Restoration of Water Storage Potential in a Degraded Dry Dipterocarp Forest with Enrichment Planting of Three Needle Pine (*Pinus kesiya* Royle ex Gordon), Northern Thailand

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ARTICLE INFO

Received: 2 Jun 2020
Received in revised: 17 Aug 2020
Accepted: 27 Aug 2020
Published online: 28 Oct 2020
DOI: 10.32526/ennrj/19/2020130

Keywords:
Biomass water/ Dry dipterocarp forest/ Plant biomass/ Soil water/ Water storage

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ABSTRACT

The research assessed water storage in a dry dipterocarp forest (DDF) with enriched 34-year-old pine planting and the role of pine. Plant surveys were carried out using 10, 40×40 m^2 plots, and data were obtained by measuring tree stem girths and heights. Plant features, biomass, and stored water amounts were measured. Fresh plant samples of abundant species were taken one time per month from January to December 2018. Three soil pits were made in three plots, and soil samples along 100 cm depth were taken on the same days of collecting plant samples for studying fied capacity, water content and water amount. The DDF was divided into three stands based on the most dominant tree species; *Shorea obtusa*, *Dipterocarpus tuberculatus*, and *Dipterocarpus obtusifolius*. The forest was composed of 86 species with biomass at 101.62 Mg/ha and contained an average water amount of 88.01 m^3/ha. The water amount in biomass varied with sampling times from 58.74 to 111.83 m^3/ha. The average MWHC of 100 cm soil was estimated to be 5,113.74 m^3/ha. The water amount in soil also varied with sampling times from 3,651.50 to 4,481.06 m^3/ha. As a result, the total water amount in plant biomass and soil (ecosystem) of the DDF varied in a range from 3,735.0 to 4,558.67 m^3/ha. The pine contributed to 30.87 m^3/ha (35.07% of the total) and could increase by 64.92% the water storage potential of the forest, and thus these results support the concept of pine enrichment planting in the poor DDF.

1. INTRODUCTION

Deforestation in tropical counties such as Thailand has been mainly caused by forest clearing for people settlement and agriculture, and thus the present forest area of the country has decreased to 31.68% of the total in 2018 (Royal Forest Department, 2019). However, most remaining forests have suffered in part from forest concession, and illegal cutting by investors and local people. The secondary degraded forests can be observed in many areas over the country. The ecosystem function of water storage in forest biomass was different among abundant and degraded forests (Phongkhamphanh et al., 2018). Enrichment planting of selective tree species in the degraded forests is considered as an alternative method of forest restoration within a shorter period. The degraded forests have more opened canopy with big gaps, higher light intensity, fluctuating site temperature and poorer soil due to erosion as compare to the undisturbed forest. The tree species selected for enriched planting should be light demanding, fast growing, drought tolerant and have lesser nutrient requirements (Santos et al., 2020). Some enriched planting in poor natural forests has been practiced in Thailand, but very few data are published. Asanok et al. (2013) studied functional traits and the ability of tree species to reestablish in 15-year-old enriched secondary montane forest in the uplands of northern Thailand. The planted trees were native species such as *Castanopsis acuminatissima* (Blume) A. DC., *Betula alnoides* Buch. Ham. ex G. Don, *Cinnamomum iners* Reinw. ex Blume, *Diospyros glandulosa* Lace, and *Ternstroemia gymnanthera* (Wight and Arn.) Bedd. *Betula alnoides* Buch. Ham. ex G. Don could grow the

Citation: Thichan T, Anongrak N, Khamyong S, Kachina P. Restoration of water storage potential in a degraded dry dipterocarp forest with enrichment planting of three needle pine (*Pinus kesiya* Royle ex Gordon), Northern Thailand. Environ. Nat. Resour. J. 2021;19(1):10-23. (https://doi.org/10.32526/ennrj/19/2020130)

best with 12 cm stem DBH and 8.3 m height. In some counties, enrichment planting of native species in forest plantation of exotic species may be practiced as replacing the stand to avoid invasion of exotic species into natural forest. Chu et al. (2019) reported that enriched planting of native tree species in a 16-year-old *Eucalyptus* plantation in South China showed significantly reducing surface water flow, soil erosion and nutrient losses.

Forest ecosystems can store water in various components after rainfall. As the rain falls into the forest, a part is intercepted by the forest canopy and later lost into the atmosphere through evaporation, and the remains pass the canopy as through fall and stem flow to the forest floor. Organic layers on the forest floor can absorb a part of water, and the remaining amounts infiltrate into mineral soil. The water is also lost from the forest floor and soil through evaporation. Some water is retained by soil organic matter, fibrous roots and particles, particularly silt and clay which are varied with multiple soil layers along soil depth (He et al., 2019), while the excess amount percolates into the underground water table and moved out into the streams. Plants usually absorb a large amount of water as well uptake nutrients from soil solution for their physiological processes and growth. The functional role of the water cycle in forest ecosystems is important to maintain all organisms including plants, animals and microbes. Forest removal in the seasonal tropical montane forest resulted in typically increasing mean annual water yield and decreasing dry-season flows (Peña-Arancibia et al., 2019). Noywuli et al. (2019) reported that the forest-removal upstream watershed in Indonesia had a low carrying capacity condition indicated prominently by drought.

In the tropics, rainfall is only one source of water supply to watersheds and all types of ecosystem, and the forest ecosystem is considered as the most effective ecosystem in water cycle through many processes. However, different forests have variable roles on the water cycle. Typically, five forests in northern Thailand are classified: the dry dipterocarp forest, mixed deciduous forest, dry evergreen forest, pine forest (pine-dry dipterocarp forest and pine-lower montane forest) and the montane forest (Khamyong et al., 2004; Khamyong and Anongrak, 2016). Most literature studies focus on inputs of precipitation into forest ecosystems and movement of water through many processes, particularly interception-evaporation by forest canopy, through fall, stem flow, plant uptake, transpiration, water flow through vegetation, evaporation from soil, infiltration into soil, drainage and runoff, stream flow, etc. However, very few data are available for the water quantity stored in the plant biomass of forests. As for the montane forest, Khamyong et al. (2014a) provided the pioneer work on water storage in plants and soils of two community montane forests of Karen tribe in northern Thailand. Phongkhamphanh et al. (2018) compared the water storage potential of two-site DDFs. Khamyong et al. (2014b) and Sumanochitraporn et al. (2014) also evaluated the role of reforestation on watershed hydrology including 22-year-old teak and pine plantations in Chiang Rai Province, northern Thailand.

