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Role of a Pine (*Pinus kesiya*) Plantation on Water Storage in the Doi Tung Reforestation Royal Project, Chiang Rai Province, Northern Thailand

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ABSTRACT

A 22-year-old pine (*Pinus kesiya* Royle ex. Gorgen) plantation under the Doi Tung Reforestation Royal Project, Chiang Rai province, was investigated for the potential of water storage in plant biomass of pine and successional tree species, and soil system. Ten sample plots, each of size 40×40 m, were used for the vegetation study. The plots were located randomly within areas of an altitude ranging from 953 to 1,444 m m.s.l. The tree stem girth at 1.30 m above ground (gbh) and tree height of all pine and succession species of height $\geq$1.5 m were measured. The pine and succession species mean densities were 84.0$\pm$9.3 and 10.0$\pm$8.0 trees plot^{-1}, respectively. The pine average stem gbh and height were 112.29$\pm$19.46 cm and 28.3$\pm$2.5 m, respectively. The successional species in the ten plots varied between 2 and 13 species. The pine and successional species average biomass was 64.59$\pm$9.41 Mg plot^{-1} (403.70$\pm$58.80 Mg ha^{-1}), and the average amount of water stored in biomass of 52.34$\pm$7.80 m^3 plot^{-1} (327.10$\pm$48.77 m^3 ha^{-1}). Within 2-m soil depth, the maximum capacity of water storage was estimated at 1,763.67$\pm$8.44 m^3 plot^{-1} (11,022.93$\pm$52.76 m^3 ha^{-1}). The water storage in the rainy season (on 17thAugust 2013) was found to be 1,411.36$\pm$9.89 m^3 plot^{-1} (8,821.0$\pm$61.84 m^3 ha^{-1}, 80.02% of the maximum storage). The total water storage in the pine plantation (plant biomass and 2-m soil depth was 1,816.01 m^3 plot^{-1} (11,350.06 m^3 ha^{-1}). In the rainy season (on 17th August 2013), the total water storage reached 1,463.70 m^3 plot^{-1} (9,148.13 m^3 ha^{-1}, 80.60%). The water storage in plant biomass was low (3.58% of the total stand) and was high in soil (96.42%). In conclusion, the pine plantations have an important role on water storage that can reduce streamflow and flooding. The successional species in the pine stand also contribute to water storage in biomass.

Keywords: Doi Tung Reforestation Royal Project, Pine plantation, Water storage

INTRODUCTION

Reforestation has been conducted in the devastated highland watershed in northern Thailand by the Royal Forest Department. Many Watershed Development Stations were established in 1970 for reforestation on watersheds. The tree species planted in the early period included *Pinus kesiya* Royle ex. Gorgen, *Prunus cerasoides* D.Don, *Docynia indica* (Andr.) Dencne., and *Betula alnoides* Buch.-Ham. ex G.Don. Nowadays, more broad-leaved tree species are planted. The three needle pine (*P. kesiya*) is still the most common species for the highland reforestation because it can grow very rapidly (Pornleesangsuwan, 2012). About 150,000 ha of the pine plantation in northern Thailand were reported (RFD, 1993). The reforestation in shifting cultivation areas on the highland watershed is important to restore the watershed functions of nutrient cycling, particularly the carbon cycle (Nongnuang *et al*., 2012) and the hydrologic cycle (Landberg and Gower, 1997; Waring and Running, 1998; Kimmins, 2004; Chang, 2006). This pine grows naturally in areas of an altitude ranging between 1,000 and 1,900 m m.s.l., and can grow well on poor soil (Seramethakun *et al*., 2012).

Doi Tung areas are mountainous highland with the highest altitude of about 1,500 m. In the past, most forest had been cleared for agriculture and opium cultivation. In the year 1988, the Doi Tung development project was established through Her Royal Highness the Princess Mother (HRH the Princess Mother)'s initiative. The project area is located in Mae Fah Luang and Mae Sai districts, Chiang Rai province, and covers 93,515 rai (149.624 km^2) in an altitude range of 400-1,500 m m.s.l. The area is a head watershed supplying water to many streams which are beneficial to 27 villages of various 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 people received extra income from labour wage, agriculture, handicraft and commerce during the project. Nowadays, the overall areas of Doi Tung are green and covered by diversified forest tree species, and many places are beautiful and attract both Thai and foreign tourists.

