.902}$$

$$W_B = 0.125Ws^{1.204}$$

$$1/W_L = (11.4/ws^{0.90}) + 0.172$$

where W_S = stem biomass in kilogram (kg)

W_B = branch biomass in kg

W_L = leaf biomass in kg.

The unit of measurement for stem diameter (D) and tree height (H) was meter (m). Based on the bark thickness, the average value of its biomass was estimated to be 10% of the stem biomass (Sumanochitraporn, 2014b). The root biomass was calculated using the equation suggested by Ogawa *et al.* (1965), which is $W_R = 0.026\,(D^2H)^{0.775}$, where W_R is the root biomass. The units used in this equation were kg for W_R, cm for D, and m for H.

4. Water storage in plants and soils

(1) Water storage in plant biomass

Samples of fresh bark, stem, branch, and leaf on the standing trees, of four dipterocarps (*Shorea obtusa, Shorea siamensis, Dipterocarp tuberculatus* and *Dipterocarp obtusifolius*) in the DDF, were taken in December 2015 for **Site 1**, and in December 2014 for **Site 2**. Three individual trees, with stem-gbh classes <50 cm, 51–75 cm, and >76 cm, were used as the sample trees for each species. Fresh plant samples, of 10 to 30 grams in weight, were oven dried at 75°C until a constant weight was achieved, and later quantified for their water content. The water quantity in the biomass of each dipterocarp species was calculated by multiplying its biomass with the water content of each stem-gbh class. The average water content of these dipterocarps was used to calculate the amount of water in the plant biomass of other species in the forest.

(2) Water storage in soils

In Site 1, the soil derived from the sandstone in the DDF, was studied only in the *D. obtusifolius* stand. A pit, 1.5 m × 2 m × 0.8 m in size, was made, and soil samples were collected from various depths using a 100 cm^3 corer. Samples were collected during two seasons (winter, December 12, 2015, and rainy season, July 26, 2016) from seven soil depths with three replications: 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, and 60–80 cm.

As for Site 2, the soil study was also conducted only in the *D. obtusifolius* stand, which has a deep-weathered soil derived from granitic rocks, with the soil samples taken from ten depths with three replications: 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 80–60, 80–100, 100–120, and 120–140 cm. Some physical properties measured on the sampling days, such as soil mass, maximum water holding capacity (MWHC), and field moisture content, were later analyzed in a laboratory.

The MWHC was determined from the field capacity (FC) (Brady and Weil, 2010). Water was added into the soil sample with the 100 cm^3 corer until the soil sample was completely saturated with water, after which the water was allowed to drain out of the macro pores.The soil samples were then oven dried at 105°C within a few days or until they achieved a constant weight, and later on, their moisture content value was determined. Also, the soil was sent for the estimation of the field water capacity, and it was later measured for moisture content by volume. The FC was calculated using the equation FC = Vw/Vt, where Vw is the volume of water and Vt is the total volume of soil. Finally, the amount of water storage per unit area in each soil layer was determined and the total amount within the respective soil depths per unit area was calculated.

RESULTS AND DISCUSSION

The results of this research study included findings on plant community structures, amount of standing plant biomass, water content levels, and storage in plant biomass and soils, of the DDF in the two locations.

1. Plant community structures, diversity, and forest conditions

Site 1: HHKRDS Center

The plant community structures of the DDF in the HHKRDS Center have already been described in detail in a previous study by Khamyong *et al.* (2016). A brief description based on the data obtained by them is included here. A total of 12 sampling plots, 40 × 40 m^2 in area, were used, in which identified species of 60 species (50 genera and 31 families) were found. The forest was divided into four stands based on the dominant tree species: eight plots of Hiang (*Dipterocarpus obtusifolius*), two plots of Rang (*Shorea siamensis*), and one plot each of Teng (*Shorea obtusa*) and Pluang (*Dipterocarpus tuberculatus*). These stands consisted of 59, 19, 20, and 28 species, respectively, and had an average density of 4,763, 1,763, 1,525, and 3,225 trees ha^{-1}.

The values of the Shannon-Wiener Index (SWI), which is an indicator of plant species diversity were in the following order: 3.29, 2.70, 2.88, and 3.46 (3.17$\pm$0.32, on average), while the forest condition index (FCI) values were measured to be 1.70, 2.83, 2.19, and 1.79, or 1.94$\pm$1.98, on average.