This research was conducted in the Huai Hong Khrai Royal Development Study (HHKRDS) Center established in 1982, Doi Saket District, Chiang Mai Province. It is about 27 km to the north of Chiang Mai City on the road to Chiang Rai Province. Before 1982, the two forests, mixed deciduous forest and dry dipterocarp forest, in this area were devastated to become extremely poor. Most medium and big trees were cut for timber whereas many small trees were used for fuel woods and only the small trees of 5 to 10 m heights with a scattered distribution remained (Khamyong et al., 2016). After heavy rainfall in rainy season, a lot of eroded soil transported in surface runoff was moved to the streams with dissolved red-sediment water. In dry season, all standing trees had no leaves as their deposition on the forest floor was the major fuels of annual forest fires. It was quite an extremely poor small watershed as called “Huai Hong Khrai”. The King (Rama 9) visited this area with profound understanding of the problems and established the Center as a place of study for the people in the north about integrated watershed management. Many activities of managing forest and wildlife resources, agriculture, and fishery are demonstrated in the Center for the study and extension of officers and Thai people. Foreign visitors also come here for learning.

The research paper assesses the role of enrichment planting of three needle pine (*Pinus kesiya* Royle ex Gordon) on water storage potential in plants and soil (ecosystem) of the degraded DDF, and to find out the contribution of planted pine on ecosystem water storage. The data provide useful information for forest conservation and watershed restoration.

2. METHODOLOGY

2.1 Study area

The research area, the HHKRDS Center covers an area of 1,360 ha with an altitude range between 350 and 591 m.m.s.l. (Figure 1). There are three seasons in this area: rainy season (May to September), winter (November to February), and summer (March to April). Meteorological data recorded using instruments in the Center report the following data: average annual rainfall, 1,328.9 mm; maximum and minimum air temperatures, 32.2°C and 18.9°C; and water evaporation, 1,222.6 mm/year (Khamyong et al., 2016). The two deciduous forests, the DDF and the mixed deciduous forest, distribute in most of the area. The parent rocks include sandstone, volcanic rock, shale, and limestone.

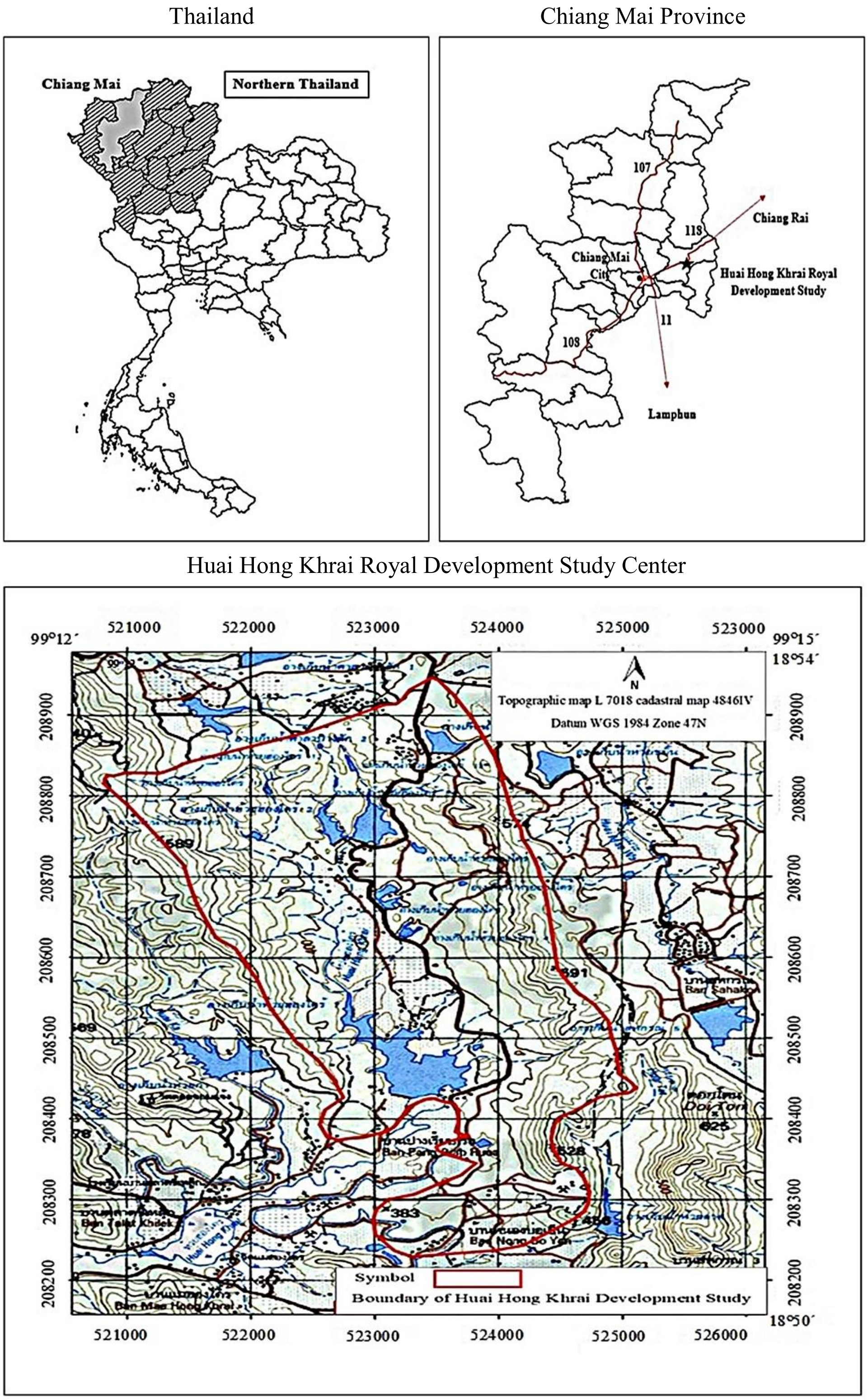

Figure 1. Location map of the study area

2.2 Plant community study

Census of plant species composition, richness, and diversity in the DDF was taken. Field vegetation survey in the forest was carried out using a method of plant community analysis. The sampling plots were 40×40 m^2 in size and ten plots were used, which were arranged randomly in the forest areas. Stem girths at breast height (gbh, 1.3 m above ground) and tree heights of all species with height over 1.5 m were measured. All plots were located using the global positioning system (GPS). The field plant data were later calculated for quantitative characteristics including frequency, density, dominance and important value index (IVI) and species diversity refer to Shannon-Wiener Index (SWI) (Krebs, 1985) and forest condition index (FCI) based on an equation studied by Seeloy-ounkeaw et al. (2014).

