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論　文（Original article）

Biomass of planted forests and biotic climax of shrub and grass communities in the central dry zone of Myanmar

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Abstract

We assessed the biomass of the planted forests of 2 main species (*Eucalyptus camaldulensis* and *Acacia catechu*) and biotic climax of shrub and grass communities in the central dry zone of Myanmar to provide a potential level of carbon sequestration by planted forests under the drier climatic conditions (mean annual rainfall of 637 mm). The biomass including roots of the 9 planted *Eucalyptus camaldulensis* forests of 6- to 11-year-old (at the 4 × 4 m planting spacing) ranged from 3.80 to 27.68 Mg ha^{-1}, averaging 14.83 Mg ha^{-1}. The mean annual increment (MAI) was estimated as 1.68 Mg ha^{-1} y^{-1}. The biomass of the planted *Acacia catechu* forest of 7-year-old (at the 4 × 8 m planting spacing) was estimated as 10.62 Mg ha^{-1} and its MAI was 1.52 Mg ha^{-1} yr^{-1}. The results show that the productivity of the planted forests is much lower than that of other places with more favorable conditions. The sum of biomass and litter weight of biotic climax of shrub and grass communities ranged from 2.36 to 23.14 Mg ha^{-1}, averaging 11.00 Mg ha^{-1}. Since tree growth is seriously compromised by the drier climate of the study area, the establishment of a productive planted forest requires new technological inputs such as fertilizer application, mulching, irrigation, use of drought-tolerant species, and protection from destructive elements.

Key words : *Acacia catechu*, baseline, carbon stock, CDM, *Eucalyptus camaldulensis*, MAI, Tropical dry zone

1 Introduction

More than half of the total land area of Myanmar (Burma) is still covered with vast and diverse forests, but the central part (about 10% of the area) is barren, having little forest cover. This part is termed the central dry zone, and receives less than 1000 mm of annual rainfall. The ratio of annual rainfall to potential evapotranspiration of the zone ranges between 0.05 and 0.65 (United Nations Conference to Combat Desertification (UNCCD), 2000). The annual deforestation rate in the dry zone is 2.07% (Myint, 1995), higher than the national average of 0.64% (Forest Department, 1999).

Aware of threatening desertification, the Myanmar Government has made tremendous efforts to combat deforestation in the dry zone by promoting greening programs since the 1960s. The greening campaign was speeded up with the establishment of the Dry Zone Greening Department (DZGD) in 1997. The department took responsibility for restoration in the dry zone and implemented various greening programs, including the establishment of large-scale planted forests through governmental, NGO, and other organizational assistance. In the 30 years to 2030, the DZGD plans to establish 405000 ha of forest in the dry zone for uses include fuel-wood supply, community needs, to protect water supplies in catchments, re-greening of mountains, roadside greening, and research. The main tree species used in planted forests are *Acacia arabica*, *Acacia catechu*, *Acacia leucophloea*, *Albizia lebbek*, *Cassia siamea* (indigenous species), *Eucalyptus camaldulensis*, *Acacia auriculiformis*, and *Leucaena leucocephala* (exotic species).

Most of the lands in the dry zone were bare at the end of 1989 and can be classified as eligible according to the Kyoto Protocol, adopted in 1997. Therefore, the newly planted forests qualify as afforestation/reforestation projects under the Clean Development Mechanism described in the Kyoto Protocol. Assessment of the land productivity can provide useful information for calculating the amount of carbon sequestered by the planted forests in the dry zone. It can also indicate the benefits of the afforestation programs for local people and ecosystems. Therefore, assessment of the biomass of the planted forests and biotic climax of shrub and grass communities in the dry zone of Myanmar, and of the socioeconomic impacts of the afforestation on local communities, will provide useful and relevant information for evaluation and management of the existing planted forests in the area.

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by the Forestry Agency, Japan: "Forestation-basic data collection aiming at small scale afforestation/reforestation CDM in environmental planting" and mostly followed up the Memorandum of Understanding signed between the Forest Department of Myanmar (FD) and the Japan International Forestry Promotion and Cooperation Center (JIFPRO) for socioeconomic studies and estimation of the biomass of the central dry zone of Myanmar. We estimated the biomass of planted forests of various stand ages, of forests of long-lived species, and of the biotic climax of shrub and grass communities near the planted forests.

The primary objective of this study was to estimate the biomass of the planted forests and biotic climax of shrub and grass communities in the central dry zone of Myanmar. Specifically, this study aimed:

- to evaluate the growth of biomass of the 2 main species planted in the dry zone of Myanmar (*Eucalyptus camaldulensis* and *Acacia catechu*)
- to estimate the potential biomass of the uncultivated land of the dry zone as baseline level of carbon sequestration
- to provide some useful information on land productivity of the planted forests.

2 Study area

Surveys were carried out in forests planted around Nyaung U town. The town is situated in central part of the dry zone. The area receives mean annual rainfall of 637 mm (mean of 1994–2005), one of the lowest levels in Myanmar, and is categorized into the climate zone of the Tropical Dry (mean annual rainfall < 1000mm; IPCC National Greenhouse Gas Inventories Programme, 2003) and tropical dry regions (mean annual rainfall < 900mm; United Nations Framework Convention on Climate Change, 2005). Like many other dry zone areas, the town suffers a rain-shadow effect due to topography. The dry period lasts for 6 months, from November to April (Figure 1), and temperatures exceeding 40 °C are not unusual during March, April, and May. Dry land farming is practiced in over half of the area (Figure 2). Most of the agricultural soils have low fertility, and cropping is mainly rainfed. Although the biggest river in Myanmar (the Ayeyarwady River) passes through the region, the water is not yet accessible to agriculture or forestry. The vegetation in the study area can be classified as dry forest, and the dominant species include *Acacia catechu* (cutch in Myanmarese name, hereafter [M]), *Acacia leucophloea* (tanaung [M]), *Tectona hamiltoniana* (dahat [M]), *Azadirachta indica* (neem [M]), and *Zizyphus jujuba* (zi [M]). Natural stands in Protected Public Forest areas are sparse and dominated by shrubby vegetation. Therefore, the forest land is almost unproductive. The main source of energy for the 300000 residents of the town and its surrounding areas is agricultural residues. Because of the lack of other energy sources, the local people are substantially dependent on the natural forest resources for their daily energy requirements. The FD and the DZGD, currently managing 17% of the land area, have been trying to remedy the depletion of the vegetation by conserving the remnant vegetation and establishing fuel-wood forests.In this study, we selected sample plots in 10 planted forests and 9 nearby shrub and grass communities near Nyaung U town. The former are 5 forests established by the FD in 1973, 1994, 1996 (2), and 1997 (hereafter 1973F, 1994F, 1996F1, 1996F2 and 1997F), 2 forests established through sponsorship from JIFPRO in 1998 and 1999 (1998JIF and 1999JIF), 2 forests established by a donation from Yomiuri in 1998 and 1999 (1998YO and 1999YO), and 1 forest established through sponsorship from the Japan International Cooperation Agency (JICA) in 1995 (1995JIC).

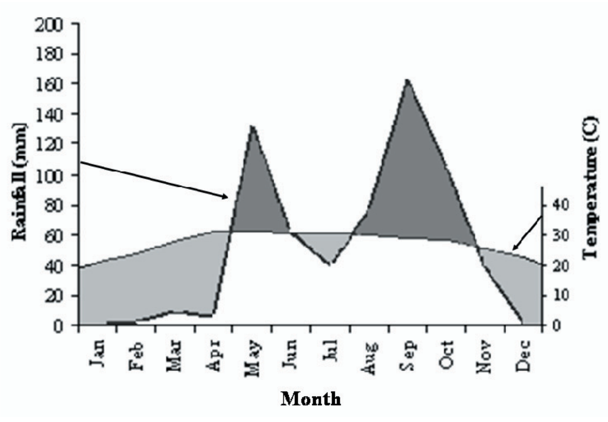

Fig. 1. Climate diagram of Nyaung U town (mean of 1994–2005).
Climate diagram is brief summaries of average climatic variables and their time course (Walter and Leith 1967). Twenty (20) mm of monthly precipitation equal 10ºC monthly average temperature. Dry periods are strongly shaded and rainy periods are lightly shaded.