Site 2: Mae Tha Subdistrict Community Forest

The plant community structures in the DDF at the Mae Tha subdistrict community forest have also been reported in detail in a previous study by Phongkhamphanh (2015) and are briefly described here. In 15 plots, 40 × 40 m^2 in area, 83 species (69 genera and 42 families) existed in the forest. This forest was divided into five stands based on the dominant tree species: six plots of Teng (*Shorea obtusa*), three plots of Rang (*Shorea siamensis*) and Pluang (*Dipterocarpus tuberculatus*), two plots of two-needle pine (*Pinus kesiya*), and one plot of Hiang (*Dipterocarpus obtusifolius*). These stands consisted of 59, 48, 31, 49, and 35 species, respectively, and had an average density of 2,723±668, 2,115±263, 1,857±681, 2,266, and 2,544 trees ha^{-1}.

The SWI values were calculated as: 3.27, 2.97, 3.43, 3.92, and 3.55 (3.35±0.46, on average), while the FCI values were measured to be 3.37, 3.11, 4.25, 3.35, and 5.87, or 4.53±3.35, on average. This implied that the species diversity and the forest condition of the DDF at Site 1 was lower than that in Site 2.

2. Standing plant biomass

Site 1: HHKRDS Center

Table 1 shows the amount of standing plant biomass in the four stands of the DDF at Site 1. The average amount of biomass in the 12 plots was around 91.99±11.44 Mg ha^{-1}, with the stem, branch, leaf, and root organs contributing 5.98 (6.50%), 53.80 (58.48%), 17.96 (19.52%), 1.99 (2.17%) and 12.26 (13.33%) Mg ha^{-1}, respectively. The average amount in the stands of *D. obtusifolius*, *S. siamensis*, *D. tuberculatus,* and *S. obtusa* were in the following order: 96.72, 86.97, 78.69, and 88.08 Mg ha^{-1}.

Site 2: Mae Tha Subdistrict Community Forest

The amounts of standing plant biomass in the 15 plots of the DDF at Site 2 are given in Table 2. The average biomass amount of all the stands was estimated to be 125.49±53.61 Mg ha^{-1}, with the contribution from bark, stem, branch, leaf, and root organs as 7.96 (6.35%), 71.68 (57.12%), 29.28 (23.34%), 1.69 (1.35%) and 14.86 (11.84%) Mg ha^{-1}, respectively. The total amount of biomass in the stands of *S. obtusa, S. siamensis, D. obtusifolius, D. tuberculatus,* and *P. merkusii* were at 134.81, 158.81, 146.08, 118.26 and 61.99 Mg ha^{-1}, respectively. This implies that the *S. siamensis* stand had the highest amount of biomass while the lowest amount was obtained for the *P. merkusii* stand. The DDF at Site 2 had a higher value of standing biomass than that in Site 1. Disturbance caused by humans through tree cutting during the forest concession and illegal cutting, before the establishment of HHKRDS Center at Site 1, could have been more severe than in Site 2 before the establishment of its community forest.

Table 1 Quantity of plant biomass in twelve plots of the DDF at Site 1.

Plot No.	Dominant tree	Plant biomass (Mg ha^{-1})					
		Bark	Stem	Branch	Leaf	Root	Total
1	*D. obtusifolius*	6.28	56.52	18.59	2.41	13.36	97.16
2	*D. obtusifolius*	4.96	44.60	15.26	1.69	9.97	76.48
3	*D. obtusifolius*	6.10	54.90	17.86	2.29	12.93	94.08
4	*D. obtusifolius*	5.88	52.91	16.50	2.33	12.54	90.16
5	*D. obtusifolius*	6.84	61.52	20.14	2.47	14.10	105.07
6	*D. obtusifolius*	6.82	61.38	20.60	2.36	13.90	105.06
7	*D. obtusifolius*	6.43	57.87	20.77	1.92	12.47	99.46
8	*D. obtusifolius*	6.92	62.29	19.34	2.80	14.96	106.31
	Mean±S.D.	6.28±0.61	56.50±5.49	18.63±1.86	2.28±0.32	13.03±1.40	96.72±9.68
9	*S. siamensis*	5.83	52.49	19.71	1.59	10.96	90.59
10	*S. siamensis*	4.73	42.56	14.24	1.64	9.61	72.78
	Mean	5.28	52.81	16.98	1.61	10.29	86.97
11	*D. tuberculatus*	5.11	46.02	15.66	1.7	10.20	78.69
12	*S. obtusa*	5.84	52.52	16.82	0.73	12.17	88.08
	Mean±S.D. (12 plots)	5.98±0.71	53.80±6.39	17.96±2.14	1.99±0.54	12.26±1.67	91.99±11.44
	%	6.50	58.48	19.52	2.17	13.33	100

Table 2 Quantity of plant biomass in fifteen plots of the DDF at Site 2.

