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RESEARCH ARTICLE

HE Bin, QIN Wuming, DAI Jun, WU Qingbiao, LIU Feng, HUANG Yong

Function and value of water conservation in different age classes of *Acacia mangium* plantations

Abstract For this paper, we studied the water-holding capacity of canopy, vegetation layer under canopy and litter layer, the water-holding capacity and permeability of soil as well as their changes with growth of stands in *Acacia mangium* plantations of three different age classes (four-, seven- and 11-year-old). Results show that total water-holding above ground in the order of 11-year stand age (52.86 t/hm^2) > seven-year stand age (41.90 t/hm^2) > seven-year stand age (25.78 t/hm^2), the increment tendency increased with stand age. Similar sequence also obtained on the water-holding capacity and permeation capacity of soil (0–40 cm). The total water-storage capacity both above ground and soil in four-year-old, seven-year-old and 11-year-old of *A. mangium* plantations were 2,023.0, 2,158.4 and 2,260.4 t/hm^2, respectively, and the all value of water conservation were 1,372.70, 1,474.42 and 1,549.91 yuan (RMB)/hm^2, respectively. Therefore, *A. mangium* plantation had a good ability to modify soil structure and good water conservation function.

Keywords *Acacia mangium* plantation, age classes, water conservation function

1 Introduction

The hydro-ecological conservation function is an important part of forest ecosystem function. The multiple structures of forest have important effects on the distribution and flows of rainfall, which would increase the flow of dry season, extend the time of wet season, decrease the time of dry season and decrease the soil erosion by reducing the rainfall momentum within the forest. Thereby, the function of water and soil conservation in forest can be realized, including the water storage capacity and penetration capacity of canopy, understory vegetation layer and litter-fall layer and the soil layer (Wu et al., 1998; Shi et al., 2005). *Acacia mangium* was first introduced to China about in 1979, which is a native tree in the coastal areas of northern Queensland in Australia and in the country of Papua New Guinea, etc. *A. mangium* has the capacity of nitrogen fixation, and show the features of extensive adaptability, low insects, severe tolerance to the dry and poor nutrient soil, straight in stem form, high in timber volume, high forest stand production and multiple utilization, etc. Besides, in summer, the rainfall climate of *A. mangium* is similar to that of southern subtropical and tropical region in China. Therefore, *A. mangium*, as pioneer species and the species of short-term rotation industrial plantations, has been planted greatly in the provinces of Guangdong, Guangxi and Hainan etc. since 1980s, and has achieved the win-win goal of great ecological and economic effects. With the successful introduction of *A. mangium* and the extensive scale of planted areas, the researches on *A. mangium* plantations gradually increase. Shen et al. (2001) and Zeng et al. (2002) have carried out researches on litter-fall biomass and hydro-ecological function in *A. mangium* plantations. In this paper, we have carried out researches on the water storage capacity, permeation capacity and their changes within the tree layer, understory vegetation layer, litterfall layer and soil layer under different age stands of *A. mangium* plantations, in order to find out the characteristics and succession of water storage capacity under *A. mangium* plantations and scientifically assess their hydro-ecological conservation functions.

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HE Bin (✉), QIN Wuming, WU Qingbiao
Forestry College of Guangxi University, Nanning 530004, China
E-mail: hebin125@sina.com

DAI Jun, HUANG Yong
Gaofeng Forestry Farm of Guangxi, Nanning 530001, China

LIU Feng
Guangxi Forestry Surveying and Planning Institute, Nanning 530011, China

2 Study area

The research site (22°58′N, 108°21′E) is located in the Jiepai Branch of Guangxi Gaofeng Forestry Farm, China. Its climate belongs to the monsoon climate of southern subtropical, mean annual temperature is 21.8°C, extreme high temperature of 40°C, ⩾10°C mean annual temperature accumulation of about 7,200°C, mean annual rainfall of 1,350 mm and most during May to September, relative humility of 79%. The standard research site is located at the middle slope of a hillside, with an altitude of 250 m and slope degree among 25°–28°, the slope aspect South-East, the soil types lateritic red earth derived from sandyshales, soil depth over 80 cm and humus topsoil layer between 15–20 cm.