At the beginning of the Doi Tung Development Project, reforestation was considered an important work to restore the watershed environment. The forest plantation was begun in 1989, as implementation of the rehabilitation plantation to celebrate the 90th year of Somdet Phra Srinagarindra Borom-arajajonani Her Royal Highness the Princess Mother (HRH the Princess Mother). The plantation area was 10,532 rai (1,685.12 ha). Many forest tree species were selected for planting. *P. kesiya* was planted in areas of higher altitude, above 950 m m.s.l. totaling 6,600 rai (1056 ha), whereas teak (*Tectona grandis* L.f.) was planted in the lower altitude areas covering a 3,600 rai (576 ha). Other species were planted in the smaller areas. In 2011, the pine and teak plantations were 22 years old. Plant succession occurred in these plantations at different levels.

Little research has been conducted in the pine forest. The ecological roles of the natural pine forest involving soil carbon and nutrient storage at Kalaya Ni Wattana district, Chiang Mai province, were studied by Seramethakun *et al*. (2012). Nongnuang *et al*. (2012) investigated biomass carbon stocks of pine and succession trees in the pine plantations at Boa Kaew Watershed Development Station, Chiang Mai province. No study has been conducted on the hydrologic cycle of the pine plantations. Most literature about forest hydrology has 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, stream flow, and so on (Landberg and Gower, 1997; Waring and Running, 1998; Kimmins, 2004; Chang, 2006). Few data are available on the potential of water storage in plant biomass and soils of the forests. 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. Flooding and drought have become the critical problems in the country. Forest conservation through protection of the remaining natural forests and reforestation in disturbed forest land is, thus, important. Research on water storage in the plantation forest is thought to be important as the basic information for watershed management.

The aim of this research is to evaluate the ecological role of the 22-year-old pine plantation under the Doi Tung Development Project on water storage. This plantation was established to celebrate the 90th year of Somdet Phra Srinagarindra Boromarajajonani, Her Royal Highness the Princess Mother (HRH the Princess Mother). The potential capacity of water storage by the plantation implies ecological benefits from the reforestation project.

MATERIALS AND METHODS

Tree and plot data collection

Sampling of forest vegetation over the pine plantations was conducted in 2011 using ten sample plots, each of size 40×40 m. The plots were selected by random sampling within areas of altitude ranging between 953 and 1,444 m m.s.l. The tree stem girth at breast height (gbh, 1.3m above ground) and tree height of all pine and succession tree species of height ≥1.5 m were measured in all plots. The plot slope gradient, slope aspect, altitude, and GPS locations, were also recorded.

Biomass estimation of standing trees

Biomass of all standing trees of pine and succession species in the plots were calculated. The pine biomass allocated in stem, branch and leaf components in the plantation were calculated using the allometric equations of the pine plantations at Boa Kaew Watershed Management Station, Sa Moeng district, Chiang Mai province (Nongnuang *et al*., 2012) as follows:

$$w_S \text{ (stem)} = 0.0503\,(D^2H)^{0.8775} \quad (r^2 = 0.9749)$$

$$w_B \text{ (branch)} = 0.0012\,(D^2H)^{1.0996} \quad (r^2 = 0.4982)$$

$$w_L \text{ (leaf)} = 0.4536\,(W_B)^{0.7933} \quad (r^2 = 0.6324)$$

where

D = diameter at breast height in centimeters

H = tree height in meters

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

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

where

D = diameter at breast height in centimeters

H = tree height in meters

Water content and storage in plant biomass

The fresh leaf, branch, stem and root samples of pine were collected in plastic bags one time in the rainy season, on 17th August 2013. The samples were gathered from three individuals of pine in the plantation, and carried to a laboratory. They were oven-dried at 80°C until attaining a constant weight, and then the water content was determined. The mean water content in various organs of 13 dominant tree species in the lower montane forest, studied by Seeloy-ounkeaw *et al*. (2012), were used to calculate water storage in the succession tree species. The mean water content in stem, branch, leaf and root organs of these tree species were 79.48±4.42, 102.49±19.50, 112.11±23.01 and 80.01±21.03% by dry weight, respectively.