3 Materials and methods

Sample plots were laid out and data were collected during May and June 2005 in accordance with guidelines devised by Japan Overseas Forestry Consultants Association (JOPP) and JIFPRO. Samples were dried in the oven at the Forest Research

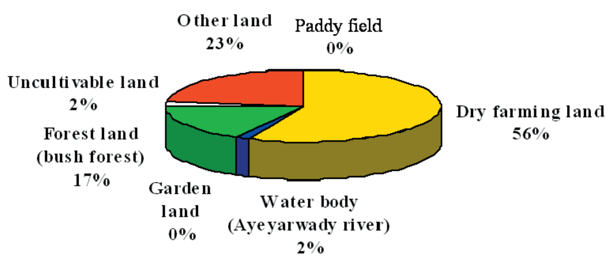

Fig. 2. Land use near Nyaung U town.

Institute, Yezin, during September and October 2005, and data were analyzed in November 2005.

3.1 Estimating biomass of the planted forests

To estimate the biomass of the selected planted forests, we set 21 circular plots in planted forests of various ages. Measurements were obtained in 19 *Eucalyptus camaldulensis* and 2 *Acacia catechu* (Photo 1) plots. The location of the plots and background information are shown in Appendix I (a). Each sample plot had a radius of 10 m (314 m^2 in area). All tree censuses (species name, diameter at 1.3 m height (DBH, cm), total tree height, alive or dead) were taken. At the same time interviews for farmers with questionnaires (location, vegetation type, land use, treatment of planted forests, history) and soil surveys were conducted. Trees with DBH > 1 cm were assessed for biomass calculation.

We calculated the biomass (including roots) (B, kg) of the planted tree species and naturally established trees in the plots using 2 equations (Equation (1): Kiyono et al., 2004; Equation (2): modified from Kiyono et al., 2005 based on 66 species and 445 trees in the tropics):

$$B = 0.0167 \times DBH^{2.46} \times D^{0.322} \quad (1)$$

$$B = 4.71 \times Ht^{0.525} \times BA^{1.02} \times D^{0.931} \quad (2)$$

where D = basic density (kg m^{-3}) of wood, Ht = tree height (m), and BA = stem basal area at 1.3 m height (m^2).

The Ds used were 713 kg m^{-3} for *Eucalyptus camaldulensis* (Anonymous, 1991) and 875 kg m^{-3} for *Acacia catechu* (Anonymous, 1993). The D for other indigenous species was assumed to be 550 kg m^{-3}, the mean basic wood density of tropical tree species (IPCC National Greenhouse Gas Inventories Programme, 2003).

Photo. 1. A planted *Acacia catechu* forest with some toddy palm trees.

Photo. 2. A shrub and grass community under grazing and fuel collection pressure near the planted forests.

3.2 Estimating biomass of biotic climax of shrub and grass communities

Nine plots were set in the shrub and grass communities under grazing and fuel production pressure near the planted forests (Photo 2). The locations of the plots and general information are shown in Appendix I (b).

Data collection in the biotic climax of shrub and grass communities was made for 2 approaches, namely, biomass estimation by applying the pre-existing formula and biomass estimation from the dry weight of the collected samples. Circular sample plots each having a radius of 10 m (314 m^2 in area) were set in the selected sites. The species name and DBH were recorded for the trees greater than 1.3 m in height and the biomass was calculated using the formula (1). The questionnaire survey (land use, history, occurrence of fire, vegetation type, etc.) was conducted with the assistance of the local people. At the same time, soil type was also recorded.

The heights of the grasses at every meter along a diameter line of the circular plot were measured, and the biomass (B, Mg ha^{-1}) of the area was estimated with Equation (3) (modified from Kiyono et al., 2004):

$$B = 1.90 \exp(1.28 \times Ht) \quad (3)$$

where Ht = mean height of the shrub and/or grass (m).
This equation was made in shrubbery communities in the climate zone of Tropical moist (IPCC National Greenhouse Gas Inventories Programme, 2003) in Indonesia.

To estimate the dry-weight biomass in biotic climax of shrub and grass communities, we took measurements and collected samples according to the following procedure:

1. A 2 × 2 m quadrat was set in each circular plot and divided into 4 sub-quadrats of 1 m^2 each.
2. The percentage coverage of the ground vegetation was recorded, and the highest grass in each sub-quadrat was measured.
3. To estimate aboveground biomass, we cut and weighed all shrubs or grasses above the ground in an average sub-quadrat. The sample (about 200 g) was taken and weighed. All the fallen litter and the deadwood above the ground were also

collected and weighed.

4. To estimate belowground biomass, we dug the same sub-quadrat to 20 cm depth, then collected, weighed, and sampled the roots.

All the collected samples were oven-dried for 48 h at 85 °C, and the dry weights were recorded. The aboveground biomass, belowground biomass, litter, and deadwood were separately calculated from the total fresh weight, sample fresh weight, and sample dry weight to the total dry weight. However, the amount of deadwood was negligible.

4 Results and discussion

4.1 Soil types of the planted forests

The general soil types in the sample plots are shown in Appendix I. The major soil type of the planted forests in the northern part (1995JIC) is Vertisols (dark compact soils of tropical dry savannah). Gully erosion caused by rain is common in this area. The soils in the southeastern part varied from Xanthic Ferralsols and Lithosols (primitive gravelly soils of tropical dry savannah) to Vertisols. Volcanic Andosols (Mt. Popa complex soils) were also found in 1998JIF.

Planted forests in the Kyauk Ku Protected Forest in the northwestern part of the town (1994F & 1996F1) seemed to have better soils, ranging from Xanthic Ferralsols (Yellow Brown Forest Soils of tropical monsoon forest) and Dystric Cambisols (Yellow Brown Dry Forest and Indaing Soils) to Rhodic Ferralsols (Red Brown Soils of tropical dry savannah). However, Vertisols were also common in the area. The dominant soil texture is sandy loam. Weathered gravels (of river beds) and fossils of shells were observed in the top layer of the soil. Most of the soils seemed to have very limited moisture content.

4.2 All tree censuses

The planted forests that we surveyed were originally protected native forests. However, the growth of the natural vegetation is seriously compromised by the drier climate, repeated cutting for fuel-wood, grazing, and encroachment of agriculture. The natural growth was to some extent enhanced by the prohibition of grazing and fuel-wood collection, and by cultural operations such as weeding and mulching when the forests were expanded by planting. Therefore, we regarded naturally established trees in the planted forests as part of the planted forest, and we surveyed any that grew in the sample plots. We recorded 30 tree species in the planted forests and nearby shrub and grass communities during the study (Appendix II).

Three types of growth of both the planted and naturally established trees were assessed: main stems; coppice regrowth; and new shoots (less than 1.3 m high). The new shoots were omitted from height and diameter calculations. They were, however, taken into account in the biomass calculations. Although the shoots may not be recognized as 'trees' from a silvicultural point of view, they contribute to fuel-wood production as a by-product of the planted forest during the tending operations.