2.3 Standing plant biomass

The standing biomass amounts in the stem, branch, leaf, and root organs were calculated using allometric equations studied in the deciduous forests in Thailand by Ogino et al. (1967). The root biomass was calculated using an equation given by Ogawa et al. (1965).

2.4 Water storage in plants and soils

2.4.1 Water storage in plant biomass

Samples of fresh bark, stem, branch, and leaf on the standing trees of ten abundant species in the DDF were taken 12 times (each per month) from January to December 2018. Four stem-gbh classes of <25 cm, 26-50 cm, 51-75 cm, and >76 cm were divided for big tree species, and applied two or three gbh classes for the medium-sized and small tree/shrub species. Three tree individuals of each species were used as the sample trees for each gbh class. The fresh plant samples of 10 to 30 g were oven dried at 75°C until constant weights were achieved, and later quantified for their water content. The water content in the root used average values of the water content in the stem and branch because of having woody tissues as root. The water amount in biomass of each species was calculated by multiplying its biomass with the water content (by dry weight) of each gbh class. The average contents of these species were used for calculating the water amounts in biomass of the other species.

2.4.2 Water storage in soils

The soil derived from the volcanic rock in the DDF was studied by making three pits, 1.5 m × 1 m × 1 m in size, in selected three plots, and soil samples were collected along the depth using a 100 cm^3 corer in 12 months (each per month) as the same days of collecting fresh plant samples from eight soil depths with three replications: 0-5, 5-10, 10-20, 20-30, 30-40, 40-60, 60-80, and 80-100 cm. Some physical properties, organic matter (OM) by Walkley and Black Titration (Nelson and Sommers, 1996), field capacity (FC), maximum water holding capacity (MWHC), and water content on the sampling days were later analyzed in a laboratory (Brady and Weil, 2010). The MWHC was determined from the field capacity (FC). Water was added into the soil sample with the 100 cm^3 corer until the soil sample was completely saturated with water, and the water allowed to drain out of the macro pores. Then, the soil samples were oven dried at 105°C within a few days or until they achieved constant weights, and later, their moisture contents were determined by volume as field capacity (FC). Finally, the amount of water storage per unit area in each soil layer was determined and the total amount within the soil depth per unit area was calculated.

3. RESULTS AND DISCUSSION

3.1 Results

The results of this study include findings on plant community structures, amounts of standing plant biomass, values of water content, and water storage in plant biomass and soil within three seasons of the DDF with pine enriched planting.

3.1.1 Assessment of plant community structures, diversity, and forest conditions

Based on Smitinand (2014), the woody plants sampled within 10 sampling plots, each of size 40×40 m^2, were identified to be a total of 83 species, 69 genera, and 36 families (Table 1). These included 15 big trees, 24 medium-sized trees, 21 small trees, 16 shrubs, 3 climbers, and 3 unknown species. The forest was divided into three stands based on the dominant tree species: seven plots of *Dipterocarpus tuberculatus*, two plots of *Dipterocarpus obtusifolius* and one plot of *Shorea obtusa*. The species richness of these stands varied between 22 and 45 species per plot and tree densities varied from 1,688 to 3,606 trees/ha. The pine density contributed to only 5.53% of the total density.

The quantitative characteristics of plant species in the forest were investigated. Twelve species had the highest frequency value (100%); *Pinus kesiya, Dipterocarpus tuberculatus, Shorea obtusa, Aporosa villosa, Wendlandia tinctoria, Pterocarpus* *macrocarpus, Strychnos nux-vomica, Canarium subulatum, Syzygium cumini, Dalbergia oliverli, Bridelia retusa,* and *Quercus kerrii*. The dipterocarps species of *Dipterocarpus obtusifolius* and *Shorea siamensis* had the values as 70% and 10%, respectively.

Average density of all species was 2,729 trees/ha. The species with the highest density was *Dipterocarpus tuberculatus* (473 trees/ha), followed by *Shorea obtusa* (291), *Aporosa villosa* (266), *Dipterocarpus obtusifolius* (201), *Wendlandia tinctoria* (151), *Pinus kesiya* (146), *Gluta usitata* (143), *Symplocos recemosa* (76), *Strychnos nux-vomica* (71), *Canarium subulatum* (60), *Dalbergia cultrata* (54), and *Pterocarpus macrocarpus* (52). These 12 species accounted for 72.70% of the total density.

The dominance of tree species was calculated from the stem basal area by measurement of stem girths at the breast height. *Pinus kesiya* had the highest dominance (31.81%), followed by *Dipterocarpus tuberculatus* (16.79), *Shorea obtusa* (12.06), *Dipterocarpus obtusifolius* (11.87), *Gluta usitata* (6.34), *Aporosa villosa* (3.52), *Pterocarpus macrocarpus* (2.03), *Semecarpus ancardium* (1.78), *Dalbergia cultrata* (1.54), *Strychnos nux-vomica* (1.27), and *Wendlandia tinctoria* (1.22). These 11 species accounted for 90.23% of the total dominance.

Table 1. A species list of tree species in the DDF with planted pine

Family	Scientific name	Growth form
1. Acanthaceae	1. *Justica modesta* (Bremek.) V.A.W. Graham	shrub
2. Anacardiaceae	2. *Buchanania lanzan* Spreng.	big tree
	3. *Gluta usitata* (Wall.) Ding Hou	big tree
	4. *Lannea coromandelica* (Houtt.) Merr.	big tree
	5. *Semecarpus anacardium* Linn.f.	medium tree
3. Apocynaceae	6. *Aganosma marginata* (Roxb.) G.Don	climber
4. Bignoniaceae	7. *Markhamia stipulata* (Wall.) Seem. var. *pierrei* (Dop) Santisuk & Vidal	medium tree
	8. *Heteropanax sulfureum* Kurz.	small tree
	9. *Stereospermum cylindricum* Pierre ex Dop.	medium tree
	10. *Stereospermum neuranthum* Kurz	medium tree
5. Burseraceae	11. *Canarium subulatum* Guillaumin	big tree
6. Celastraceae	12. *Celastrus paniculata* Willd.	climber
7. Clusiaceae	13. *Garcinia cowa* Roxb. ex Choisy	small tree
8. Combretaceae	14. *Terminalia alata* Heyne ex Roth	big tree
	15. *Terminalia chebula* Retz. var. *chebula*	medium tree
9. Chrysobalanaceae	16. *Parinari anamensis* Hance	medium tree
10. Dilleniaceae	17. *Dillenia obovata* (Blume) Hoogland	small tree
11. Dipterocarpaceae	18. *Dipterocarpus obtusifolius* Teijsm. ex Miq.	big tree
	19. *Dipterocarpus tuberculatus* Roxb.	big tree
	20. *Shorea siamensis* Miq.	big tree
	21. *Shorea obtusa* Wall. ex Blume	big tree
12. Ebenaceae	22. *Diospiros ehretioides* Wall. ex G. Don	small tree
13. Ericaceae	23. *Craibiodendron stellatum* (Pierre) W.W. Sm.	small tree
14. Fabaceae	24. *Acacia catechu* (L.f.) Willd.	medium tree
	25. *Albizia odoratissima* (L.f.) Benth.	medium tree
	26. *Albizia chinensis* (Osbeak) Merr.	big tree
	27. *Butea superba* Roxb.	climber
	28. *Dalbergia cultrata* Graham ex Benth	big tree
	29. *Dalbergia dongnaiensis* Pierre	medium tree
	30. *Dalbergia oliveri* Gamble	medium tree
	31. *Dalbergia velutina* Benth.	climber
	32. *Indigofera sootepensis* Craib	shrub
	33. *Leucaena leucocephala* (Lam.) de Wit	small tree
	34. *Millettia xylocarpa* Miq.	medium tree
	35. *Millettia extensa* (Benth.) Baker	medium tree