Maximum capacity and water storage in soils

Since the soil is deeper than 2.0 meters, a soil pit, each of size 1.5 x 2 x 2 m, was made in a selected plot of the pine plantation. The collection of soil samples along soil profile was taken 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 soil samples were gathered in areas at about 1.5 m apart from the left and the right side of the pit. All soil samples were used to determine maximum water holding capacity, and water content on 17th August 2013 in a laboratory. Determination of the maximum water holding capacity was determined from 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 by gravity. 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. The water storage in each soil layer per unit area was measured, and then the total amount within 2-m soil depth per unit area was determined.

RESULTS AND DISCUSSION

Tree density, girth and height

The pine stem girth at breast height and tree height were different among the ten sample plots. As shown in Table 1, the mean densities of pine and succession species were 84.0±9.3 and 10.0±8.01 trees plot^{-1}. The mean stem girth and height of pine were 112.29±19.46 cm and 28.3±2.5 m, respectively. The variation in pine densities among the plots was caused by the different survival rates. Differences in the physiographic factors, particularly slope gradient, aspect, and altitude in these plots might affect pine growth. Plant succession occurred in the pine plantation, and it varied among the sample plots. The number of species and densities of the succession species varied, 2-13 species and 2-26 trees plot^{-1}, respectively.

The succession species included *Castanopsis acuminatissima* (Blume) A.DC., *Diospyros grandulosa* Lace, *Litsea glutinosa* (Lour.) C.B.Robb., *Gluta obovata* Craib, *Schima wallichii* (DC) Korth, *Ficus ribes* Reiw. ex Blume, *Dalbergia cultrata* Graham ex Kurz, *Mangifera indica* L., *Bauhinia variegata* L., *Gmelina arborea* Roxb., *Premna tomentosa* Willd., *Albizia odoratissima* (L.f.) Benth., and *Vitex pinnata* L. Some of these species normally exist in the lower montane forest, while the others are commonly found in the mixed deciduous forest.

Table 1 Tree density of pine and successional species, and tree girth and height of pine, in the ten sample plots.

Plot	Tree density (trees plot^{-1})		Mean tree GBH (Pine) (cm)	Mean tree height (Pine) (m)
no.	Pine	Other species		
1	83	18	98.30±17.90 (18.21)	28.0±3.4 (12.1)
2	76	10	107.70±22.10 (20.56)	28.5±2.1 (7.21)
3	84	4	101.30±21.00 (20.71)	28.9±1.5 (5.29)
4	83	4	99.10±17.30 (17.48)	30.8±1.4 (4.55)
5	62	13	128.40±18.20 (14.15)	29.8+3.5 (11.70)
6	75	5	118.60±18.10 (15.30)	28.9±2.1 (7.39)
7	79	3	109.80±18.40 (16.78)	29.3±1.8 (6.16)
8	74	2	129.50±18.70 (14.48)	29.9±3.5 (11.59)
9	62	26	122.00±23.10 (18.94)	20.1±2.8 (11.36)
10	60	17	108.15±19.84 (18.34)	28.3+2.7 (9.42)
Mean±S.D.	84±9.3 (12.58)	10±8.01 (79.22)	112.29±19.46 (17.35)	28.3±2.5 (8.79)

Plant biomass and water storage

In the pine plantation, the majority of plant biomass was in pine, and a small proportion was in successional tree species (Table 2). The plant biomass in the ten sample plots varied between 49.32 and 83.17 Mg plot^{-1} (average: 64.59±9.41 Mg plot^{-1} or 403.70±58.80 Mg ha^{-1}). The average biomass allocated in stem, branch, leaf and root were 40.80±5.79, 10.46±1.89, 1.70±0.24 and 11.63±1.54 Mg plot^{-1}, respectively.

As shown in Table 3, the total water storage in plant biomass in the ten sample plots of the pine plantation varied from 39.76 to 67.77 m^3 plot^{-1} (average: 52.34±7.80 m^3 plot^{-1} or 327.10±48.77 m^3 ha^{-1}). In the stem, branch, leaf and root, the average amount of water stored in biomass were 32.30±4.54, 12.50±2.28, 2.19±0.31, and 5.35±0.70 m^3 $plot^{-1}$, respectively It was highest in the stem, followed by branch, root and leaf. The water storage in the biomass of successional tree species were small, and varied between 0.99% and 6.90% of the total storage in plant biomass.

Table 2 Biomass allocation in various organs of pine in the ten sample plots.