4.3 DBH and height growth of the evaluated planted forests

The plot means for DBH and height of *Eucalyptus camaldulensis* only, naturally established trees in the *Eucalyptus camaldulensis* plots, and the entire stands are shown in Appendix III. The DBH of *Eucalyptus camaldulensis* varied from 1.4 to 25.7 cm according to the tree censuses from the 19 sample plots, and the height from 2.0 to 14.8 m (Table 1). Mean DBH and mean height were 6.4 cm and 5.5 m respectively. Those values were further reduced when naturally established trees were included in the calculation. The native species grew as suppressed or undergrowth communities in the *Eucalyptus* forests.

The mean DBH of planted *Acacia catechu* trees was 6.0 cm (range, 2.0 to 14.7 cm), and mean height was 3.4 m, much lower than that of *Eucalyptus camaldulensis*. When naturally established trees were included, however, the mean DBH and mean height were increased, because *Acacia catechu* had smaller DBH and lower height than the other native species (Table 1). The relative dominance of the planted *Acacia catechu* trees indicates the results of competition for horizontal and vertical growth in the stand.

4.3.1 DBH and height growth by classes

Table 1. Mean DBH and height of the investigated trees.

Evaluated trees and stands	DBH (cm)				Height (m)				No. of
	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	trees
Planted *Eucalyptus camaldulensis* trees	1.4	25.7	6.4	2.2	2.0	14.8	5.5	0.7	333
Naturally established trees	1.1	17.5	5.8	2.6	2.0	6.5	3.5	0.8	55
Stand	1.1	25.7	6.3	2.1	2.0	14.8	5.2	0.7	388
Planted *Acacia catechu* trees	2.0	14.7	6.0	3.1	2.0	4.3	3.4	0.8	34
Naturally established trees	2.6	16.0	8.9	5.0	2.0	5.5	4.0	1.4	8
Stand	2.0	16.0	6.6	3.6	2.0	5.5	3.5	0.9	42

Most of the planted *Eucalyptus camaldulensis* trees were distributed in the smaller DBH classes (Figure 3). All distributions look heterogeneous. Trees with DBH > 15 cm were not found except in 1996F1 and 1998YO. In the *Acacia catechu* stands, all the DBH classes were represented, and more trees were distributed in the smaller classes.

In all evaluated stands, no tree exceeded 15 m in height (Figure 4). Trees exceeding 10 m were also scarce, found only in 5 planted *Eucalyptus camaldulensis* forests. Growth of the trees by height class was analogous to that by DBH class, with more trees in lower classes. Stunted growth of the native species is common in the dry zone area: most of the tree species in the dry zone are shrubs in their early stages of growth, and growth is limited by the drier climate.

The DBH and height by class indicate the poor growth of *Eucalyptus camaldulensis*. The planted trees have sometimes been damaged by little rain, grazing etc. in the early years of the plantations, and consequently the height and DBH growth were poor. According to our field observation, the proportion of coppice regrowth in all *Eucalyptus camaldulensis* communities was very high except in 1996F1, 1996F2, and 1998JIF. Those communities were composed mainly of coppices and shoots, newly emerging from the stems and root systems.

Among the planted *Eucalyptus camaldulensis* forests, the

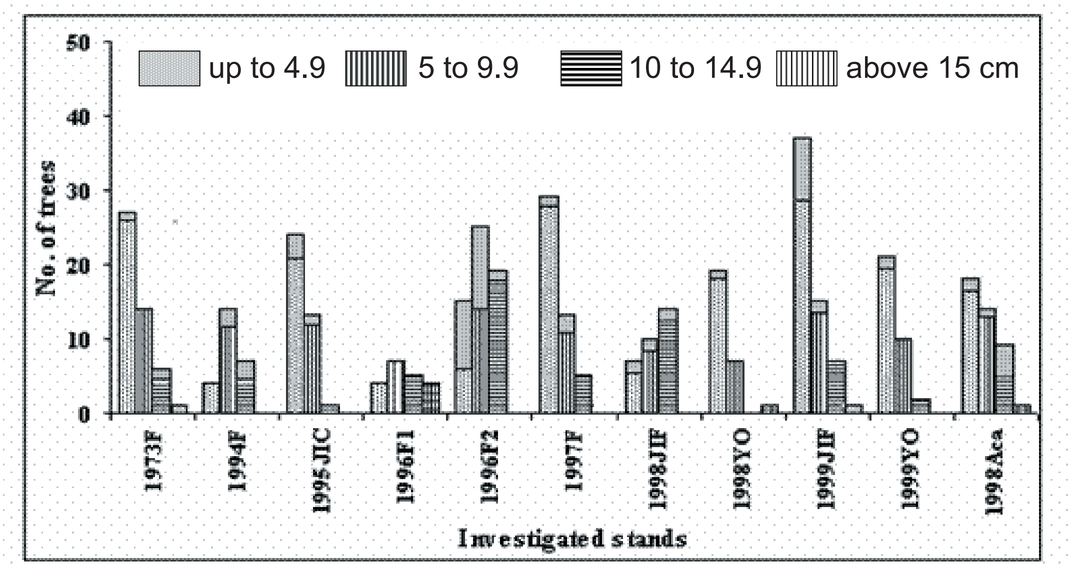

Fig. 3. Growth of the investigated stands by DBH class (topmost gray segment of each bar represents the naturally established trees in the stand).

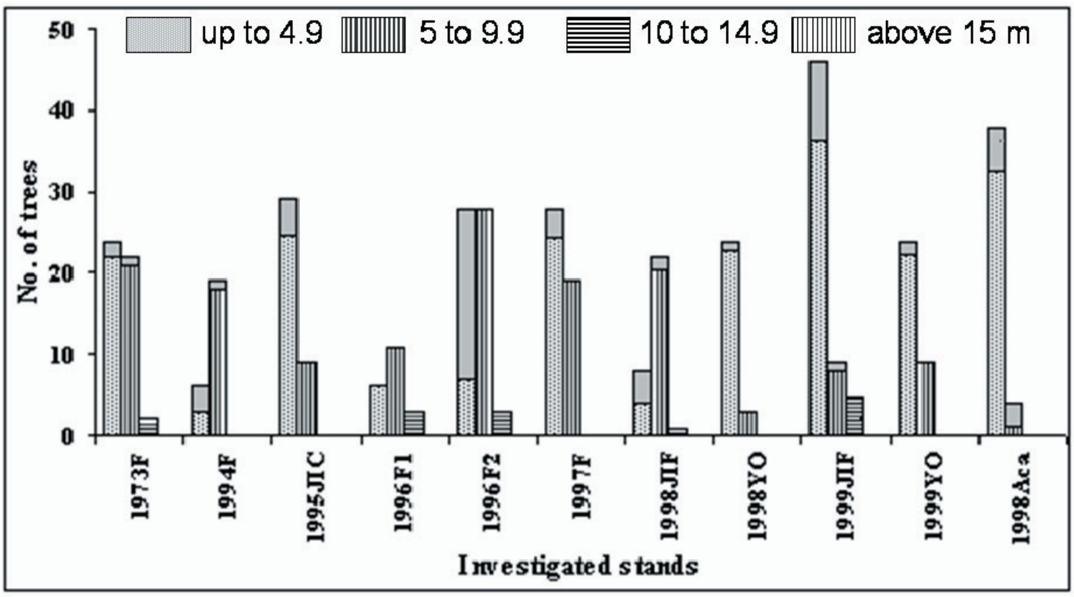

Fig. 4. Growth of the investigated stands by height class (topmost gray segment of each bar represents the naturally established trees in the stand).

land use before planting was dry land farming, and agro-forestry for some years in 1996F1, 1996F2, and 1998JIF (according to the questionnaire results).