3 Materials and methods

3.1 Materials

The *A. mangium* was generally planted in the cut-over area of previous *Cunninghamia lanceolata* plantations, and the dominant understory species were *Heteropogon ontomtus*, *Miscanthus floridulus* and *Clerodendrum bungei* etc. After slash-burning and site preparation, the *A. mangium* was planted in April of the subsequent year. *Acacia mangium* plantations of three different age classes (four-year, seven-year and 11-year) were investigated. First, the four-year plantation of *A. mangium* had an even-aged stand, with a canopy coverage of 0.75, density of 1,140 trees/hm^2, the mean tree height (MTH) of 12.0 m, and the mean diameter at breast height (DBH) of 14.0 cm. The coverage of understory vegetation was about 70%, and dominant understory species were *Heteropogon ontomtus*, *Miscanthus floridulus*, *Clerodendrum bungei*, *Rhodomyrtus tomentosa*, *Medinilla condidum* and *Rubus alceaefolius* etc. The litterfall layer was 2–3 cm. Second, the 7-year plantation of *A. mangium* also had an even-aged stand, the canopy coverage of 0.85, the tree density of 930 trees/hm^2, MTH of 17.7 m and DBH of 18.3 cm. The coverage of understory vegetation was about 70%, and dominant understory species were *Mallotus barbatus*, *Rhodomyrtus tomentos*, *Medinilla condidum*, *Blechnum orientale*, *Miscanthus floridulus*, *Heteropogon ontomtu* and *Rubus alceaefolius* etc. The litterfall layer was about 3 cm. Third, the 11-year plantation of *A. mangium* also had an even-aged stand, the canopy coverage of 0.85, the tree density of 775 trees/hm^2, MTH of 19.0 m and DBH of 23.5 cm. The coverage of understory vegetation was about 70%, and dominant understory species were *Litsea glutinosa*, *Rhus chinensis*, *Psychotria rubr*, *Woodwardia japonica*, *Dicranopteris linearis*, *M. floridulus* and *R. alceaefolius* etc. The litterfall layer was about 4–5 cm.

3.2 Methods

With the similar site conditions and similar soil parents, the *A. mangium* plantations of three different age classes (four-year, seven-year and 11-year) were selected as standard sample plots (20 m × 20 m, in triplicate), and the four-year plantation was the stationary plot. After an overall investigation of the standard plots stands, three standard trees were selected in light of the MTH and DBH. The Monsi and Saeki method of “layered cutting” was adopted to measure the biomass of branches and leaves, and the dug-up method was for root biomass and harvest method for the biomass of understory vegetation and litterfall (Shi et al., 2005). The water holding capacity was estimated by wet water. Three holes were dug in the every standard plot, and the soil samples were collected in the topsoil layer (0–20 cm) and subsoil layer (20–40 cm). The soil hydro-physics, permeability and organic matter contents were analyzed using common methods found in DSTMF (1992).

4 Results and analysis

4.1 Above-ground water-holding capacity

The forest ecosystems had a good water-holding capacity, which ascribed to their complex structure, including multiple layers of canopy, shrub layer, herb layer and litter. These complex layers could partly intercept rainfall and reduce the runoff. The water storage function was determined by the structural complexity of stand (Zhang and Li, 1988). As for silvicultural plantations with distinct ages, the above-ground water-holding capacity was correlated to the biomass of canopy, the ratio of branches/leaves, leaves area index (LAI), the roughness of leaves, the number and composition of understory vegetation species, the size and characteristics of litter-fall, etc. There were various water-holding capacities in the plantations with different ages. As shown in Table 1, the water-holding capacities of four-year, seven-year and 11-year plantations of *A. mangium* were 25.78, 41.90 and 52.86 t/hm^2, respectively, and increased with the development of *A. mangium* plantations.

4.1.1 Water-holding capacity in canopy

The canopy interception of rainfall was an important part of forest water storage functions. The ability of canopy

Table 1 Water-holding capacity of aboveground part in different age classes of *Acacia mangium* plantations