Sample Plot no.	Tree species	Biomass amounts (Mg $plot^{-1}$)				
		Stem	**Branch**	**Leaf**	**Root**	**Total**
1	Pine	33.64	7.98	1.39	9.90	52.91
	Others	1.89	0.55	0.11	0.42	2.95
	Total	**35.51**	**8.53**	**1.50**	**10.32**	**55.86**
2	Pine	37.19	9.27	1.53	10.78	58.76
	Others	2.49	0.76	0.13	0.52	3.91
	Total	**39.68**	**10.03**	**1.66**	**11.30**	**62.67**
3	Pine	37.26	9.07	1.53	10.88	58.75
	Others	0.38	0.11	0.03	0.09	0.60
	Total	**37.64**	**9.18**	**1.56**	**10.97**	**59.35**
4	Pine	37.38	9.06	1.54	10.93	58.90
	Others	2.10	0.33	0.06	0.23	1.73
	Total	**38.48**	**9.39**	**1.60**	**11.16**	**60.63**
5	Pine	41.97	11.24	1.72	11.87	66.80
	Others	2.06	0.61	0.13	0.46	3.26
	Total	**44.03**	**11.85**	**1.85**	**12.33**	**70.06**
6	Pine	43.28	11.16	1.78	12.40	68.62
	Others	1.68	0.52	0.09	0.34	2.63
	Total	**44.96**	**11.68**	**1.87**	**12.74**	**71.25**
7	Pine	40.54	10.16	1.67	11.72	64.09
	Others	0.23	0.07	0.01	0.06	0.36
	Total	**40.77**	**10.23**	**1.68**	**11.78**	**64.45**
8	Pine	51.53	13.92	2.12	14.54	82.11
	Others	0.68	0.21	0.03	0.14	1.06
	Total	**52.21**	**14.13**	**2.15**	**14.68**	**83.17**
9	Pine	40.32	10.79	1.66	11.41	64.18
	Others	3.16	0.94	0.18	0.71	4.98
	Total	**43.48**	**11.73**	**1.84**	**12.12**	**69.16**
10	Pine	29.28	7.27	1.20	8.49	46.26
	Others	1.96	0.59	0.11	0.42	3.06
	Total	**31.24**	**7.86**	**1.31**	**8.91**	**49.32**
Mean (Mg $plot^{-1}$)		**40.80±5.79**	**10.46±1.89**	**1.70±0.24**	**11.63±1.54**	**64.59±9.41**
Mean (Mg ha^{-1})		**255.00±36.16**	**65.37±11.77**	**10.63±1.47**	**72.69±9.58**	**403.70±58.80**

Table 3 Water storage in biomass of various organs of tree species in ten sample plots.

Sampling Plot no.	Tree species	Water storage in plant biomass (m^3 $plot^{-1}$) Stem	Branch	Leaf	Root	Total	%
1	Pine	26.59	9.64	1.81	4.52	42.56	94.86
	Others	1.46	0.50	0.11	0.24	2.31	5.14
	Total	**28.05**	**10.14**	**1.92**	**4.76**	**44.87**	**100**
2	Pine	29.39	11.20	1.99	4.92	47.51	93.99
	Others	1.93	0.69	0.13	0.29	3.04	6.01
	Total	**31.32**	**11.89**	**2.12**	**5.22**	**50.55**	**100**
3	Pine	29.45	10.96	1.99	4.97	47.37	99.01
	Others	0.29	0.10	0.03	0.05	0.47	0.99
	Total	**29.74**	**11.06**	**2.02**	**5.02**	**47.84**	**100**
4	Pine	29.54	10.95	2.01	4.99	47.49	95.74
	Others	1.62	0.30	0.06	0.13	2.11	4.26
	Total	**31.17**	**11.25**	**2.07**	**5.12**	**49.60**	**100**
5	Pine	33.17	13.58	2.24	5.42	54.41	95.55
	Others	1.59	0.55	0.13	0.26	2.53	4.45
	Total	**34.76**	**14.14**	**2.37**	**5.68**	**56.95**	**100**
6	Pine	34.20	13.49	2.32	5.66	55.67	96.45
	Others	1.30	0.47	0.09	0.19	2.05	3.55
	Total	**35.50**	**13.96**	**2.41**	**5.85**	**57.72**	**100**
7	Pine	32.04	12.28	2.17	5.35	51.85	99.45
	Others	0.18	0.06	0.01	0.03	0.29	0.55
	Total	**32.22**	**12.34**	**2.18**	**5.39**	**52.13**	**100**
8	Pine	40.72	16.82	2.76	6.64	66.95	98.78
	Others	0.53	0.19	0.03	0.08	0.82	1.22
	Total	**41.25**	**17.01**	**2.79**	**6.72**	**67.77**	**100**
9	Pine	31.86	13.04	2.16	5.21	52.28	93.10
	Others	2.44	0.85	0.18	0.40	3.87	6.90
	Total	**34.31**	**13.89**	**2.34**	**5.61**	**56.15**	**100**
10	Pine	23.14	8.79	1.56	3.88	37.37	93.97
	Others	1.52	0.53	0.11	0.24	2.40	6.03
	Total	**24.66**	**9.32**	**1.67**	**4.11**	**39.76**	**100**
Mean (m^3 $plot^{-1}$)		**32.30±4.54**	**12.50±2.28**	**2.19±0.31**	**5.35±0.70**	**52.34±7.80**	
Mean (m^3 ha^{-1})		**201.86±28.40**	**78.13±14.25**	**13.69±1.92**	**33.42±4.35**	**327.10±48.77**	