4.3.2 DBH–height relations

DBH (logarithmic transforms) and height of planted *Eucalyptus camaldulensis* trees showed a normal relation with an R^2 value of 0.6628 (Figure 5a). However, DBH and height of the native species showed a poor relationship, with a lower R^2 value (Figure 5b). Planted *Acacia catechu* trees showed very poor height growth, and the relation with the lowest R^2 value (Figure 5c).

The poor DBH–height relation in native trees reflected the environmental conditions of the dry zone area. Light is not a limiting factor, so trees do not need to compete for it. In addition, the trees must have strong and deep root systems that can take up available water from the deeper part of the soil. Therefore, they may not have to grow tall.

4.4 Estimating biomass of the planted forests

Table 2. Stand density and basal area of the planted forests.

Planted forests	Stand density (trees ha^{-1})			Basal area (m^2 ha^{-1})		
	Planted trees	Naturally established trees	Total	Planted trees	Naturally established trees	Total
Eucalyptus camaldulensis						
1973F	1,911	223	2,134	4.48	0.94	5.42
1994F	350	96	446	1.86	0.51	2.37
1995JIC	876	207	1,083	1.15	0.12	1.27
1996F1	334	0	334	3.70	0	3.70
1996F2	637	653	1,290	4.11	1.14	5.25
1997F	1,019	239	1,258	1.87	0.15	2.02
1998JIF	541	127	668	2.79	0.51	3.30
1998YO	844	287	1,131	0.98	0.03	1.01
1999JIF	1,019	271	1,290	2.33	0.56	2.89
1999YO	828	589	1,417	1.08	0.06	1.14
Mean	836 (76) [a]	269 (24) [a]	1,105	2.44(86) [a]	0.40(14) [a]	2.84
s.d.	452	205	512	1.29	0.40	1.60
Acacia catechu						
1998Aca	573 (80) [a]	143 (20) [a]	716	1.94 (66) [a]	1.01 (34) [a]	2.95

The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m.
F, F1, F2: Forest Department of Myanmar, JIC: JICA, JIF: JIFPRO, YO: Yomiuri, Aca: *Acacia*.
[a] Numbers in parentheses are mean percentage of total.

Table 3. Biomass of the planted forests estimated by Equations (1) and (2).

Planted forests	Biomass by Eq. (1) (Mg ha^{-1})			Biomass by Eq. (2) (Mg ha^{-1})		
	Planted trees	Naturally established trees	Total	Planted trees	Naturally established trees	Total
Eucalyptus camaldulensis						
1973F	21.12	4.90	26.02	24.50	3.19	27.68
1994F	9.37	2.47	11.83	10.06	1.87	11.93
1995JIC	4.81	0.13	4.94	5.10	0.46	5.57
1996F1	23.42	0	23.42	23.55	0	23.55
1996F2	21.56	3.97	25.53	23.16	3.59	26.75
1997F	8.61	0.56	9.18	9.86	0.43	10.30
1998JIF	14.87	2.31	17.18	16.06	1.91	17.97
1998YO	4.53	0.079	4.61	3.73	0.077	3.80
1999JIF	11.60	2.77	14.37	13.84	2.06	15.91
1999YO	4.53	0.11	4.63	4.74	0.12	4.86
Mean	12.44 (90) [a]	1.92 (10) [a]	14.17	13.46 (92) [a]	1.52 (8) [a]	14.83
s.d.	7.40	1.80	8.58	8.09	1.32	9.01
Acacia catechu						
1998Aca	1.20 (19) [a]	5.18 (81) [a]	6.38	7.14 (67) [a]	3.48 (33) [a]	10.62

The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m.
[a] Numbers in parentheses are mean percentage of total.

4.4.1 Density and basal area of the evaluated stands

The original stocking density of *Eucalyptus camaldulensis* at the time of planting was 750 trees ha^{-1}. The stand densities now vary from half of that (334 trees ha^{-1}) to more than double (1911 trees ha^{-1}), as shown in Table 2. Most of the extra trees originated as coppice sprouts that became established and grew to tree size in lower DBH classes in *Eucalyptus camaldulensis* communities. The planted trees comprised 76% of the total tree density but 86% of basal area, showing that naturally established native species were suppressed in DBH as well as in number of trees.

The original stocking density of *Acacia catechu* was 375 trees ha^{-1}, at the planting spacing of 4 × 8 m. These trees also increased their numbers by sprouts. Planted trees occupied 80% of the total stand density and 66% of total basal area. The composition of naturally established native trees indicated strong competition with *Acacia catechu* and even better DBH growth, occupying 34% of the total basal area of the stand.

For *Eucalyptus camaldulensis* stands (Appendix IV (a)), a total number of trees and new shoots less than 5 cm in DBH accounted for 63% of the total, but their contribution to total basal area was less than 11% (Appendix IV (b)). Similarly, for the *Acacia catechu* stand (Appendix IV), the stand density of trees less than 5 cm in DBH accounted for 50% of the total, but their contribution to total basal area was less than 13%.

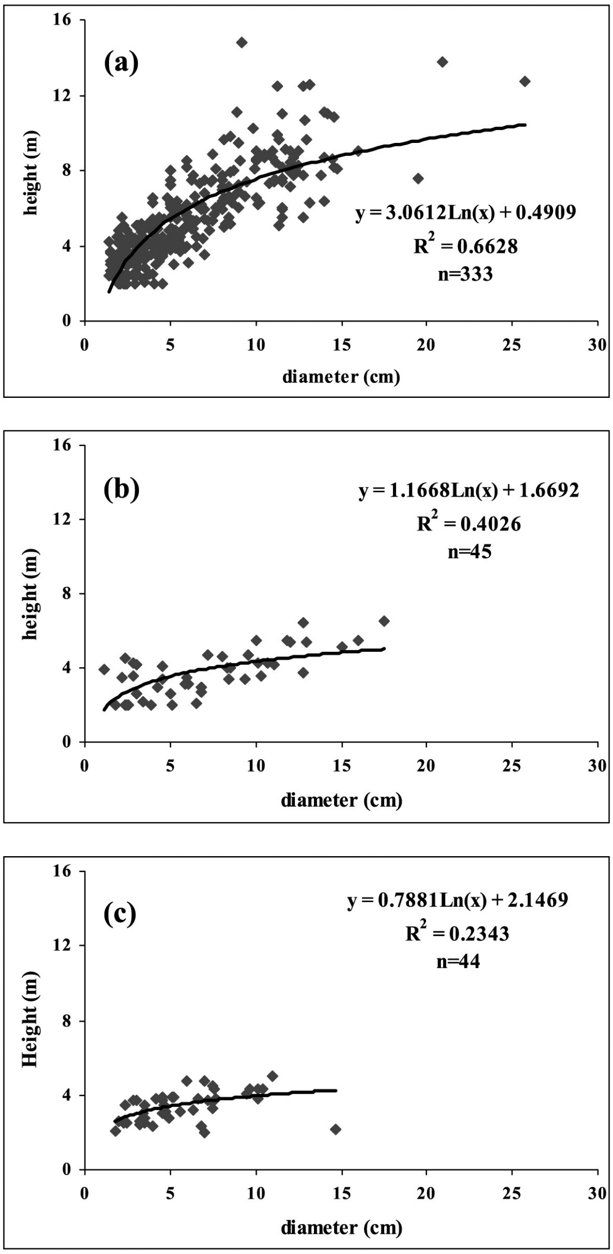

Fig. 5. DBH –height relations of (a) planted *Eucalyptus camaldulensis* trees, (b) naturally established trees, and (c) planted *Acacia catechu* trees in the investigated stands.