Plot No.	Dominant tree	Plant biomass (Mg ha^{-1})					
		Bark	Stem	Branch	Leaf	Root	Total
1	*S. obtusa*	8.05	72.49	24.89	1.86	16.18	123.47
2	*S. obtusa*	15.52	139.67	88.98	2.33	23.15	269.64
3	*S. obtusa*	6.25	56.22	21.53	0.87	11.67	96.53
4	*S. obtusa*	6.24	56.13	17.50	2.99	13.48	96.33
5	*S. obtusa*	8.89	80.02	31.40	2.70	17.04	140.06
6	*S. obtusa*	5.39	48.47	13.36	3.18	12.41	82.81
	Mean±S.D.	8.39±3.40	75.50±30.62	32.94±25.69	2.32±0.78	15.66±3.86	134.81±63.23
7	*S. siamensis*	12.15	109.32	43.46	1.21	21.63	187.76
8	*S. siamensis*	11.20	100.83	36.92	1.33	21.24	171.53
9	*S. siamensis*	7.70	69.29	22.46	1.78	15.93	117.16
	Mean±S.D.	10.35±1.91	93.15±17.22	34.28±8.77	1.44±0.25	19.60±2.60	158.81±30.1900
10	*D. obtusifolius*	9.42	84.75	32.16	2.11	17.64	146.08
11	*D. tuberculatus*	9.20	82.82	40.69	0.46	14.75	147.93
12	*D. tuberculatus*	6.51	58.58	20.51	1.57	13.01	100.18
13	*D. tuberculatus*	5.14	46.28	15.95	1.12	10.36	78.85
	Mean±S.D.	7.09±2.93	68.11±16.28	27.33±9.72	1.32±0.61	13.94±2.65	118.26±29.720
14	*P. merkusii*	5.02	45.20	21.34	0.91	8.56	81.03
15	*P. merkusii*	2.79	25.14	8.11	1.01	5.89	42.94
	Mean	3.91	35.17	14.73	0.96	7.22	61.99
	Mean±S.D. (15 plots)	7.96±3.14	71.68±28.24	29.28±18.71	1.69±0.80	14.86±4.71	125.49±53.6100
	%	6.35	57.12	23.34	1.35	11.84	100

3. Water storage in plants and soils of DDF

3.1 Amount of water stored in plant biomass

Data regarding the water content (as a percentage, %, by fresh weight), in the different organs of the four dipterocarp tree species, in the DDFs at Site 1 and Site 2 are given in Table 3. The water content used in the root was the average of the water content in the stem and the branch because these organs are composed of woody tissues as roots. The water content by fresh weight of the four dipterocarps in the two sites varied in the same range, and the differences between the three stem-gbh classes was not large. In the bark, the water content for the *S. obtusa, S. siamensis,* and *D. obtusifolius* was found to range between 44.75% to 59.97%. As for *D. tuberculatus*, the content was higher than that in these three dipterocarps, ranging between 57.35% to 70.85%. The water content in the stem, branch, leaf, and root of these species also varied in the same ranges: stem, 31.33% to 51.95%; branch, 46.24% to 67.87%; leaf, 46.62% to 71.31%; and root, 41.98% to 59.75%. The stem had a lower water content compared to the other organs. The values were higher for the branch and the highest content was in the leaves of young trees of *S. obtusa* and *S. siamensis*.

In Table 4, the data related to water content (as a percentage, %, by dry weight) in these four dipterocarps are indicated. These data were used for the calculation of the amount of water in the standing plant biomass of the dipterocarps. The mean value of the water content in the bark, stem, branch, leaf, and root was used for the estimation of the amount of water in the plant biomass of the other species.

Site 1: HHKRDS Center

Table 5 shows the amount of water in the plant biomass in the 12 plots of the DDF at Site 1. The average amount of water in the plant biomass of all the stands (12 plots) was calculated as 100.70±9.91 m^3 ha^{-1}. The average value in the stands of *D. obtusifolius*, *S. siamensis, D. tuberculatus,* and *S. obtusa* was 103.95, 93.70, 89.35, and 100.11 m^3 ha^{-1}, respectively. Thus, there were small differences in the amounts of water in the plant biomass between the four stands. The percentages of the amounts of water in the bark, stem, branch, leaf, and root were in the following order: 7.48%, 46.37%, 27.82%, 5.38%, and 12.95%, respectively.