Maximum capacity and water storage in soil

Since soil in the pine plantation was deep, the maximum capacity of water storage and moisture content on the sampling day (17^{th} August 2013) in rainy season were investigated to 2-m soil depth. The physical properties, including mean bulk density and gravel content along three soil profiles, were studied (Table 4). It was found that the soil bulk densities varied from low to very low throughout the soil profile, varied from 0.74 ± 0.14 to 1.17 ± 0.02 Mg m^{-3}. The gravel content was relatively small in the upper 160 cm depth, and increased in the deeper horizon.

Table 4 shows the field capacities of water in different layers along the soil profile. The values were relatively high throughout the soil profile. It was higher at the 0-5 cm depth that might be influenced by the high content of organic matter which can absorb the large amount of water.

In Figure 1, the maximum capacity of water storage within 2-m soil depth was $1,763.67 \pm 8.44$ m^3 $plot^{-1}$ ($11,022.93 \pm 52.76$ m^3 ha^{-1}). In the rainy season, water storage in soil was examined on 17^{th} August 2013. It is found that the average water storage in the 2-m soil depth was $1,411.36 \pm 9.89$ m^3 $plot^{-1}$ ($8,821.0 \pm 61.84$ m^3 ha^{-1}). Thus, the water storage on this day was 80.02% of the maximum capacity. The heavy rainfall occurring in the middle of rainy season on the highland of Doi Tung areas caused such high soil moisture storage.

Table 4 Bulk density, gravel content, field capacity (FC), water content on 17th August 2013, maximum capacity of water storage, and water storage on 17th August 2013 along soil profiles in the pine plantation.