4.4.2 Biomass of the evaluated stands

Allometric equations for biomass estimation are generally based on stem DBH, tree height, and plant dry matter (Kato et al., 1978, Yamakura et al., 1986). Many allometric equations have been developed to estimate aboveground biomass for various species at different sites using those parameters; e.g., aboveground biomass (AGB) per tree for *Eucalyptus* sp. = 1.22 × DBH^2 × Ht × 0.01 by Senelwa and Sims, 1998; AGB per tree for *Citrus sinensis* = –6.64 + (0.279 × BA) + (0.000514 × BA^2) by Schroth et al., 2002; and many other equations (as quoted in IPCC National Greenhouse Gas Inventories Programme, 2003).

On the other hand, inclusion of height in allometric equations does not necessarily increase the accuracy of estimation (Nelson et al., 1999). It is probably because difficulty in determining a representative height for trees that lack a single main stem. It is not easy to measure heights if trees have not well-defined leaders. The accuracy of height information may be low for trees such as those in the present study that lack a clearly defined main stem. Since DBH is the most commonly used tree measurement and the most easily measurable variable, allometric equations including only DBH were also developed; e.g., AGB per tree for *Tectona grandis* = 0.0908 × DBH$^{2.575}$ by Kraenzel et al. , 2003; AGB per tree for *Pinus pinaster* = 0.08859 × DBH$^{2.235}$ by Ritson and Sochacki , 2003 (as quoted in IPCC National Greenhouse Gas Inventories Programme, 2003).

We used 2 allometric equations for estimating biomass. Equation (1) uses 2 parameters: DBH and basic wood density, an indicator for dry matter; Equation (2) uses 3 parameters: DBH (converted to basal area), height, and basic wood density. The biomass of each investigated stand calculated by both equations is shown in Table 3.

Eucalyptus biomass calculated by Equation (2) was slightly larger than that by Equation (1), with the exception of 1998YO where 89% of the stand was occupied by small trees with DBH < 5 cm.

In the *Acacia catechu* stand, biomass calculated using

Equation (2) was much higher than that calculated using Equation (1). On the other hand, the biomass of naturally established trees calculated by Equation (2) was lower than that by Equation (1), with the exception of 1995JIC and 1999YO. This might be due to the stunted height growth and variation in DBH growth of the naturally established trees. Appendix V shows the biomass by DBH classes calculated using Equations (1) and (2).

4.4.3 Mean annual increment (MAI) of biomass and carbon stock in the evaluated forests

The mean annual increment (MAI) of biomass of planted *Eucalyptus camaldulensis* forests varied from 0.54 to 2.97 Mg ha^{-1} (Table 4). MAI values in 1996F1, F2, 1998JIF, and 1999JIF are the highest class and for 3 (1996F1, 1996F2, and 1998JIF) of them, the land use before planting was dry land farming, and agro-forestry for some years (*4.3.1*). The mean value was estimated as 1.68 Mg ha^{-1} y^{-1} and the MAI value of carbon stock was 0.84 C Mg ha^{-1} y^{-1} (carbon fraction was assumed to be 0.5). The MAI for *Acacia catechu* was 1.52 Mg ha^{-1} y^{-1} at the 4 ×8 m planting spacing, implying about 3.0 Mg ha^{-1} y^{-1} at the 4 × 4 m planting spacing, and the MAI value of carbon stock was 0.76 C Mg ha^{-1} y^{-1}. 1973F was excluded from the calculation for MAI because it was cut several times in the past and is currently managed by coppicing, and no concrete data were available at the time of our study.

Table 4. Mean annual increment (MAI) of biomass of the planted forests.

Planted forests	Stand age (y)	Mean annual increment (MAI) of biomass: Planted trees ($Mg\ ha^{-1}\ y^{-1}$)	Naturally established trees ($Mg\ ha^{-1}\ y^{-1}$)	Total ($Mg\ ha^{-1}\ y^{-1}$)	Total ($C\ Mg\ ha^{-1}\ y^{-1}$)
Eucalyptus camaldulensis					
1994F	11	0.92	0.17	1.09	0.54
1995JIC	10	0.51	0.05	0.56	0.28
1996F1	9	2.62	0	2.62	1.31
1996F2	9	2.57	0.40	2.97	1.49
1997F	8	1.23	0.05	1.29	0.64
1998JIF	7	2.29	0.27	2.57	1.28
1998YO	7	0.53	0.01	0.54	0.27
1999JIF	6	2.31	0.34	2.65	1.33
1999YO	6	0.79	0.02	0.81	0.41
Mean		1.53 (91) [a]	0.15 (9) [a]	1.68	0.84
s.d.		0.90	0.16	1.01	0.50
Acacia catechu					
1998Aca	7	1.02 (67) [a]	0.50 (33) [a]	1.52	0.76

Equation (2) was used for estimating biomass. Carbon fraction is assumed to be 0.5 for biomass. The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m.
[a] Numbers in parentheses are mean percentage of total.

Table 5. Comparison of parameters between Kantherlay CF (community forest) and one of the best grown Nyaung U stands.

Evaluated parameters	1996F2 (9-year-old) planted *Eucalyptus camaldulensis* forest: Planted trees	Naturally established trees	Total	Kantherlay CF[a] (11-year-old) planted *Eucalyptus camaldulensis* forest: Planted trees	Naturally established trees	Total
Min. DBH (cm)	2.0	2.2	–	3.3	4.0	–
Max. DBH (cm)	14.0	10.7	–	32.5	18.0	–
Mean DBH (cm)	8.6	5.6	–	15.3	10.5	–
Min. height (m)	2.0	2.0	–	3.0	3.0	–
Max. height (m)	12.5	4.8	–	23.5	11.1	–
Mean height (m)	6.7	3.2	–	15.3	7.6	–
Tree density (trees ha^{-1})	1,290	637	1,927	600	52	652
Basal area ($m^2\ ha^{-1}$)	4.11	1.14	5.25	11.03	0.51	11.54
Biomass (Mg ha^{-1})	23.20	3.60	26.80	74.10	2.10	76.20
Mean annual increment (Mg ha^{-1} y^{-1})	2.60	0.40	3.00	6.70	0.20	6.90

[a] Community forest managed by local people at Magwe town to the south of Nyaung U (Source: unpublished data of Kyaw, 2005).

Table 6. DBH, tree density, basal area, and biomass of remnant trees in the shrub and grass communities.

Plot No. (Shrub and grass communities)	Min. DBH (cm)	Max. DBH (cm)	Mean DBH (cm)	Tree density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Biomass (Mg ha^{-1})
3 (near 1973F &1996F2)	1.0	4.8	1.8	3,662	1.32	3.73
2 (near 1994F)	1.0	2.9	2.0	127	0.05	0.14
9 (near 1995JIC)	1.0	4.5	1.4	2,102	0.43	1.15
1 (near 1996F1)	1.0	4.2	1.5	764	0.20	0.60
4 (near 1997F)	1.0	4.5	1.6	1,879	0.52	1.38
5 (near 1998JIF)	1.0	4.9	2.7	669	0.52	1.84
8 (near 1998YO)	1.0	3.1	1.1	637	0.07	0.15
6 (near 1999 JIF)	1.0	4.5	1.3	8,121	1.25	2.69
9 (near 1999YO)	1.0	1.0	1.0	1,783	0.14	0.23
Mean	1.00	3.82	1.44	2,194	0.50	1.32

Table 7. Mean tree density, basal area, and biomass of remnant trees in the shrub and grass communities by DBH classes.