Site 2: Mae Tha Subdistrict Community Forest

As shown in Table 6, some differences in the amount of water in the plant biomass in the DDF were observed between Site 1 and Site 2. The average amount of water in the plant biomass of all the stands (15 plots) at Site 2 was a little higher than that at Site 1, as indicated by a value of 124.55±45.40 m^3 ha^{-1}. However, the amount of water differed greatly between the five stands. The amounts in the stands of *S. obtusa*, *S. siamensis*, *D. obtusifolius*, *D. tuberculatus,* and *P. merkusii* were estimated to be 129.04, 151.05, 158.28, 113.62, and 70.85 m^3 ha^{-1}, respectively. The amount of water stored in the *S. siamensis* stand was the greatest, whereas the *P. merkusii* stand had the lowest amount. This was a result of different levels of forest disturbance through selective tree cutting in the past. The percentages of the amount of water in the bark, stem, branch, leaf, and root were in the following order: 7.15%, 42.79%, 31.26%, 8.15%, and 12.64%, respectively.

Table 3 Water content (as a percentage, %, by fresh weight) in plant organs of four Dipterocarps having three stem-gbh classes in DDFs at Site 1 and Site 2.

Stem-gbh class (cm)	Site	Water content in different plant organs (% by fresh weight)				
		Bark	Stem	Branch	Leaf	Root
		Shorea obtusa				
<50	1	51.29±2.10	48.82±3.91	58.31±8.16	68.40±3.78	52.25±4.79
	2	49.01±2.19	36.47±2.34	46.95±2.16	50.16±2.56	44.14±1.21
51–75	1	45.22±1.49	46.83±11.49	46.24±12.79	70.92±4.46	46.81±1.40
	2	46.70±1.90	32.12±3.09	47.56±3.05	50.60±1.04	42.13±1.59
>76	1	47.77±3.04	40.01±3.93	54.37±5.58	61.93±5.75	45.95±1.92
	2	48.93±3.73	37.33±3.05	46.89±4.75	50.81±0.83	44.38±3.39
		Shorea siamensis				
<50	1	59.97±2.62	51.95±4.30	66.27±3.85	71.31±4.87	56.02±2.43
	2	47.22±5.57	47.13±3.66	60.90±0.23	55.93±5.28	51.75±2.69
51–75	1	58.88±2.96	46.92±3.73	65.27±2.80	70.95±2.57	55.29±3.73
	2	51.68±4.27	41.59±2.12	62.60±2.61	57.44±3.37	51.69±1.97
>76	1	54.91±5.35	47.97±3.88	65.86±4.34	65.95±4.27	53.05±4.05
	2	49.75±1.68	38.36±6.68	59.85±0.53	58.08±3.92	49.32±2.50
		Dipterocarpus obtusifolius				
<50	1	47.10±2.90	48.65±3.54	58.55±2.15	51.21±1.91	47.88±2.33
	2	58.81±5.83	49.83±3.19	56.81±2.30	53.79±1.97	55.15±3.26
51–75	1	53.68±14.57	31.33±19.54	57.42±6.96	46.62±11.95	45.73±2.73
	2	46.57±9.42	41.14±4.17	56.81±2.30	53.79±1.97	43.86±5.41
>76	1	45.40±3.61	45.78±2.13	56.67±3.17	50.42±6.84	45.35±2.63
	2	44.75±2.73	39.20±1.31	59.85±0.53	58.08±3.92	41.98±2.01
		Dipterocarpus tuberculatus				
<50	1	65.00±2.94	50.58±1.53	67.63±5.46	66.09±2.35	57.64±2.35
	2	70.85±3.89	40.02±1.59	68.38±3.97	63.58±4.27	59.75±0.57
51–75	1	64.75±3.02	48.26±3.69	58.14±4.66	61.50±3.09	58.38±1.57
	2	57.35±6.47	38.70±3.35	65.89±4.94	58.90±1.75	51.75±5.46
>76	1	57.50±4.27	44.44±4.13	63.98±9.76	62.18±1.06	53.05±3.33
	2	61.78±5.82	38.56±3.61	67.87±4.94	62.57±1.75	52.37±4.70

Table 4 Water content (as a percentage, %, by dry weight) in plant organs of four Dipterocarps having three stem-gbh classes in DDFs at Site 1 and Site 2.