Depth (cm.)	B.D. ($Mg\ m^{-3}$)	Gravel, % (by weight)	F.C. (%) (by volume)	Moisture (% by volume)	Maximum of water storage ($m^3\ ha^{-1}$)	Maximum of water storage ($m^3\ plot^{-1}$)	Water storage (17/7/2013) ($m^3\ ha^{-1}$)	Water storage (17/7/2013) ($m^3\ plot^{-1}$)	More capacity ($m^3\ plot^{-1}$)
0-5	0.74±0.14, L	14.06±10.6	60.56±0.72	44.86±2.76	302.79±3.57	48.45±0.57	224.32±13.82	35.89±2.21	11.56
5-10	0.90±0.03, L	5.34±0.75	57.73±1.98	42.85±2.94	288.65±9.91	46.18±1.59	214.27±14.74	34.28±2.36	11.90
10-20	0.85±0.01, L	10.54±1.62	57.91±1.14	41.61±2.43	579.06±11.40	92.65±1.82	416.14±24.32	66.58±3.89	26.07
20-30	0.90±0.04, L	8.44±2.86	56.20±0.99	42.32±2.84	562.00±9.90	89.92±1.58	423.20±28.39	67.71±4.45	22.21
30-40	0.95±0.02, L	7.45±3.77	56.96±1.32	42.70±4.49	569.65±13.24	91.14±2.12	427.01±44.89	68.32±7.18	22.82
40-60	1.01±0.02, L	7.62±0.40	54.73±2.20	44.19±0.31	1094.66±43.93	175.15±7.03	883.84±6.13	141.41±0.98	33.74
60-80	1.03±0.06, L	6.46±3.05	55.76±2.34	42.86±1.60	1115.24±46.92	178.44±7.51	857.14±32.02	137.14±5.12	41.30
80-100	1.09±0.04, L	5.82±2.20	56.04±1.34	44.94±1.22	1120.82±26.77	179.33±4.28	898.72±24.48	143.79±3.92	35.54
100-120	1.07±0.01, L	6.41±1.00	54.80±0.88	44.01±0.36	1096.02±17.72	175.36±2.84	880.31±7.21	140.85±1.15	34.51
120-140	1.17±0.02, L	7.10±0.10	56.29±1.49	47.19±0.94	1125.84±29.80	180.13±4.77	943.83±18.76	151.01±3.00	29.12
140-160	1.17±0.02, L	6.37±3.05	55.19±0.96	47.13±0.23	1103.76±19.10	176.60±3.06	942.68±4.50	150.83±0.72	25.77
160-180	0.89±0.38, L	28.16±25.4	49.90±5.36	40.26±2.26	998.05±107.22	159.69±17.15	805.21±45.17	128.83±7.23	30.86
180-200	0.98±0.10, L	21.95±6.41	53.32±0.70	45.22±0.94	1066.39±13.95	170.62±2.23	904.36±18.75	144.70±3.00	25.92
				Total	11022.93±52.8	1763.67±8.4	8821.0±61.8	1411.36±9.9	352.31

Notes: 1. L = low, according to Nongkarn (1986) mentioned by Anongrak (2003)

2. More capacity = maximum water storage water storage on 17th August 2013

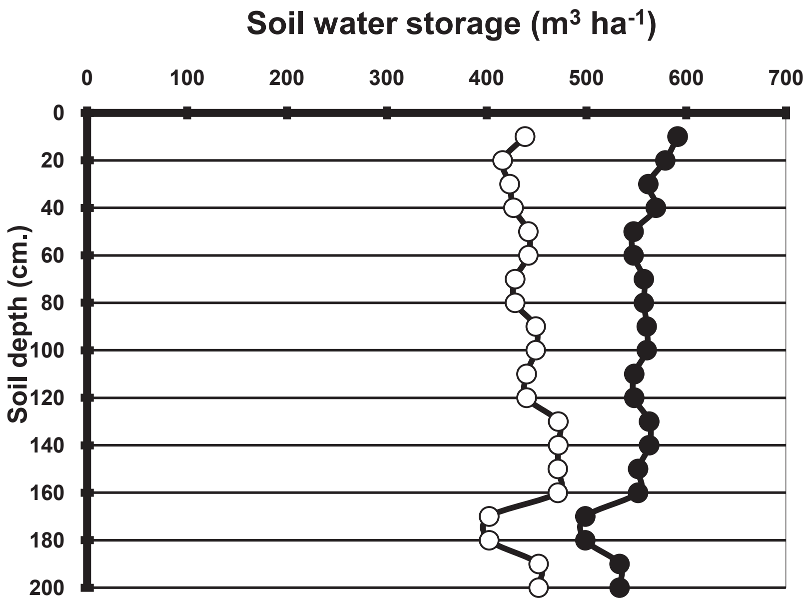

Figure 1 Amounts of water storage along soil profile in 22-year-old pine plantation. (● = maximum water storage, ○ = water storage on 17th August 2013)

Ecosystem water storage

In the pine plantation, the water storage was contained mainly in two components, plant biomass and soil system. The average amount of water stored in biomass of pine and succession tree species was 52.34±7.80 m^3 $plot^{-1}$ (327.10±48.77 m^3 ha^{-1}). The maximum capacity of water storage in the 2-m soil depth was 1,763.67±8.44 m^3 $plot^{-1}$ (11,022.93±52.76 m^3 ha^{-1}). Therefore, the total amount of water storage (plant biomass and soil) in the pine plantation was 1,816.01 m^3 $plot^{-1}$ (11,350.06 m^3 ha^{-1}). The water storage in plant biomass was only 2.88% of total water storage in the stand. The remaining 97.12% of water were stored in the soil profile.