DBH classes	Tree density (trees ha^{-1})	Basal area (m^2 ha^{-1})	Biomass (Mg ha^{-1})
Shoots [a]	1,610 (73) [b]	0.13 (25) [b]	0.21 (16) [b]
0 < DBH < 5 cm	584 (27) [b]	0.37 (75) [b]	1.11 (84) [b]
Total	2,194	0.50	1.32

[a] Less than 1.3 m high.
[b] Numbers in parentheses are percentage of total.

4.4.4 Comparison with the preceding study in the same region

To evaluate the productivity of the evaluated planted forests near Nyaung U, we compared the parameters with those from another moderately productive *Eucalyptus camaldulensis* forest, the Kantherlay Community Forest (CF), situated in Magwe town to the south of Nyaung U (Kyaw, 2005) in the central dry zone. This CF is managed by local people, to whom the FD has granted a 30-year lease. The original stocking density was 750 trees ha^{-1}. Some trees were cut for use. Most parameters including MAI of Kantherlay CF were higher than those of this study (Table 5) although the accurate reasons of the difference are unknown.

4.5 Estimating values of biomass and litter of shrub and grass communities

4.5.1 Biomass of remnant trees

A circular plot was set near each forest to estimate the biomass of the remnant vegetation. Trees greater than 1 cm in DBH at 1.3 m height were recorded, and their biomass was calculated using Equation (1). The biomass ranged from 0.14 to 3.73 Mg ha^{-1}, averaging 1.32 Mg ha^{-1}. Most sites were covered with shrubs and grasses, and the maximum DBH of the recorded remnant trees did not exceed 5 cm (Table 6). Shoots and sprouts emerging from the base of main stems accounted for 73% of the tree density, but only 16% of the biomass (Table 7).

4.5.2 Values of biomass and litter of shrub and grass communities

The total value of aboveground and belowground biomass and litter ranged from 2.36 to 23.14 Mg ha^{-1}, averaging 11.00 Mg ha^{-1} (Table 8). Well-conserved sites had higher biomass; e.g., near 1973F and 1996F2. Belowground biomass was much greater than aboveground biomass at most sites, and accounted for 58% of the total. The measured carbon stock in biomass (including remnant trees) and litter varied from 1.12 to 11.23 C Mg ha^{-1}, averaging 5.35 C Mg ha^{-1} (Table 8).

The total value of biomass and litter was also estimated using Equation (3) (Table 9). The calculated biomass was multiplied by recorded coverage to give the actual biomass of the communities. Estimated and measured values differed considerably (Tables 8 and 9), on account of the heterogeneous distribution of the remnant trees. There are at least 2 possible reasons for large difference in the estimates. The first reason is the influence of climate upon root-shoot-ratio. The used equation was obtained in shrub communities (*Lantana camara* and *Chromolaena odorata* are dominant) under the climate with annual rainfall of 1132 ± 290 mm y^{-1} (Tropical Moist; IPCC National Greenhouse Gas Inventories Programme, 2003) in Indonesia. Root-to-shoot ratio of the communities ranged between 0.36 and 1.22 (averaged 0.72) (Kiyono et al., unpublished), while the ratio of this study was 0.48 to 5.38 (averaged 2.54) and the mean values are significantly different (P = 0.011). According to our observation, *Chromolaena odorata* was scarce and *Lantana camara* were allowed to survive along creeks or under tree shade in the central dry zone. The shortage of water in plant life in the central dry zone requires plant to develop root systems, as we discussed in *4.3.2* for trees. The second reason is that aboveground organs of shrub community is highly vulnerable to various destructive pressures such as wildfire, grazing, and cutting for fuel-wood in the central dry zone. To get reliable data on aboveground biomass, we need to study its growth and loss rates in permanent plots; and therefore, the comparison of values between the climate zones requires further investigation.

Table 8. Measured biomass and litter amounts of the investigated shrub and grass communities.

Plot No. (Shrub and grass communities)	Remnant trees (Mg ha^{-1})	Above-ground biomass (Mg ha^{-1})	Below-ground biomass (Mg ha^{-1})	Litter (Mg ha^{-1})	Total biomass and litter (Mg ha^{-1})	Total biomass and litter (C Mg ha^{-1})
3 (near 1973F &1996F2)	3.73	4.90	11.89	2.62	23.14	11.23
2 (near 1994F)	0.14	1.75	5.46	0.95	8.30	4.02
9 (near 1995JIC)	1.15	3.91	8.39	1.03	14.48	7.10
1 (near 1996F1)	0.60	4.50	4.53	1.09	10.72	5.22
4 (near 1997F)	1.38	2.37	1.15	1.48	6.38	3.00
5 (near 1998JIF)	1.84	1.91	5.33	1.36	10.45	5.05
8 (near 1998YO)	0.15	0.62	1.14	0.45	2.36	1.12
6 (near 1999 JIF)	2.69	1.62	6.00	0.96	11.27	5.51
9 (near 1999YO)	0.23	1.75	9.40	0.55	11.93	5.89
Mean	1.32	2.59 (28)[a]	5.92 (58)[a]	1.17 (14)[a]	11.00	5.35
s.d.	1.18	1.48	3.57	0.64	5.75	3.35

[a].Numbers in parentheses are percentage of total. Carbon fraction is assumed to be 0.5 for biomass and 0.37 for litter (IPCC National Greenhouse Gas Inventories Programme, 2003).

Table 9. Estimated biomass and litter amounts of shrub and grass communities by Equation (3).

Plot No. (Shrub and grass communities)	Mean max. height (m)	Biomass and litter (Mg ha^{-1})
3 (near 1973F & 1996F2)	1.0	6.83
2 (near 1994F)	0.4	3.17
9 (near 1995JIC)	0.9	6.01
1 (near 1996F1)	1.2	8.83
4 (near 1997F)	1.1	7.77
5 (near 1998JIF)	1.1	7.77
8 (near 1998YO)	0.7	4.66
6 (near 1999 JIF)	0.9	6.01
9 (near 1999YO)	1.0	6.83
Mean	0.9	6.43
s.d.	0.2	1.72

5 Conclusion (a potential level of carbon sequestration by planted forests under the climate zone of the Tropical Dry)

The biomass of the 9 planted *Eucalyptus camaldulensis* forests of 6 to 11-year-old ranged from 3.80 to 27.68 Mg ha^{-1}, averaging 14.83 Mg ha^{-1}. The MAI value was estimated as 1.68 Mg ha^{-1} y^{-1} and 0.84 C Mg ha^{-1} y^{-1} (at the 4 |× 4 m planting spacing). The biomass of the planted *Acacia catechu* forest was estimated as 10.62 Mg ha^{-1}. The MAI was 1.52 Mg ha^{-1} yr^{-1} and 0.76 C Mg ha^{-1} y^{-1} (at the 4 × 8 m planting spacing). The results show that the productivity of the planted forests is much lower than that of other places with more favorable conditions (e.g. MAI values of planted forests of non-fast-growing trees such as *Peronema canescens* and *Swietenia mahagoni*; range, 1.90-18.80 Mg ha^{-1} y^{-1}; average, 10.71 ± 7.18 Mg ha^{-1} year^{-1} in 10- to 25-year-old stands under climatic conditions with mean annual rainfall 2000-3000 mm; Kiyono et al., 2005).

The total weight of biomass and litter of biotic climax of shrub and grass communities ranged from 2.36 to 23.14 Mg ha^{-1}, averaging 11.00 Mg ha^{-1}. Mean carbon stock of the communities was 5.35 C Mg ha^{-1}. It will be able to conclude that, roughly speaking, carbon stock of planted forests will take more than 6 to 7 years to exceed the carbon stock of baseline vegetation in the study area.