Stem-gbh class (cm)	Site	Water content in different plant organs (as a % of dry weight)				
		Bark	Stem	Branch	Leaf	Root
		Shorea obtusa				
<50	1	105.61±8.99	96.53±15.34	147.48±53.79	221.07±33.33	111.37±22.55
	2	90.72±8.39	58.83±5.72	91.57±7.79	91.57±10.66	91.57±3.53
51–75	1	82.65±4.93	95.01±48.08	92.44±40.66	249.73±57.76	88.09±4.90
	2	87.78±6.61	47.53±6.82	91.13±11.17	102.49±4.24	75.48±5.11
>76	1	91.91±11.54	67.15±10.61	121.41±27.65	167.11±43.76	85.16±6.70
	2	96.54±14.74	59.81±7.98	89.27±16.36	103.34±3.42	81.87±11.55
		Shorea siamensis				
<50	1	151.08±16.54	109.81±19.01	200.80±31.98	258.78±61.87	127.85±12.55
	2	90.92±20.15	89.78±13.64	155.75±1.54	129.17±28.15	112.15±9.66
51–75	1	144.00±17.39	89.02±13.33	189.12±22.52	246.13±31.41	124.66±18.22
	2	108.06±18.89	71.36±6.12	168.26±18.46	135.92±18.65	115.89±9.46
>76	1	123.97±27.59	92.93±14.54	196.25±39.48	197.06±39.92	114.06±18.36
	2	99.16±6.65	63.59±18.88	149.07±3.27	139.88±21.55	103.94±7.08
		Dipterocarpus obtusifolius				
<50	1	89.66±11.13	96.60±13.11	142.77±14.22	107.38±7.33	92.36±8.53
	2	145.91±33.25	99.89±12.83	131.99±12.38	116.67±9.51	125.93±17.58
51–75	1	134.65±89.67	52.70±37.36	139.42±42.20	93.12±38.78	84.58±9.39
	2	91.00±32.79	70.46±11.78	131.99±12.38	116.67±9.51	80.73±18.85
>76	1	83.70±12.37	84.61±7.16	131.62±16.82	104.13±35.02	83.27±9.04
	2	41.98±8.72	81.29±3.49	149.07±3.27	139.88±21.55	72.91±6.08
		Dipterocarpus tuberculatus				
<50	1	187.51±23.69	102.54±6.12	215.05±54.39	196.71±21.52	136.90±13.51
	2	247.34±47.60	66.79±4.50	219.62±40.81	177.16±33.08	177.9±5.59
51–75	1	185.10±24.55	93.94±13.96	140.94±27.60	160.88±21.17	140.49±9.30
	2	137.82±33.18	63.45±8.84	196.29±42.99	143.56±10.41	120.2±32.32
>76	1	136.96±25.08	80.67±14.03	193.38±87.85	164.58±7.45	113.74±15.74
	2	166.07±43.49	63.14±9.91	211.21±42.99	167.15±10.41	172.5±93.89

Table 5 Amount of water stored in plant biomass in twelve plots of the DDF at Site 1.

Plot No.	Dominant tree	Amount of water in plant biomass ($m^3\ ha^{-1}$)					
		Bark	**Stem**	**Branch**	**Leaf**	**Root**	**Total**
1	*D. obtusifolius*	7.50	49.59	30.04	5.74	13.82	106.69
2	*D. obtusifolius*	6.62	40.55	25.48	3.56	11.34	87.55
3	*D. obtusifolius*	7.36	47.40	27.15	5.56	13.37	100.84
4	*D. obtusifolius*	7.03	44.52	24.90	6.35	12.61	95.41
5	*D.obtusifolius*	8.97	49.43	30.77	7.68	14.57	111.43
6	*D. obtusifolius*	8.62	50.35	31.24	6.96	14.24	111.40
7	*D. obtusifolius*	7.47	48.46	30.49	5.17	12.47	104.05
8	*D. obtusifolius*	8.31	54.14	29.55	6.86	15.36	114.22
	Mean±S.D.	7.73±0.76	48.06±3.81	28.70±2.34	5.98±1.20	13.47±1.22	103.95±8.49
9	*S. siamensis*	7.53	47.38	34.79	3.91	12.18	105.78
10	*S.siamensis*	5.99	37.63	22.98	4.44	10.59	81.62
	Mean	6.76	42.51	28.88	4.17	11.38	93.70
11	*D. tuberculatus*	7.18	42.70	24.05	3.41	12.00	89.35
12	*S. obtusa*	7.80	48.21	24.74	5.37	13.99	100.11
Mean of 12 plots		7.53±0.79	46.70±4.39	28.01±3.48	5.42±1.33	13.04±1.36	100.70±9.91
%		7.48	46.37	27.82	5.38	12.95	100

Table 6 Amount of water stored in plant biomass in fifteen plots of the DDF at Site 2.