Table 1. A species list of tree species in the DDF with planted pine (cont.)

Family	Scientific name	Growth form
	36. *Peltophorum pterocarpum* (DC.) Backer ex K.	medium tree
	37. *Pterocarpus macrocarpus* Kurz	big tree
	38. *Spatholobus parviflorus* (DC.) Kuntze	climber
	39. *Xylia xylocarpa* Taub. Var. *kerrii* Nielsen	big tree
15. Fagaceae	40. *Quercus kerrii* Craib.	medium tree
	41. *Lithocarpus elegans* (Blume) Hatus. ex Soepadmo	medium tree
16. Hypericaceae	42. *Cratoxylum formosum* Byer	small tree
17. Irvingiaceae	43. *Irvingia malayana* Oliv. ex A. W. Benn.	big tree
18. Lamiaceae	44. *Vitex peduncularis* Wall. ex Schauer	medium tree
19. Lauraceae	45. *Litsea glutinosa* (Lour.) C.B. Rob.	medium tree
	46. *Phoebe lanceolata* (Nees) Nees	medium tree
20. Malvaceae	47. *Colona flagrocarpa* (C.B. Clarke)	small tree
	48. *Decaschistia siamensis* Craib	shrub
	49. *Sterculia balanghas* L.	shrub
21.Melastomataceae	50. *Memecylon plebejum* Kurz var. *plebejum*	shrub
22. Meliaceae	51. *Chukrasia tabularis* A. Juss.	medium tree
23. Moraceae	52. *Ficus* sp.	medium tree
24. Myrtaceae	53. *Eucalyptus camaldulensis* Dehnh.	medium tree
	54. *Syzygium albiflorum* (Duthie & Kurz) Bahadur & R.C. Gaur	medium tree
	55. *Syzygium cumini* (L.) Skeels	small tree
25. Ochnaceae	56. *Ochna intergerrima* (Lour.) Merr.	small tree
26. Oleaceae	57. *Chionanthus ramiflorus* Roxb.	small tree
	58. *Olea salicifolia* Wall. Ex G. Don	small tree
27. Opiliaceae	59. *Meilentha suavis* Pierre	small tree
28. Pentaphylacaceae	60. *Anneslea fragrans* Wall.	small tree
29. Phyllanthaceae	61. *Antidesma acidum* Retz.	shrub
	62. *Antidesma ghaesembilla* Gaertn.	shrub
	63. *Antidesma sootepene* Craib	shrub
	64. *Aporosa villosa* (Wall. ex Lindl.) Baill.	shrub
	65. *Bridelia retusa* (L.) A. Juss.	medium tree
	66. *Glochidion zeylanicum* (Gaaertn.) A. Juss.	shrub
	67. *Phyllanthus emblica* L.	small tree
30. Pinaceae	68. *Pinus kesiya* Royle ex Gordon	big tree
31. Rhamnaceae	69. *Zizyphus rugosa* Ram.	climber
32. Rubiaceae	71. *Catunaregam spathulifolia* Tirveng.	shrub
	72. *Gardenia sootepensis* Hutch	small tree
	73. *Gardenia obtusifolia* Roxb. ex Gordon	shrub
	74. *Haldina cordifolia* Ridsd.	medium tree
	75. *Ixora cibdela* Craib	shrub
	76. *Morinda coreia* Ham.	small tree
	77. *Pavetta indica* RL.	shrub
	78. *Wendlandia tinctoria* (Roxb.) DC.	small tree
	79. *Vangueria pubescens* DC.	shrub
33. Saliciaceae	80. *Casearis gallifera* Tathana	small tree
34. Symplocaceae	81. *Symplocos recemosa* Roxb.	small tree
35. Strychnaceae	82. *Strychnos nux-vomica* L.	shrub
36. Ulmaceae	83.*Ulmus lancaefolia* Roxb. ex Wall.	small tree
Unknown	84-86. Climber -1, 2, 3	climber

The importance value index combines three factors of the relative frequency, relative density and relative dominance into a measure that can be used to imply the ecological influence of each species in the DDF. The species with the highest IVI was *Pinus kesiya* (13.32% of all species), followed by *Dipterocarpus tuberculatus* (12.31%), *Shorea obtusa* (8.51%), *Dipterocarpus obtusifolius* (7.07%), *Aporosa villosa* (5.36%), *Gluta usitata* (4.70%), *Wendlandia tinctoria* (3.19%), *Pterocarpus macrocarpus* (2.25%), *Strychnos nux-vomica* (2.23%), *Symplocos recemosa* (2.03%), *Dalbergia cultrata* (1.93%), and *Canarium subulatum* (1.79%). These 12 species accounted for 64.69% of the total value.

As shown in Table 2, the values of the SWI as indicating plant species diversity were different among plots, 3.49 to 4.31 (3.87±0.24 on average), while the forest condition index values were measured to be a range of 1.03 to 10.98 (6.18±3.24 on average). If the pine was not planted in the forest, the values would decrease to 3.79±0.25 for the SWI, and 2.70±2.24 for the FCI.