Tree growth is seriously compromised by the severe climate of the central dry zone. The establishment of a productive and sustainable planted forest in the climate zone of the Tropical Dry (mean annual rainfall < 1000mm; IPCC National Greenhouse Gas Inventories Programme, 2003) may require conservative inputs of technologies: they are such as fertilizer application, mulching, irrigation, use of drought-tolerant species, and protection from destructive elements.

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Appendix 1.
(a) General description and soils of the sample plots in the investigated planted forests.

Plot No.	Location	Main species	Spacing	Soil type	Stand age (planting years)	Established by[a]	Remarks
5	20°57.358' N 95° 03.344' E	*Eucalyptus camaldulensis*	4 × 4 m	Xanthic Ferralsols	– 1973	FD	Old planted forest managed by coppice system
3	21°11.840' N 94° 55.267' E	*Eucalyptus camaldulensis*	4 × 4 m	Vertisols	11	FD	
4	21°11.788' N 94° 55.322' E			Xanthic Ferralsols	1994		Old dry land farm
20	21° 8.990' N 95° 0.202' E	*Eucalyptus camaldulensis*	4 × 4 m	Lithosols	10	JICA	
21	21° 8.987' N 95° 0.143' E			Vertisols	1995		
1	21°11.569' N 94° 56.418' E	*Eucalyptus camaldulensis*	4 × 4 m	Rhodic Ferralsols	9		
2	21°11.322' N 94° 56.905' E			Dystric Cambisols	1996	FD	Old dry land farm
6	20°57.420' N 95° 3.314' E	*Eucalyptus camaldulensis*	4 × 4 m	Xanthic Ferralsols	9		Agro-forestry, ploughed
7	20°57.341' N 95° 3.296' E				1996	FD	Old dry farm land
8	20°57.305' N 95° 3.291' E	*Eucalyptus camaldulensis*	4 × 4 m	Vertisols	8		
9	20°57.240' N 95° 3.266' E			Dystric Cambisols	1997	FD	
12	20°57.670' N 95° 3.073' E	*Eucalyptus camaldulensis*	4 × 4 m	Andosols	7	JIFPRO	
13	20°57.747' N 95° 3.544' E				1998		Old dry land farm
18	20°51.363' N 95° 2.988' E	*Eucalyptus camaldulensis*	4 × 4 m	Vertisols	7	Yomiyuri	Eroded, boulders apparent, uncultivable
19	20°57.900' N 95° 9.040' E				1998		
14	20°60.857' N 95° 3.629' E	*Eucalyptus camaldulensis*	4 × 4 m	Lithosols	6	JIFPRO	
15	20°60.666' N 95° 3.983' E			Xanthic Ferralsols	1999		
16	20°58.339' N 95° 3.096' E	*Eucalyptus camaldulensis*	4 × 4 m	Vertisols	6	Yomiyuri	
17	20°51.363' N 95° 2.988' E				1999		
10	20°59.467' N 95° 2.039' E	*Acacia catechu*	4 × 8 m	Andosols	7	JIFPRO	Agro-forestry, ploughed
11	20°59.376' N 95° 2.175' E				1998		

[a] FD: Forest Department; JICA: Japan International Cooperation Agency; JIFPRO: Japan International Forestry Promotion and Cooperation Center.

Appendix 1.
(b) General description and soils of the sample plots in shrub and grass communities.

Plot No.	Location	Soil type	Supposed soil fertility	Vegetation type/ dominant spp.	Wildfire [a]	Land use	Remarks
3	20°57.377' N 95° 3.406' E (near 1973F, 1996F)	Xanthic Ferralsols	Poor	Forest/ *Rhus paniculata* & *Morinda angustifolia*	Prevented	Forest land	Failed planted forest area, well conserved
2	21°11.532' N 94° 55.363' E (near 1994F planted forest)	Dystric Cambisols (sandy soil)	Poor	Grassland/ *Acacia catechu*	Prevented	Grazing land	Grazing land
9	21° 8.937' N 95° 00.080' E (near 1995JIC planted forest)	Lithosols	Poor	Shrub community/ *Millettia multiflora* & *Terminalis oliveri*	Prevented	Forest land	Near dry land farm
1	21°12.135' N 94° 56.431' E (near 1996F1 planted forest)	Rhodic Ferralsols	Medium	Shrub community/ *Acacia catechu*	Prevented	Forest land	Well conserved natural vegetation of FD & DZGD
4	20°57.100' N 95° 03.373' E (near 1997F planted forest)	Dystric Cambisols	Poor	Shrub community/ *Rhus paniculata* & *Morinda angustifolia*	No	Collection of fallen litter	Near farmland
5	20°57.500' N 95° 3.677' E (near 1998JIF planted forest)	Andosols	Poor	Roadside shrub community/ *Acacia catechu*	No	Grazing land	Old dry land farm
8	20°57.908' N 95° 2.930' E (near 1998YO planted forest)	Vertisols	Very poor	Grass community/ *Acacia catechu* & *Morinda angustifolia*	Every year/ partially	No use	Eroded, boulders apparent, uncultivable
6	20°59.442' N 95° 3.023' E (near 1999JIF planted forest)	Xanthic Ferralsols	Poor	Shrub community/ *Rhus paniculata* & *Emblica officinalis*	Sometimes/ partially	Forest land	Near farmland
7	20°58.290' N 95° 2.956' E (near 1999YO planted forest)	Vertisols	Very poor	Forest/ *Flacourtia indica*	Sometimes	Forest land	Old dry land farm

[a] Wildfires are caused mainly by hunting. Normally, residents prevent wildfires in order not to burn their agricultural residues. FD and DZGD practice fire protection in the protected forest area. Grazing lands are vulnerable to wildfires because everybody can use this type of land, and no fire prevention action is taken.

Appendix Ⅱ.
Tree species recorded in the planted forests and nearby shrub and grass communities.

	Local name (Myanmar)	Species	Family
1	Sha (cutch tree)	*Acacia catechu*	Mimosaceae
2	Tanaung	*Acacia leucophloea*	Mimosaceae
3	Myanmar kokko	*Albizia lebbek*	Mimosaceae
4	Tama (neem tree)	*Azadirachta indica*	Meliaceae
5	Palan	*Bauhinia malabarica*	Caesalpiniaceae
6	Khan	*Carissa carandas*	Apocynaceae
7	Mezali	*Cassia siamea*	Caesalpiniaceae
8	Tapauk	*Dalbergia paniculata*	Fabaceae
9	Gyoke	*Diospyros montana*	Ebenaceae
10	Ziphyu	*Emblica officinalis*	Euphorbiaceae
11	Tamasay	*Eranthemum macrophyllum*	Acanthaceae
12	Eucalypt (planted)	*Eucalyptus camaldulensis*	Myrtaceae
13	Na-ywe	*Flacourtia indica*	Flacourtiaceae
14	Yingat	*Gardenia sootepensis*	Rubiaceae
15	Tayaw	*Grewia hirsuta*	Tiliaceae
16	Zimani	*Hiptage candicans*	Malpighiaceae
17	Pashu	*Kleinhovia hospita*	Sterculiaceae
18	Nabe	*Lannea grandis*	Anacardiaceae
19	Bawzagaing	*Leucaena leucocephala*	Mimosaceae
20	Thabut	*Miliusa velutina*	Annonaceae
21	Pingan	*Millettia multiflora*	Fabaceae
22	Nibase	*Morinda angustifolia*	Rubiaceae
23	Zaung-chang	*Osyris wightiana*	Santalaceae
24	Khaung	*Rhus paniculata*	Anacardiaceae
25	Aw-le	*Sapium eugeniifolium*	Euphorbiaceae
26	Danaung	*Sphaeranthus indicus*	Asteraceae
27	Dahat	*Tectona hamiltoniana*	Verbenaceae
28	Than	*Terminalia oliveri*	Combretaceae
29	Taukkyan	*Terminalia tomentosa*	Combretaceae
30	Zi (Plum tree)	*Zizyphus jujuba*	Rhamnaceae

Appendix Ⅲ .