Plot No.	Dominant tree	Amount of water in plant biomass (m^3 ha^{-1})					
		Bark	Stem	Branch	Leaf	Root	Total
1	*S. obtusa*	9.09	51.38	32.96	8.13	16.46	118.02
2	*S. obtusa*	17.13	98.31	94.59	13.4	23.24	246.67
3	*S. obtusa*	6.74	37.40	26.35	10.39	11.57	92.45
4	*S. obtusa*	6.31	39.39	20.01	12.87	12.91	91.49
5	*S. obtusa*	10.25	59.92	39.38	13.2	17.25	140.00
6	*S. obtusa*	6.10	35.07	17.55	14.13	12.73	85.58
	Mean	9.27±3.83	53.58±21.80	38.47±26.16	12.02±2.09	15.69±3.95	129.04±55.85
7	*S. siamensis*	6.31	39.39	65.03	5.46	23.49	139.68
8	*S. siamensis*	12.64	79.23	53.41	4.65	22.27	172.20
9	*S. siamensis*	11.74	71.54	33.64	6.82	17.53	141.27
	Mean	10.23±3.42	63.39±21.14	50.69±15.87	5.64±1.10	21.10±3.15	151.05±18.337
10	*D. obtusifolius*	10.28	69.49	43.89	17.03	17.59	158.28
11	*D. tuberculatus*	11.57	55.13	54.1	4.44	16.74	141.98
12	*D. tuberculatus*	8.49	43.30	33.36	8.25	15.31	108.72
13	*D. tuberculatus*	7.81	33.69	27.47	8.02	13.19	90.17
	Mean±S.D.	9.29±1.64	44.04±8.77	38.31±11.42	6.90±1.74	15.08±1.46	113.62±21.431
14	*P. merkusii*	5.71	31.13	30.17	12.86	9.19	89.06
15	*P. merkusii*	3.43	17.73	12.19	12.63	6.66	52.65
	Mean	4.57	24.43	21.18	12.75	7.93	70.85
	Mean±S.D. (15 plots)	8.91±3.35	50.81±20.769	38.94±20.39	10.15±3.76	15.74±4.73	124.55±45.40
	%	7.15	42.79	31.26	8.15	12.64	100

Khamyong *et al.* (2014b) studied the water storage in a lower montane forest in northern Thailand. The community forest of Karen village was divided into conservation forest and utilization forest. Selective tree cutting for house construction and fuel wood was permitted by village regulations only in the utilization forest. The conservation forest was protected for the watershed. The amount of standing plant biomass in the conservation forest (252.4±72.5 Mg ha^{-1}) was higher than that in the utilization forest (139.7±36.3 Mg ha^{-1}). The amounts of water in the plant biomass varied between seasons. The amounts of water in the conservation forest varied between 208.2±68.9 m^3 ha^{-1} and 231.2±70.7 m^3 ha^{-1}, whereas the amounts of water in the utilization forest varied in the range 107.1±29.7 m^3 ha^{-1} to 129.0±33.3 m^3 ha^{-1}. The lower montane forest had higher amounts of water stored in plant biomass than the DDF at the two sites analyzed in this study.

3.2 Water storage in soils

The physical properties of soil, particularly depth, gravel content, bulk density, texture, and organic matter content, have an influence on the water movement and retention throughout the soil profile (Brady and Weil, 2010). The data related to the physical properties of soil in the DDFs at Site 1 and Site 2 are given in Table 7.

Site 1: HHKRDS Center

The soil derived from the sandstone in this site, dominated by *D. obtusifolius,* was shallow. The soil study related to water storage was carried out at two times (December 23, 2015, and July 26, 2016), as indicated by the data presented in Table 8. The values of MWHC calculated from the FC varied with soil depth, and the total amount within a depth of 80 cm was measured at 1,837.21±96.35 m^3 ha^{-1}. The amount of water in the winter (December 23, 2015) and rainy season (July 26, 2016) was determined at 330.83±102.37 m^3 ha^{-1} (18.0% of MWHC) and 1,072.46±18.93 m^3 ha^{-1} (58.30%), respectively.

Site 2: Mae Tha Subdistrict Community Forest

The soil derived from the granitic rocks in the *D. obtusifolus* stand of Site 2 was deep. The water storage in this soil was studied once (October 12, 2014), as indicated by the data presented in Table 9. The FC at various soil depths was different and much higher than that of Site 1. MWHC were also observed to vary with the soil profile. The subsoil, at 80–140 cm depth, was found to have a higher value of MWHC. The total MWHC at Site 2 was estimated to be 4,981.57±132 m^3 ha^{-1}, which was higher than that of Site 1. The amount of water in the soil at the end of the rainy season (October 12, 2014) was measured at 783.58±21.00 m^3 ha^{-1} (15.70% of MWHC).

Since the soil was shallow at Site 1 and deep at Site 2, it was concluded that the soil depth was an important factor affecting the soil water storage. The FC at various soil depth at Site 1 was lower than that in Site 2. This was caused by a high gravel content and low soil mass, as indicated by very low bulk densities along the soil profile of Site 1. The surface soils of both the sites had a coarse texture, loamy sand, and sandy loam, but the sub soils were different. The subsoil of Site 1 was sandy clay loam and sandy loam, while that of Site 2 was of a finer texture, sandy clay loam and clay. Fine-textured soil with a high clay accumulation in the subsoil has a higher water retention than a coarse-textured soil with small clay content in the subsoil. Soil organic matter has some ability to absorb water (Brady and Weil, 2010). However, the percentage of soil organic matter was not different between the soils of these sites. They were low to moderate in the surface soils and moderately low to low and very low in the subsoils at these sites.