Stand	Canopy /(t·hm^{-2})		Vegetation layer under canopy /(t·hm^{-2})		Litter layer /(t·hm^{-2})		Total above-ground water-storage capacity /(t·hm^{-2})
	Biomass	Water-holding capacity	Biomass	Water-holding capacity	Biomass	Water-holding capacity	
18-year *C. lanceolata* plantation	15.08	6.27	3.15	2.10	2.40	5.52	13.89
4-year *A. mangium* plantation	16.41	7.04	3.69	2.55	6.53	16.19	25.78
7-year *A. mangium* plantation	36.50	15.70	5.10	3.07	9.22	23.13	41.90
11-year *A. mangium* plantation	37.89	16.29	5.93	3.66	13.11	32.91	52.86

rainfall interception was determined by their branches-leaves biomass, the leaves area indices and the water-holding ratio. Due to the flourishing leaves, complex structure and high LAI in *A. mangium* plantations, the canopy branches-leaves biomass and the water-holding capacity of four-year *A. mangium* plantations were higher than those of 18-year *C. lanceolata* plantations (Table 1), which showed good functions of water and soil conversation. Besides, due to the interrupt of rainfall drop momentum by canopy branches and leaves, the direct topsoil washout could be reduced. The time of rainfall attaining to the topsoil was also prolonged, which was favorable to the water-holding function development in litterfall layers and soil layers.

4.1.2 Water-holding capacity in understory vegetation layer

The through rainfall could be intercepted again by understory vegetation layer, which was helpful for the reduction of rainfall momentum to topsoil. The species number and composition of understory vegetation were also developed differently under various aged plantations, which could influence their water-holding capacity (He et al., 2003). As shown in Table 3, the understory vegetation species in four-year *A. mangium* plantations and in 18-year *C. lanceolata* plantations were similar, most species belonging to the herb layer, but the biomass and the water-holding capacity were higher in the former. As the development of *A. mangium* plantations (seven-year and 11-year), the understory species were dominantly controlled by shrub species, and the biomass and water-holding capacity of their understory vegetation accordingly increased.

4.1.3 Water-holding capacity in litter layer

The litterfall layer was last defense of the topsoil. The litterfall layer not only had the high water-holding, permeation and rainfall-interception capacity, also had the high rough surface. Therefore, the litterfall layer could also greatly reduced the through rainfall momentum and the soil water erosion, which was helpful for the soil structure and soil water-holding capacity through the formation of humus substances (Li et al., 2005). Compared to the litterfall biomass in the stands of *Pinus massoniana*, *C. lanceolata* and moso bamboo (Jiang et al., 2002), the litter biomass in the broad-leaved *A. mangium* plantation was higher (Table 1), and also increased with the development of plantations. Therefore, the *A. mangium* plantations were favorable to the interception of rainfall and the improvement of soil structure and soil permeation.

4.2 Soil water-holding capacity

The soil layer has a great water-holding capacity, including the dynamic storage capacity (water permeation) and stationary storage capacity (water-holding capacity), which attributed to the complicated capillary in the soil layer. The sources and formation of capillary could be various, including the die of root, the activities of soil macro animals, the formation of organic-mineral substances and water-stable macro-aggregates, etc. Generally, the soil water-holding capacity could be higher than that in the above-ground layers.

4.2.1 Soil permeation rates

Soil permeation capacity was correlated to the soil bulk densities, soil texture, soil organic matter (SOM) and the size of capillary. The high permeation capacity and permeation rate could convert most of the through rainfall as soil and groundwater flows, which was helpful to reduce the surface flows and erosion.

The soil permeation capacity was generally shown by the permeation coefficient at 10°C (K_{10}), and the permeation rate (mm/min) in the soil profile was carefully investigated every minute. The permeation rates and K_{10} in the topsoil (0–20 cm) and subsoil (20–40 cm) layers under all *A. mangium* plantations (four-year, seven-year and 11-year) were higher than those in 18-year *C. lanceolata* plantations (Table 2), and increased with the development of plantations. With the growth of *A. mangium* plantations, they could improve their soil hydro-physics, increasing their water permeation rates in order to reduce the surface flows and runoff.