In the rainy season (17^{th} August 2013), the amount of water storage within 2-m soil depth in the plantation was 1,411.36±9.89 m^3 $plot^{-1}$ (8,821.0±61.84 m^3 ha^{-1}). Thus, the total amount of water storage (plant biomass and soil) in the pine plantation on this day was 1,463.70 m^3 $plot^{-1}$ (9,148.13 m^3 ha^{-1}). The water storage in plant biomass on this day was 3.58% of the total water storage in the stand, and the remaining 96.42% were in the soil.

The pine plantation with a total area of 6,600 rai (1,056 ha) could store the maximum amount of water in the ecosystem (2-m soil depth) of about 11,985,666 m^3, and the total stand water storage in the mid-rainy season (17^{th} August 2013) was 9,660,420 m^3, and could store more rain water of 2,325,246 m^3. In general, the water storage in the 22-year-old pine plantation ecosystem varies with time of the year.

Discussion

The growth of pine in the 22-year-old pine plantation at Doi Tung areas was better than in other sites at Hot district (Khamyong, 2001) and Samoeng district (Pornleesangsuwan *et al*., 2012), Chiang Mai province. In this study area, the mean stem girth and height of pine were 112.29±19.46 cm and 28.3±2.5 m, respectively, whereas those at Hot and Samoeng districts were 80.32 cm and 18.24 m, and 82.80 cm and 21.20 m, respectively. The pine plantation at Doi Tung area had been established for restoration of the devastated highland watershed, not for the commercial purposes.

In forest plantations, plant succession is usually occurs, and the stands reach the climax stage. Khamyong (2001) reported that plant succession is poor in 7-37 years old pine plantations at Hot district, which had been covered by pine-dry dipterocarp forest. The poor succession caused by weeding in the plantations, which was the old silvicultural practice employed by the Royal Forest Department in the past. In some plantations, all individuals of other broad-leaved tree species were removed to stimulate the pine growth. However, the succession by broad-leaved species including oaks and some dipterocarp species were observed in some plots which were far from the Watershed Development Station. Pornleesangsuwan *et al.* (2012) found that plant succession in the pine plantations at Samoeng district consisted of 72 broad-leaved tree species which also existed in the nearby fragmented lower montane forests.

The pine plantation can store water in mainly two components, forest biomass and soil system. The organic layers on forest floor were thin due to the rapid litter decomposition, and, thus, the role on water storage might be small. In plant biomass, the water is stored in different organs including stem, branch, leaf and root. Water storage varies among tree species, and even within 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. The soil water retention has been improved since organic matter gradually 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 by re-radiation, convection and wind removal. Unfortunately, there are no data on the water storage in plant biomass of the forests. The water storage in plant biomass of the 22-year-old plantation was rather high, 52.34±7.80 m^3 $plot^{-1}$ (or 327.10±4.54 m^3 ha^{-1}). The successional tree species contributed slightly to the water storage in biomass in the pine stand. The plant succession seemed to be in the early stage, and resulted in low contribution of the succession species to water storage, i.e., only 0.55-6.90% of the total stand.

This study did not focus on the seasonal change over the year. In general, the water storage in soil varied with time; it is high in rainy season and very low in dry season. The water storage in soil profile within the 2-m depth in the mid-rainy season (on 17th August 2013) under the pine plantation was 80.02% of the maximum capacity. The storage in forest biomass was rather low (3.45%) compared to that in soil (96.55%). *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 volumes of 9475.5, 4782.0, 3184.3, 2611.8 and 1441.5 m^3ha^{-1}, respectively. Further study on the water storage in different natural forests, plantation forests and agro-forests should be based on the seasonal changes during the year.

CONCLUSION

The reforestation on devastated highland watershed, such as, the 22-year-old pine plantation at the Doi Tung areas, has essential ecological roles on the hydrologic cycle in terms of water storage, which is important to the management of forests and watershed. The conclusions of this study are as follows:

1. The growth of pine in the plantations at Doi Tung areas was better than in other areas in northern Thailand. The mean stem girth and height of pine were 112.29±19.46 cm and 28.3±2.5 m, respectively. The water storage in this pine plantation ecosystem was rather high, and occurred mainly in two components: plant biomass of pine and succession tree species, and soil system. In the mid-rainy season (17th August 2013), the amount of water storage within 2-m soil depth in the plantation ecosystem was estimated at 8,821.0±61.84 Mg ha^{-1}. The maximum water storage (plant biomass and soil) in the pine stand was 11,350.06 m^3 ha^{-1}.