Khamyong *et al.* (2014b) reported that the conservation community forest in the lower montane of Karen village, which had a soil depth of 2 m, could store a large amount of water in the soil, at 9,584±934 m^3 ha^{-1}. This value is 4.94 times greater than that of the soil in the DDFs at Site 1 and 1.86 times greater than that at Site 2.

Table 7 Some physical properties at various soil depths in the DDF at Site 1 and Site 2.

Soil depth (cm)	Bulk density (Mg m^{-3})	Organic matter (%)	Gravel content %	Soil particle-size distribution (%)			Soil texture
				Sand	Silt	Clay	
Site 1							
0–5	0.31	2.23	69.23	83.30	10.30	6.40	Loamy sand
5–10	0.34	1.48	65.89	79.12	12.00	8.88	Loamy sand
10–20	0.54	0.58	46.30	75.00	14.00	11.00	Sandy loam
20–30	0.42	0.39	58.06	67.10	2.90	30.00	Sandy clay loam
30–40	0.34	0.30	65.94	65.00	24.00	11.00	Sandy loam
40–60	0.34	0.19	66.46	71,12	16.38	12.50	Sandy loam
60–80	0.25	0.19	75.00	63.00	18.00	19.00	Sandy loam
Site 2							
0–5	1.64	1.42	4.88	82.10	11.20	6.70	Loamy sand
5–10	1.45	1.33	9.66	78.30	13.75	7.95	Loamy sand
10–20	1.26	1.24	14.43	74.50	16.30	9.20	Sandy loam
20–30	1.19	1.05	28.72	69.40	15.10	15.50	Sandy loam
30–40	1.12	0.86	27.58	64.30	13.90	21.80	Sandy clay loam
40–60	1.23	0.69	26.40	52.25	15.90	31.85	Sandy clay loam
60–80	1.33	0.67	25.23	40.30	17.90	41.80	Clay
80–100	1.49	0.67	10.44	40.80	17.30	41.90	Clay
100–120	1.51	0.64	13.94	41.20	16.10	42.70	Clay
120–140	1.52	0.57	17.44	41.40	16.70	41.90	Clay

Table 8 Amount of water in the soil of the DDF at Site 1.

Soil depth (cm)	Site 1			
	Field capacity (% by volume)	Maximum water holding capacity (MWHC) (m^3 ha^{-1})	Water amount	
			December 23, 2015 (m^3 ha^{-1})	July 26, 2016 (m^3 ha^{-1})
0–5	17.76 ± 5.25	153.82 ± 7.17	10.54 ± 2.77	53.47 ± 9.80
5–10	12.53 ± 3.96	125.04 ± 15.06	13.55 ± 4.75	72.99 ± 37.81
10–20	12.41 ± 3.06	240.99 ± 25.98	21.98 ± 1.41	81.70 ± 66.22
20–30	9.08 ± 3.93	221.32 ± 24.84	23.87 ± 6.04	132.79 ± 7.01
30–40	7.55 ± 1.40	230.83 ± 8.26	30.69 ± 9.34	147.30 ± 3.74
40–60	8.11 ± 0.98	438.83 ± 39.14	83.25 ± 22.46	309.94 ± 20.64
60–80	5.43 ± 0.86	426.39 ± 18.03	146.95 ± 60.51	274.28 ± 26.73
	Total	**1,837.21 ± 96.35**	**330.83 ± 102.37**	**1,072.46 ± 18.93**
	%		**18.00**	**58.37**

Table 9 Amount of water in the soil of the DDF at Site 2.

Soil depth (cm)	Site 2		
	Field capacity (% by volume)	Maximum water holding capacity (MWHC) ($m^3\ ha^{-1}$)	Water amount October 12, 2014 ($m^3\ ha^{-1}$)
0–5	36.18 ± 5.59	180.91 ± 27.97	28.95 ± 4.48
5–10	30.12 ± 1.97	150.61 ± 9.86	24.10 ± 1.58
10–20	28.48 ± 1.48	284.77 ± 14.76	45.56 ± 2.36
20–30	26.76 ± 0.68	267.58 ± 6.83	42.81 ± 1.09
30–40	26.02 ± 0.35	260.25 ± 3.50	41.64 ± 0.56
40–60	28.28 ± 1.20	565.61 ± 24.06	90.50 ± 3.85
60–80	33.16 ± 1.84	663.24 ± 36.73	106.12 ± 5.88
80–100	40.45 ± 0.63	808.90 ± 12.65	129.42 ± 2.02
100–120	43.11 ± 1.70	862.23 ± 33.93	137.96 ± 5.43
120–140	42.66 ± 1.42	853.27 ± 28.38	136.52 ± 4.54
Total		**4,981.57 ± 132**	**783.58 ± 21**
%			**15.72**