4.2.2 Soil water-holding capacity

The soil layer was an important pool for forest ecosystem water conservation. Under the similar soil types and soil

Table 2 Soil permeation capacity in different age classes of *Acacia mangium* plantations

Stand	Depth /cm	Bulk density /(g·cm^{-3})	Organic matter /(g·kg^{-1})	Permeation rate /(mm·min^{-1})		Permeation coefficient K_{10} /(mm·min^{-1})	
				Begin	Final	Begin	Final
18-year *C. lanceolata* plantation	0–20	1.283	18.91	17.64	11.40	6.63	4.29
	20–40	1.405	9.65	12.78	6.03	4.80	2.27
4-year *A. mangium* plantation	0–20	1.091	24.79	25.74	16.37	9.68	6.15
	20–40	1.395	12.41	14.20	7.16	5.34	2.69
7-year *A. mangium* plantation	0–20	1.048	29.65	30.04	17.65	11.29	6.64
	20–40	1.358	12.69	15.26	8.02	5.74	3.02
11-year *A. mangium* plantation	0–20	0.975	32.79	32.78	18.29	12.32	6.88
	20–40	1.363	13.22	15.34	7.84	5.80	2.95

Table 3 Water-holding capacity within 0–40 cm depth in different age classes of *Acacia mangium* plantations

Stand	Depth /cm	Total water-storage capacity of non capillary /(t·hm^{-2})	Total water-storage capacity /(t·hm^{-2})	Total water-storage capacity within 0–40 cm /(t·hm^{-2})
18-year *C. lanceolata* plantation	0–20	150.0	975.8	1,903.8
	20–40	107.6	928.0	
4-year *A. mangium* plantation	0–20	190.4	1,057.6	2,023.0
	20–40	93.6	965.4	
7-year *A. mangium* plantation	0–20	256.2	1,183.8	2,158.4
	20–40	122.4	974.6	
11-year *A. mangium* plantation	0–20	287.2	1,243.6	2,260.4
	20–40	134.0	1,016.8	

depth, the forest soil water-holding capacity was determined by the size and composition of soil capillary and non-capillary pores. The capillary was a major tunnel of soil water evaporation and flows. The soil capillary-holding water could be used as the need of tree evapotranspiration and the adjustment of the soil water pools. Meanwhile, the non-capillary had large pore size and high water storage, as the major channels of rainfall permeating to the soil. Within a certain intensity of rainfall, the rainfall could be quickly stored by the non-capillary, which was helpful for the forest water-holding functions. Therefore, the soil non-capillary water-holding capacity was an important index for the assessment of the forest soil water storage capacity. The total water-storage capacity, including the capillary and non-capillary water-holding capacity, represented the potential ability of soil water storage and adjustment. The total water-storage capacity could be calculated as this formula (Li et al., 2005)

Total water-holding capacity of non-capillary (t/hm^2) = non-capillary soil pore size (%) × soil depth (m) × 10^4 × forest area (hm^2)

Total soil water-holding capacity (t/hm^2) = total soil pore size (%) × soil depth (m) × 10^4 × forest area (hm^2)

As shown in Table 3, within 0–40 cm, the total soil water-holding capacity under all *A. mangium* plantations (four-year, seven-year and 11-year) was 119.2, 254.6 and 356.6 t/hm^2 higher respectively than that in 18-year *C. lanceolata* plantations (Table 3), and increased with the development of *A. mangium* plantations. Besides, the total water-holding capacity of non-capillary, as an index of water storage in dry season, was also 26.4, 121.0 and 163.6 t/hm^2 higher respectively than that of 18-year *C. lanceolata* plantation. It indicated that, with the development of *A. mangium* plantations, the SOM contents increased, the soil structure improved with the formation of capillary and non-capillary, and the soil water storage capacity also increased.

4.3 Water-holding storage capacity distribution and their values

4.3.1 Water-holding storage capacity distribution

As shown in Table 4, the total water-holding capacity of forest ecosystem was composed of those in the canopy, understory vegetation layer, litter layer and soil layer, etc. Although the total above-ground water-holding storage could only occupied a small part (1.26%–2.28%) of total in all forest ecosystem parts, the above-ground layers could have great effects on the interception of rainfall, the decrease of through rainfall momentum and the reduction of surface runoff and soil erosion. With the increasing age of *A. mangium* plantations, the total above-ground water-holding storage increased gradually. Besides, the water storage of soil layer was the major part in forest ecosystem water storage function, which occupied above 97.72% of the total in all forest ecosystem parts. Furthermore, the total water storage capacities in the four-year, seven-year and 11-year *A. mangium* plantations were 131.1, 282.6 and 395.6 t/hm^2 significantly higher than that in 18-year *C. lanceolata* plantation. It indicated that the *A. mangium* plantations had good water conversation function.