Table 2. Plant communities within 10 sampling plots in the DDF

Plot No.	Dominant Species	Species richness	Density (ha)	Pine density (ha)	Pine density %	SWI A	SWI B	FCI A	FCI B
1	*D. tuberculatus*	45	3,356	175	5.21	4.31	4.24	7.72	3.79
2	*D. tuberculatus*	34	3,606	106	2.94	3.66	3.58	10.98	2.45
3	*D. tuberculatus*	30	1,788	56	3.14	3.90	3.81	6.74	1.52
4	*D. tuberculatus*	22	1,688	69	4.07	3.49	3.38	3.23	0.51
5	*S. obtusa*	40	3,594	219	6.08	4.04	3.96	9.53	6.17
6	*D. obtusifolius*	40	3,231	163	5.02	3.71	3.60	9.49	6.82
7	*D. tuberculatus*	31	1,856	263	14.14	3.86	3.82	5.12	2.47
8	*D. obtusifolius*	37	2,813	69	2.44	3.89	3.82	1.03	0.78
9	*D. tuberculatus*	38	2,817	256	9.09	4.12	4.06	3.56	0.74
10	*D. tuberculatus*	38	2,538	81	3.20	3.77	3.68	4.39	1.75
Mean		36	2,729	146	5.53	3.87	3.79	6.18	2.70
S.D.		7	741	80	3.61	0.24	0.25	3.24	2.24

Remark: A=DDF with planted pine, B=DDF without planted pine

3.1.2 Growth and population of pine

Within 10 plots, a total of 233 individuals of pine were found. The biggest pine had the stem-gbh of 129.5 cm with 25.5 m height, while the values of 10.9 cm and 4.1 m belonged to the smallest tree. The number of trees in the gbh classes of <25, 26-50, 51-75, and >75 cm were 5, 26, 97, and 105 trees, respectively, whereas the height classes of <5, 6-10, 11-15, 16-20, and >20 m consisted of 2, 19, 96, 89, and 27 trees. The average values of gbh and height were 72±22.02 cm and 15.1±3.97 m, respectively. The seedlings of pine were not observed in the forest. Thus, the annual growth rates (annual ring width) of pine varied from 0.5 to 6 mm (3.4 mm on average). The variable growth might be caused by competition with other tree species and the influences of site factors (Pornleesangsuwan, 2012).

3.1.3 Amount of standing plant biomass

Table 3 shows the amounts of plant biomass within 10 plots in the DDF with planted pine, and the average amount was measured as 101.62 Mg/ha, divided into bark, stem, branch, leaf, and root organs at 1.72 (1.69%), 64.07 (63.04%), 17.89 (17.60%), 2.34 (2.30%), and 15.59 (15.37%) Mg/ha, respectively. The biomass amounts in these stands varied in a range of 58.73 to 148.43 Mg/ha.

Among 86 species, the pine biomass was the highest, 36.79 Mg/ha (36.20% of the total). The tree species having the lower amounts were in the following order: *Dipterocarpus tuberculatus* (15.97 Mg/ha), *Dipterocarpus obtusifolius* (12.47 Mg/ha), *Shorea obtusa* (12.19 Mg/ha), *Gluta usitata* (6.59 Mg/ha), *Ptercarpus macrocarpus* (2.45 Mg/ha), *Aporosa villosa* (1.89 Mg/ha), *Semecarpus anacardium* (1.51 Mg/ha), *Dalbergia cultrata* (1.40 Mg/ha), *Irvingia malayana* (1.08 Mg/ha), etc. These 10 species accounted to 92.34 Mg/ha (90.87% of the total biomass). Therefore, the enriched planting of this pine could increase a large amount of biomass in the degraded DDF.

Table 3. Amounts of standing plant biomass of tree species in the DDF with planted pine

No.	Name	Biomass (Mg/ha)					
		Bark	Stem	Branch	Leaf	Root	Total
1	*P. kesiya*	0.24	23.90	4.50	0.95	7.20	36.79
2	*D. tuberculatus*	0.37	9.83	3.40	0.34	2.03	15.97
3	*D. obtusifolius*	0.18	7.85	2.69	0.23	1.52	12.47
4	*S. obtusa*	0.40	7.42	2.60	0.24	1.53	12.19
5	*G. usitata*	0.11	4.08	1.54	0.10	0.76	6.59
6	*P. macocarpus*	0.04	1.51	0.58	0.04	0.28	2.45
7	*A. villosa*	0.03	1.20	0.27	0.07	0.32	1.89
8	*S. anacardium*	0.03	0.94	0.30	0.03	0.20	1.51
9	*D. cultrata*	0.03	0.87	0.27	0.03	0.19	1.40
10	*I. malayana*	0.02	0.67	0.23	0.02	0.13	1.08
11	Species 11 to 86	0.26	5.79	1.51	0.30	1.44	9.29
Total		1.72	64.07	17.89	2.34	15.59	101.62

3.1.4 Water storage in plants and soil of DDF with planted pine

(1) Amount of water stored in plant biomass

Data regarding the water contents (percentage by fresh weight) in different organs of ten dominant tree species in the DDF were studied. The water contents of these species varied greatly among species, sampling times and stem-gbh classes.

Four gbh classes were used for the three species. The average values of water content in bark, stem, branch, leaf and root were measured as the following order: *Dipterocarpus obtusifolius*: 49.76%, 40.16%, 58.10%, 55.46%, 41.96%, *Dipterocarpus tuberculatus*; 61.11%, 42.16%, 62.83%, 65.76%, 54.43%, and *Irvingia malayana*; 54.87%, 35.93%, 48.06%, 54.85%, 46.90%. Three gbh classes were used for *Shorea obtusa*. Their averages were 45.72%, 37.89%, 48.04%, 54.95%, 43.31%, respectively. Two gbh classes were used for the six species. The average values of water content in these organs were calculated as the following order: *Pinus kesiya*; 56.86%, 40.39%, 55.57%, 59.93%, 45.04%, *Aporosa villosa*; 41.63%, 47.86%, 59.47%, 68.88%, 44.91%, *Wendlandia tinctoria*; 52.77%, 46.65%, 53.66%, 62.83%, 49.65%, *Symplocos racemosa*; 46.36%, 50.36%, 59.06%, 64.80%, 48.23%, *Syzygium cumini*; 55.25%, 42.55%, 49.01%, 55.34%, 46.14%. One gbh class was applied for *Memecylon plebejum* and the averages were 38.04%, 42.14%, 57.52% and 38.04%, respectively.

The water amount of all stands (10 plots) during January to December varied from 58.74 to 111.83 m^3/ha (88.01±12.61 m^3/ha on average). The percentages of water amount in the bark, stem, branch, leaf, and root were calculated as the following order: 2.40%, 50.51%, 26.69%, 4.20%, and 16.19%. The average water amounts stored in plant biomass of the DDF for 12 months varied from 58.74 to 111.83 m^3/ha (88.01±12.61 m^3/ha on average). It was the highest in July (rainy season) and the lowest in October (end of rain season). The amount was not the lowest in dry season. It is supposed that leaf fall might reduce lose through transpiration.