2. The amount of water stored in plant biomass of the pine plantation was much lower than that in soil. The soil profile in pine plantation was very deep and could store large volumes of water up to more than 90% of the total water storage in the stand.

3. Plant succession by broad-leaved tree species in the pine plantation involved many species from the lower montane forest and some from the mixed deciduous forest. These species contributed to water storage in plant biomass. This plant succession implies that the pine stand will develop into a lower montane forest, and then the succession species will have more influence on the ecosystem water storage in the advanced stages of plant succession.

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REFERENCES

Anongrak, N. 2003. **Highland soil catena as affected by land uses and land covers in Doi Inthanon area, Chiang Mai province**. Ph.D Thesis, Kasetsart University, Bangkok.

Brady, N.C. and R.R. Weil. 2010. **Elements of the Nature and Properties of Soils.** 3th edition, Pearson Education, Inc., publishing as Prentice Hall, New Jersey, USA.

Chang, M. 2006. **Forest Hydrology.** 2nd edition, Taylor and Francis Group, Baca Raton, USA.

Khamyong, S. 2001. **Ecological Effects of Pinus kesiya Plantations on Highland Watershed, Northern Thailand**. Research Report to NRCT.

Khamyong, S., T. Seramethakun and T. Seeloy-ounkeaw. 2012. **Evaluation of planted tree species and plant succession in forest plantations for land restoration in Mae Moh lignite mining area**. Final Research Report to EGAT, Faculty of Agriculture, Chiang Mai University, Chiang Mai.

Kimmins, J.P. 2004. Chapter 11 Water: The material that makes life possible. pp. 269-295. *In* **Forest Ecology: A foundation for sustainable forest management and environmental ethics in forestry.** Prentice Hall, Upper Saddle River, New Jersey, USA.

Landsberg, J.J. and S.T. Gower. 1997. Chapter 4 Forest Hydrology and Tree-Water Relations. pp. 89-124. *In* **Application of Physiological Ecology to Forest Management**. Academic Press, Inc., San Diego, USA.

Nongnuang, S., S. Khamyong, K. Sri-ngernyuang and N. Anongrak. 2012. Biomass carbon stocks of trees in pine plantations at Boa Kaew watershed management station, Chiang Mai province. **Thai.J.For** 31(2): 1-15.

Pornleesangsuwan, A., S. Khamyong, K. Sri-ngernyuang and N. Anongrak. 2012. Growth, stem volume and plant succession in Pinus kesiya plantations, northern watershed, Chiang Mai province. **Thai.J.For** 31(1): 26-37.

RFD, Royal Forest Deoartment, 1993. **Forestry statistics of Thailand 1993**. Data Centre, Information Office, Royal Forest Department, Bangkok. (in Thai)

Seeloy-ounkeaw, T., S. Khamyong and N. Anongrak 2012. **Ecosystem water storages of conservation and utilization community forests of Karen tribe, Chiang Mai, northern Thailand.** A paper presented in the 1st Mae Fah Luang University International Conference, Chiang Rai province.

Seramethakun, T., S. Khamyong, N. Anongrak and T. Kongkaew.1993. Soil properties and carbon-nutrient storages in natural pine forest, Kunlayaniwattana district, Chiang Mai province. **Journal of Agriculture** 28(3): 205-215.

Tsutsumi, T., K. Yoda, P. Sahunaru, P. Dhanmanonda and B. Prachaiyo. 1983. Forest: burning and regeneration. *In* **Shifting cultivation, an experiment at Nam Phrom, Northeast Thailand, and its implications for upland farming in the monsoon tropics**. Kyuma, K and Pairintra, C. (eds.). A report of a cooperative research between Thai-Japanese universities, Kyoto University, Japan.

Withawatchutikul, P., S. Pan-utai and P. Titirodchanawat. 2011. **Roles of forest resources and Problems about Flooding and Landslide.** A Watershed Research Report. Watershed Research Division, Department of National Parks, Wildlife and Plant Conservation. Bangkok. (in Thai)

Waring, R.H. and S.W. Running. 1998. Chapter 2 Water Cycle. pp. 19-57. *In* **Forest Ecosystems: Analysis at multiple scales**. **2nd edition**. Academic Press, USA.