4.3.2 Economic values estimation for forest water conservation

Until now, no standard criteria existed in the assessment of the real economic values in the forest water conservation, the substitute engineering method was used to assess the economic values of *A. mangium* plantations. Based on the needed 0.67 yuan (RMB)/m^3 for the construction of water reservoir (Li and Ren, 2003), the total estimated economic values of

Table 4 Total water-storage capacity and economic values in different age classes of *Acacia mangium* plantations

Stand	Total water-holding above ground		Soil (0–40 cm)		Total water-storage capacity /(t·hm^{-2})	Economic value /(yuan·hm^{-2})
	Water holding capacity /(t·hm^{-2})	% in total	Water-holding capacity /(t·hm^{-2})	% in total		
18-year *C. lanceolata* plantation	13.89	0.72	1,903.8	99.28	1,917.7	1,284.85
4-year *A. mangium* plantation	25.78	1.26	2,023.0	98.74	2,048.8	1,372.70
7-year *A. mangium* plantation	41.90	1.90	2,158.4	98.10	2,200.3	1,474.42
11-year *A. mangium* plantation	52.86	2.28	2,260.4	97.72	2,313.3	1,549.91

four-year, seven-year and 11-year *A. mangium* plantations were 1,372.70, 1,474.42 and 1,549.91 yuan/hm^2 respectively, which were 88.85, 190.49 and 265.98 yuan/hm^2 respectively higher than that of 18-year *C. lanceolata* plantation (1,284.85 yuan/hm^2) (Table 4). It indicated that the estimated economic values of water conservation in *A. mangium* plantations were appreciable, and increased with the development of *A. mangium* plantations. The understory vegetation layer and the litter layer could also decrease the runoff and maintain the soil nutrient (He et al., 2002). Besides, the fine aggregates in forest soil were favorable to the growth of microbes, which could lead to the increased water cleaning function in forest soil, comparing to the naked land (Liu et al., 1995). If these economic values were considered, the total estimated economic values could be higher in *A. mangium* plantations.

5 Conclusions

The good water conservation function of *A. mangium* plantations might be correlated to their complicated ecosystem structure, including the multiple canopy layers, high LAI, flourishing understory vegetation, high litter accumulation and good soil texture, etc.

The water-holding capacity in canopy, understory vegetation layer and litter layer of *A. mangium* plantations increased with the increase of stand age. The total above-ground water-holding capacities of four-year, seven-year and 11-year *A. mangium* plantations were 25.78, 41.90 and 52.86 t/hm^2 respectively, which were significantly higher than that of 18-year *C. lanceolata* plantation (113.89 t/hm^2).

Due to the high litterfall accumulation (2–5 cm) and the high root biomass (⩾18.6% of total biomass) in *A. mangium* plantations, it could be favorable to improving the soil texture and other soil hydro-physical characteristics. The total under-ground water-holding capacities in 0–40 cm soil depth under four-year, seven-year and 11-year *A. mangium* plantations were 119.2, 254.6 and 356.6 t/hm^2 higher respectively than that of 18-year *C. lanceolata* plantation. At the same time, the soil permeation of *A. mangium* plantations was also better than that of *C. lanceolata* plantation.

The total ecosystem water-holding capacities of four-year, seven-year and 11-year *A. mangium* plantations, including the above-ground and the under-ground layers, were 2,048.8, 2,200.3 and 2,313.3 t/hm^2, which were 131.1, 282.6 and 395.6 t/hm^2 significantly higher than that in 18-year *C. lanceolata* plantation.

The total estimated economic values of four-year, seven-year and 11-year *A. mangium* plantations were 1,372.70, 1,474.42 and 1,549.91 yuan/hm^2 respectively, which were 88.85, 190.49 and 265.98 yuan/hm^2 higher respectively than that of 18-year *C. lanceolata* plantation (total estimated values as 1,284.85 yuan/hm^2).

It indicated that, with the development of *A. mangium* plantations, the water conservation function and economic values synchronously increased. If the economic values in water purification function of *A. mangium* plantations were considered, the total estimated economic values could be even higher. Therefore, as the pioneer species and short-term rotation species, the plantations of *A. mangium* not only have the functions of high production, nitrogen fixation and soil improvement, but also have the good soil-water conservation functions, which was important to the soil nutrient maintenance, ecosystem nutrient cycling and the ecological environment protection.

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