As shown in Table 4, the average water amount in pine biomass (sp.1) was the highest among 86 species, 30.87 m^3/ha or 35.07% of the total. The species with lower amounts were in the following order: *Dipterocarpus tuberculatus* (sp.2, 16.68 m^3/ha), *Dipterocarpus obtusifolius* (sp.3, 10.36), *Shorea obtusa* (sp.4, 8.77), *Gluta usitata* (sp.5, 5.53), *Ptercarpus macrocarpus* (sp.6, 2.07), *Aporosa villosa* (sp.7, 1.99), *Semecarpus anacardium* (sp.8, 1.31), *Dalbergia cultrata* (sp.9, 1.21), *Strychnos nux-vomica* (sp.10, 0.87), etc. These 10 species accounted to 79.67 m^3/ha or 90.52% of the total.

(2) Water storage in soils

The soil derived from volcanic rock in the DDF dominated mainly by *Diterocarpus tuberculatus* was very deep, more than 2 m, and classified into the more developed soil of Order Oxisols. It is the reddish soil containing the high content of iron oxides. In general, the physical properties of the soil, particularly depth, gravel content, bulk density, texture, and organic matter content, have an influence on water movement and retention throughout the soil profile (Brady and Weil, 2010). The data on the soil physical properties in the DDF are given in Table 5. The bulk density (BD) was almost moderately high throughout soil depth. The organic matter was high only at the soil surface and decreased to low and very low to subsoil while the gravel content was almost very low. Except for the intermediate content of sand at the soil surface, this soil contained the low content of sand and silt, but the clay content was relatively high throughout the soil profile.

Table 4. Amounts of water stored in biomass of tree species in the DDF with planted pine

Month	Water in plant biomass (m^3/ha)											Total
	Species number											
	sp.1	sp.2	sp.3	sp.4	sp.5	sp.6	sp.7	sp.8	sp.9	sp.10	11-86	
Jan	28.56	16.89	11.14	8.73	5.49	2.06	1.99	1.30	1.20	0.87	8.27	86.51
Feb	29.79	15.91	9.58	8.44	5.31	1.98	1.72	1.23	1.13	0.78	7.61	83.49
Mar	29.36	18.35	9.84	9.07	5.37	2.03	1.74	1.27	1.18	0.84	7.90	86.94
Apr	25.61	15.45	9.99	9.34	5.31	2.00	2.18	1.27	1.17	0.85	8.11	81.29
May	35.63	18.45	10.93	10.09	5.87	2.22	2.35	1.44	1.33	0.99	9.25	98.56
Jun	29.49	16.39	10.89	9.29	5.47	2.06	1.99	1.32	1.21	0.88	8.41	87.41
Jul	40.44	21.10	12.59	11.21	6.95	2.59	2.32	1.63	1.51	1.09	10.40	111.83
Aug	40.32	16.17	10.69	8.31	5.91	2.20	2.31	1.37	1.27	0.89	8.62	98.07
Sep	29.85	17.84	10.38	8.62	5.66	2.13	2.12	1.35	1.26	0.92	8.79	88.92
Oct	17.71	12.05	6.88	5.58	3.94	1.48	1.43	1.01	0.90	0.70	7.07	58.74
Nov	35.78	15.49	11.19	7.91	5.90	2.17	1.90	1.32	1.22	0.82	8.10	91.81
Dec	27.90	16.06	10.24	8.66	5.21	1.96	1.75	1.23	1.13	0.80	7.66	82.61
Mean	30.87	16.68	10.36	8.77	5.53	2.07	1.99	1.31	1.21	0.87	8.35	88.01
S.D.	6.39	2.19	1.35	1.34	0.69	0.25	0.29	0.14	0.14	0.10	0.87	12.61

Table 5. Physical properties of 100 cm soil under the DDF with planted pine

Depth	OM	BD	Gravel	Particle distribution (%)			Texture	FC	MWHC
(cm)	(%)	Mg/m^3	%	Sand	Silt	Clay		(%)	m^3/ha
Pedon 1									
0-5	4.34	1.64	33.60	65.4	12.0	22.6	SCL	44.85	277.06
5-10	2.06	1.66	31.91	46.4	9.0	44.6	SC	37.17	273.55
10-20	1.24	1.67	32.06	33.4	6.0	60.6	C	37.53	554.39
20-30	0.84	1.65	35.29	48.0	8.0	44.0	SC	39.50	533.81
30-40	0.61	1.74	29.28	34.5	6.5	59.0	C	39.36	555.21
40-60	0.46	1.69	28.98	32.7	5.2	62.1	C	41.23	1,095.07
60-80	0.44	1.74	30.45	34.5	6.0	59.5	C	41.63	1,092.76
80-100	0.44	1.71	30.96	29.6	6.0	64.4	C	43.50	1,124.35
Total									5,506.19
Pedon 2									
0-5	4.34	1.62	36.48	24.2	40.2	35.6	CL	41.73	239.20
5-10	1.65	1.83	35.75	25.5	36.5	38.0	CL	36.47	216.05
10-20	0.72	1.81	32.69	15.2	30.2	54.6	C	35.85	514.84
20-30	0.45	1.82	34.86	16.5	26.6	56.9	C	33.90	442.70
30-40	0.44	1.72	32.98	17.1	24.4	58.5	C	38.42	484.31
40-60	0.22	1.79	28.53	13.2	24.6	62.2	C	38.60	1,055.12
60-80	0.15	1.85	32.30	15.5	20.3	64.2	C	39.72	885.88
80-100	0.13	1.77	29.56	14.4	20.1	65.5	C	39.85	991.18
Total									4,829.29

Remarks: SCL=Sandy Clay Loam; SC=Sandy Clay; C=Clay; CL=Clay Loam

Table 5. Physical properties of 100 cm soil under the DDF with planted pine (cont.)