3.3 Water storage in the DDF ecosystem (plants and soils)

The main components of the DDF ecosystem include plant communities, soil, and organic layers on the forest floor. However, in this forest, the organic layers usually disappear because of forest fire and rapid decomposition. The contributions from animals and microbes are not accounted for because of their very low contribution to the biomass. Thus, the storage of water in the DDF ecosystem occurs mainly in the plant biomass and soil system.

Figure 1 shows the amount of water stored in the DDF ecosystems at Site 1 and Site 2 at the time of MWHC of the soils. However, the amount of water in these soils could vary with season. The amount of water is high during the rainy season and low in the winter, and the lowest in the summer months. The water storage potential in the DDF ecosystem at Site 1 was lower than that of the DDF ecosystem at Site 2. At Site 1, the amount of water stored in the plant biomass and the soil in the *D. obtusifolius* stand was 103.95 Mg ha^{-1} (5.40%) and 1,837.21 Mg ha^{-1} (94.60%), respectively.

As for Site 2, the amount of water stored in the two components of the *D. obtusifolius* stand was 158.28 Mg ha^{-1} (3.0%) and 4,981.57 Mg ha^{-1} (97.0%), respectively. The total amounts of water stored in the DDF of Site 1 (1,941.16 m^3 ha^{-1}) was 2.7 times lower than that stored in the DDF of Site 2 (5,139.85 m^3 ha^{-1}).

Khamyong *et al.* (2014b) found that the conservation community forest of Karen village, could store 231.2$\pm$70.7 m^3 ha^{-1} of water in the plants and 9,584$\pm$934 m^3 ha^{-1} in the soil , respectively, or a total of 9,815.2 m^3 ha^{-1}. This is 5.10 times greater than the DDF ecosystem at Site 1 and 1.91 times greater than that of Site 2.

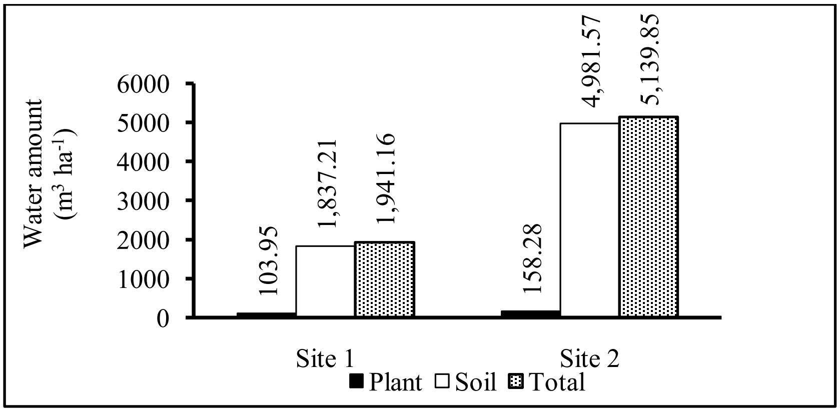

Figure 1 The amount of water in plant biomass of theDDF at Site 1 and Site 2.

CONCLUSION

The DDF at Site 1 (HHKRDS Center) was divided into four stands based on the most dominant tree species. The average amount of plant biomass in these stands was measured to be 91.99±11.44 Mg ha^{-1}, and with water storage amount at 100.70±9.91m^3 ha^{-1}. The soil derived from sandstone was shallow (0–80 cm) and could store a maximum of 1,837.21±96.35 m^3 ha^{-1} of water. The DDF at Site 2 (Mae Tha sub district community forest) consisted of five stands. Its biomass amount was estimated to be 125.49±53.61 Mg ha^{-1}, and it could store higher amounts of water than Site 1, at 124.55±45.40 m^3 ha^{-1}. The soil derived from granitic rocks was deep (0–140 cm), and it had a higher MWHC, at 4,981.57±132 m^3 ha^{-1}. It can be concluded that the water storage potential in the DDF ecosystem (plants and soil) of the *D. obtusifolius* stand at Site 1 was about 2.65 times lower than the water storage potential of the same kinds of forest and stand at Site 2. Very little research work on water storage in plant biomass and soil has been done till date. The standard deviation from the mean especially of plant biomass and water storage was high. This was caused by different levels of human disturbance through selective tree cutting in the past, which resulted in a high fluctuation of standing plant biomass among the plots.

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