Depth (cm)	OM (%)	BD Mg/m^3	Gravel %	Particle distribution (%) Sand	Silt	Clay	Texture	FC (%)	MWHC m^3/ha
Pedon 3									
0-5	4.20	1.67	32.26	60.6	14.9	24.5	SCL	41.76	250.96
5-10	1.85	1.69	31.36	40.4	23.2	36.4	CL	41.85	248.08
10-20	0.88	1.71	28.56	48.4	5.0	46.6	SC	42.73	555.75
20-30	0.60	1.69	31.14	33.5	7.5	59.0	C	41.92	513.43
30-40	0.44	1.68	33.42	33.7	6.3	60.0	C	46.47	490.80
40-60	0.44	1.70	33.96	30.7	5.2	64.1	C	46.92	965.23
60-80	0.38	1.72	38.38	30.5	5.0	64.5	C	47.87	967.07
80-100	0.20	1.65	34.90	30.6	6.0	63.4	C	46.53	1,014.42
Total									5,005.74

Remarks: SCL=Sandy Clay Loam; SC=Sandy Clay; C=Clay; CL=Clay Loam

The soil study on water storage was carried out 12 times (January to December 2018). The field capacities of water (% by weight) in three soil pits (pedons) varied along soil depths: 33.90 to 47.87%. The water contents in different soil depth of the three pedons varied greatly with sampling times with the values lower than the field capacity. The values were low in dry season (mid-February to April), increased in rainy season especially September, and decreased in winter (November to mid-February). These caused the variations of water amount in 100 cm soil during a year. The maximum water holding capacity which was calculated from the field capacity varied with soil depth and three pedons, and the total amount within 100 cm depth varied from 4,829.29 to 5,506.19 m^3/ha (5,113.74 m^3/ha on average). This capacity could store the maximum rainfall amount of 514 mm. The amount of soil water was the lowest in February (3,651.50 m^3/ha, 71.40% of MWHC) and the highest in October (4,481.06 m^3/ha, 87.62%).

(3) Water storage in the DDF ecosystem (plants and soils) with planted pine

Figure 2 shows the amounts of water stored in the DDF ecosystem (plant biomass and soil system) during January and December 2018. Generally, the amounts of water stored in plant biomass and soil can vary day by day, month by month, and year by year. However, the results of this study show that the amount varied from the lowest (3,651.50 m^3/ha in February) to the highest (4,481.06 m^3/ha in October). The difference was only 829.56 m^3/ha. It could be concluded that the soil (100 cm depth) in the DDF ecosystem could store the largest water amount at 97.86% and the remainder (2.14%) belonged to the plant biomass. The movement of water between soil and plants is due to water uptake by roots as influenced by transpiration to the atmosphere (Landberg and Gower, 1997).

3.2. Discussion

3.2.1 Contribution of planted pine to community structures, species diversity and forest condition

The enrichment planting of three needle pine in the degraded DDF could increase species composition, number of species (species richness) as well as species diversity indicated by SWI of species diversity. The SWI was calculated from the equation derived from species richness and relative population abundance of each species in the plot. One species of pine with the average density of 146±80 trees/ha contributed to community structure in the DDF, and resulted in the small increase of SWI value from 3.79±0.25 to 3.87±0.24 whereas the forest condition index (FCI) was raised from 2.70±2.24 to 6.18±3.24. These data implied that the enrichment planting could increase species diversity and improve forest condition of the forest after planting for 34 years. This pine occurs naturally in dry areas from 1,000 to 1,900 m altitude in the transition zone (ecotone) between the DDF and lower montane forest of northern Thailand (Seramethakun, 2012; Marod et al., 2019), and is recognized as a fast-growing tree species. Thus, the pine could reduce the time of plant succession and forest development of the degraded DDF (Pornleesangsuwan, 2012). Seeloy-ounkeaw (2014) reported that the utilization community forest (UF) was distributed in areas of 1,000 to 1,250 m altitude. Within 50 sampling plots, three needle pine had 98% frequency value with the density of 153 trees/ha. Its dominance and IVI were measured to be 25.82% and 11.97%, respectively. In the conservation community forest as the watershed covered the areas of 1,100 to 1,800 m, this pine had the lower frequency value (58%) with the density of 94 trees/ha. However, it had the highest values of dominance and IVI among 236 species within 50 plots: 15.77% and 6.51%, respectively. This pine has the high potential to plant in the opened dry areas of degraded forests.

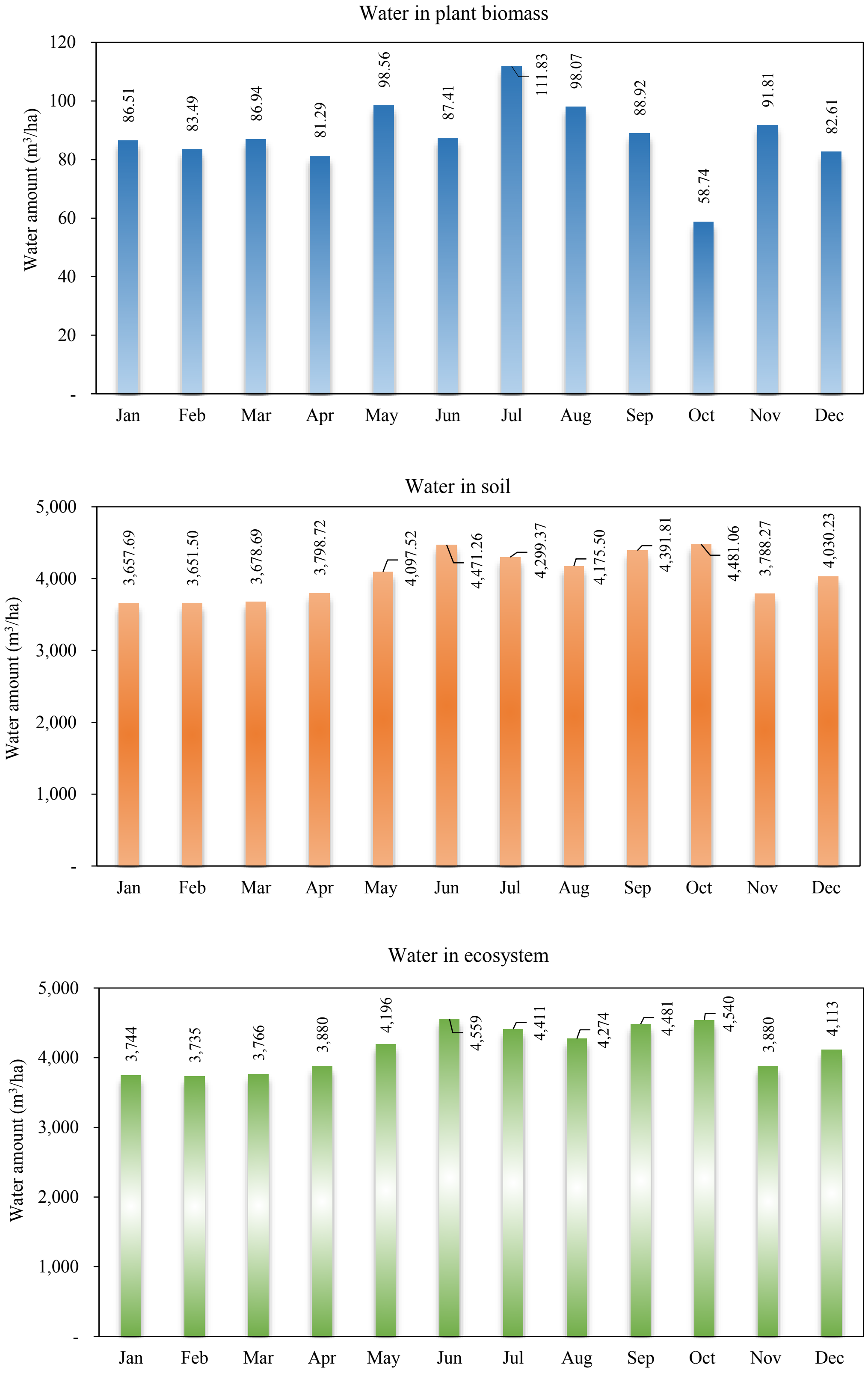

Figure 2. The water amounts stored in plant biomass, soil and ecosystem of the DDF during January to December 2018

3.2.2 Contribution of planted pine to plant biomass and water storage

The enrichment planting of three needle pine in the degraded DDF could increase also plant biomass as well as the water storage potential. The pine produced the amount of plant biomass at 36.79 Mg/ha (32.20% of the total) within 34 years, and increased the biomass from 64.83 to 101.62 Mg/ha. This pine species could store the amount of water at 28.57 m^3/ha (32.46% of the total) and restore the water storage potential in plant biomass in the forest from 59.44 to 88.01 m^3/ha. Therefore, the enrichment planting of this pine could increase 48.07% (1.41 m^3/ha/yr) of the total water storage potential in the DDF (without planted pine). Sutthawan et al. (2016) found that the DDF on sandstone in adjacent area has the annual increment of plant biomass as 1.38 Mg/ha or 1.77 m^3/ha of water. Seramethakun (2012) reported that the natural pine-DDF dominated by *Shorea obtusa* at Kanlaya Ni Wattana District in Chiang Mai could produce the amount of biomass at 84.96 Mg/ha, and the pine had the contribution to the biomass at 31.12 Mg/ha (36.62% of the total). As for the degraded lower montane forest which had the amount of biomass at 79.48 Mg/ha, the contribution of pine to the biomass was high as 67.94% of the total.

Khamyong et al. (2014a) studied water storage in the lower montane forest in northern Thailand. The community forest of Karen village was divided into the conservation forest (CF) and the utilization forest (UF). Selective tree cutting for house construction and fuelwood was permitted by village regulations only in the UF. The CF was protected for the watershed and become a recovery forest. The amount of standing plant biomass in the CF (252.4±72.5 Mg/ha) was higher than that in the UF (139.7±36.3 Mg/ha). The amounts of water in the plant biomass varied between seasons. The amounts of water in the CF varied between 208.2±68.9 and 231.2±70.7 m^3/ha, whereas the amounts of water in the UF varied in the range from 107.1±29.7 to 129.0±33.3 m^3/ha. Thus, the lower montane forest had higher amounts of water stored in plant biomass than the DDF with planted pine as present study (88.01 m^3/ha).

Different soils have the variable capacity of water storage depending upon soil depth, organic matter, gravel content, bulk density and textures (sand silt and clay content). The soil in this study was a very deep reddish soil, and classified into Order Oxisols. The bulk density, gravel content and organic matter were almost low throughout the 100 cm depth, but the clay content was very high. The soil with the high clay content usually has the high retention of water, but the clay of the Oxisols is aggregated to a strong grade of fine and very fine granular structure which causes it has the rapid permeability after rainfall (Soil Survey Staff, 1999), and the water storage by this soil maybe not be as high as predicted as other soils with the high clay content. Within 100 cm soil, this soil had the MWHC of 5,113.74 m^3/ha. This value was nearly the same to the deep soil of Order Ultisols in the lower montane forest, 4,956 m^3/ha (Khamyong et al., 2014a). Sumanochitraporn et al. (2014) found that the deep soil (the Ultisols) in a 22-year-old teak plantation could store the lower amount of water at 3,617.60 m^3/ha while the Ultisols under the 22-year-old three needle pine had the higher value of 5,632.87 m^3/ha (Khamyong et al., 2014b).

Very few researches have investigated directly on pine restoration causing dehydration in the rehabilitation area. However, some assumptions can be considered by the fact that the pine is an evergreen species with transpiration throughout a year. However, the transpiration of pine is normally lower than other species (Urban et al., 2019). The second is mycorrhizal fungi in the root system can absorb more water from soil into the pine root as commonly occurred in most forest tree species (Barea et al., 2011; Leski et al., 2019; Rożek et al., 2020). These leads to movement of soil water into the tree roots. A part is stored in different organs and the rest is lost into atmosphere through transpiration.

3.2.3 Suggestion for further research

Various aspects of further research are considered. Enrichment planting of pine increased tree density as well as biomass in the forest. The air temperature beneath its canopy can reduce light intensity throughout a year because it is an evergreen species. The water stored in its biomass could absorb solar radiation and released the heat through transpiration, and then soil water can be assimilated by roots into the tree. This can cool the forest environment and give a specific microclimate such as soil temperature. Thus, the research on effects of pine enrichment planting on changing microclimate is considerably important. Also, since there are other evergreen and deciduous tree species used in enrichment planting worldwide, the different effects among species will be the interacting research topic. Different tree species have variable transpiration. Urban et al. (2019) found that the annual transpiration of two stands with the same age (49 years old) was different. *Pinus sylvestris* had 20% lower than *Larix sibirica* transpiration in central Siberia. Therefore, the study on different transpiration among enrichment planting species is also a significant aspect.

4. CONCLUSION

Enrichment planting of tree species in the xeric degraded forest in the tropic is usually difficult. The selected species must have tolerance to drought, forest fire, extremely high surface air temperature and poor soil. Three needle pine (*Pinus kesiya*) has been used for reforestation in highland watershed in Thailand according to these tolerant natures. After 34 years, pine enrichment planting in the degraded DDF covered on the deep soil of Order Oxisols in northern Thailand could increase plant species diversity, improve forest condition, forest biomass as well as water storage since this pine species is a fast-growing evergreen tree species, and exists in some sites of the natural DDF as called the pine-DDF. The improved forest condition by its rapid growth resulted in increasing number or population of big tree individuals in the forest. This 34-year-old pine could increase the plant biomass and water storage potential in the forest at 56.75% and 48.07% of the total, respectively.

ACKNOWLEDGEMENTS

This research received financial support from National Research Council of Thailand (NRCT) in 2017, and a fund from Graduate School of Chiang Mai University. The authors would like to thank the head and officers of the HHKRDS Center for permission to conduct research in the forest, and for all facilities provided during field data collection.

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