(a) Mean DBH and height of the planted *Eucalyptus camaldulensis* trees in the planted forests.

Planted forests	DBH (cm)				Height (m)				Tree density
	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	314 m^{-2}
1973F	2.0	13.8	5.3	3.1	2.0	14.8	5.6	2.6	45
1994F	2.1	14.5	7.8	3.2	4.5	9.6	6.6	1.5	21
1995JIC	1.4	11.5	4.5	2.5	2.0	6.5	4.0	1.4	34
1996F1	2.5	25.7	10.4	6.2	2.1	13.8	7.1	3.1	20
1996F2	2.0	14.0	8.6	3.5	2.0	12.5	6.7	2.3	38
1997F	1.4	13.0	4.9	3.1	2.5	9.6	5.2	1.9	44
1998JIF	2.2	14.8	8.6	3.9	2.9	10.8	6.9	1.9	25
1998YO	1.5	16.5	4.5	3.0	2.0	6.6	4.0	1.0	26
1999JIF	1.5	14.2	4.9	3.7	2.0	12.6	4.8	3.0	49
1999YO	2.0	11.5	4.6	2.5	2.3	6.6	4.1	1.3	31
Overall	1.4	25.7	6.4	2.2	2.0	14.8	5.5	0.7	333

(b) Mean DBH and height of naturally established trees in the planted *Eucalyptus camaldulensis* forests.

Planted forests	DBH (cm)				Height (m)				Tree density
	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	314 m^{-2}
1973F	1.1	15.0	9.1	7.2	3.9	5.1	4.4	0.6	3
1994F	7.2	12.8	9.9	2.3	4.3	6.4	5.0	0.9	4
1995JIC	3.2	5.6	4.6	1.0	2.4	3.1	2.9	0.3	4
1996F1	0	0	0	0	0	0	0	0	0
1996F2	2.2	10.7	5.6	2.6	2.0	4.8	3.2	1.1	21
1997F	4.3	8.0	5.8	1.9	2.0	4.6	3.2	1.3	3
1998JIF	3.4	13.0	7.3	4.2	2.2	5.4	4.0	1.4	6
1998YO	2.8	2.8	2.8	0	3.6	3.6	3.6	0	1
1999JIF	1.8	17.5	4.7	4.5	2.0	6.5	2.7	1.5	11
1999YO	2.3	2.5	2.4	0.1	2.0	3.0	2.5	0.7	2
Overall	1.1	17.5	5.8	2.6	2.0	6.5	3.5	0.8	55

(c) Mean DBH and height of all trees in the planted *Eucalyptus camaldulensis* forests.

Planted forests	DBH (cm)				Height (m)				Tree density
	Min.	Max.	Mean	s.d.	Min.	Max.	Mean	s.d.	314 m^{-2}
1973F	1.1	15.0	5.7	3.5	2.0	14.8	5.5	2.5	48
1994F	2.1	14.5	8.1	3.1	4.5	8.6	6.4	1.5	25
1995JIC	1.4	11.5	4.5	2.4	2.0	6.5	3.9	1.4	38
1996F1	2.5	25.7	10.4	6.2	2.1	13.8	7.1	3.1	20
1996F2	2.0	14.0	7.4	3.5	2.0	12.5	5.4	2.6	59
1997F	1.4	13.0	4.9	3.1	2.0	9.6	5.1	1.9	47
1998JIF	2.2	14.8	8.4	3.9	2.2	10.8	6.3	2.1	31
1998YO	1.5	16.5	4.4	3.0	2.0	6.6	4.0	1.0	27
1999JIF	1.5	17.5	4.9	3.8	2.0	12.6	4.4	2.9	60
1999YO	2.0	11.5	4.4	2.4	2.0	6.6	4.0	1.3	33
Overall	1.1	25.7	6.3	2.1	2.0	14.8	5.2	0.7	388

Appendix Ⅳ.

(a) Stand density by DBH class of the planted forests.

Planted forest	Planted trees					Naturally established trees					Total
	Shoots [a]	≤5cm	5–9.9cm	10–14.9cm	≥15cm	Shoots [a]	≤5cm	5–9.9cm	10–14.9cm	≥15cm	
1973F	478	828	449	159	0	96	64	0	32	32	2138
1994F	16	64	191	80	0	32	0	32	32	0	446
1995JIC	303	366	191	16	0	143	48	16	0	0	1083
1996F1	0	64	127	80	64	0	0	0	0	0	334
1996F2	16	111	223	287	0	255	159	223	16	0	1290
1997F	318	446	175	80	0	191	16	32	0	0	1258
1998JIF	143	80	127	191	0	32	32	32	32	0	669
1998YO	430	287	111	0	16	271	16	0	0	0	1131
1999JIF	239	462	207	111	0	96	127	32	0	16	1290
1999YO	303	334	159	32	0	557	32	0	0	0	1417
1998Aca [b]	32	255	207	80	0	16	32	16	64	16	717

Stand density: trees ha^{-1}. [a] Stems less than 1.3 m high. [b] The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m. A total number of trees and new shoots less than 5 cm in DBH accounted for 63% of the total for *Eucalyptus camaldulensis* stands and 50% for the *Acacia catechu* stand.

(b) Basal area by DBH class of the planted forests.

Planted forest	Planted trees					Naturally established trees					Total
	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	
1973F	0.04	0.80	1.72	1.93	0	0.01	0.06	0	0.31	0.56	5.42
1994F	0	0.05	0.87	0.93	0	0	0	0.18	0.33	0	2.37
1995JIC	0.02	0.25	0.71	0.17	0	0.01	0.07	0.04	0	0	1.27
1996F1	0	0.06	0.66	0.82	2.17	0	0	0	0	0	3.70
1996F2	0	0.09	0.86	3.17	0	0.02	0.12	0.86	0.14	0	5.25
1997F	0.03	0.33	0.68	0.83	0	0.02	0.02	0.11	0	0	2.02
1998JIF	0.01	0.08	0.46	2.24	0	0	0.03	0.09	0.39	0	3.30
1998YO	0.03	0.26	0.34	0	0.34	0.02	0.01	0	0	0	1.01
1999JIF	0.02	0.24	0.62	1.45	0	0.01	0.08	0.09	0	0.38	2.89
1999YO	0.02	0.25	0.51	0.30	0	0.04	0.01	0	0	0	1.14
1998Aca [b]	0	0.25	0.87	0.81	0	0	0.02	0.03	0.64	0.32	2.94

Basal area: m^2 ha^{-1}. [a] Stems less than 1.3 m high. [b] The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m. A total number of trees and new shoots less than 5 cm in DBH accounted for 11% of the total for *Eucalyptus camaldulensis* stands and 13% for the *Acacia catechu* stand.

Appendix Ⅴ.

(a) Biomass by DBH class of the planted forests (Estimated by Equation (1)).

Planted forest	Planted trees					Naturally established trees					Total
	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	
1973F	0.07	2.60	7.59	10.86	0	0.01	0.21	0	1.51	3.17	26.02
1994F	0.002	0.16	3.97	5.23	0	0.004	0	0.79	1.67	0	11.83
1995JIC	0.004	0.79	3.08	0.90	0	0.03	0.07	0.03	0	0	4.94
1996F1	0	0.18	3.07	4.49	15.69	0	0	0	0	0	23.42
1996F2	0.002	0.28	3.76	17.52	0	0.05	0.33	2.90	0.69	0	25.53
1997F	0.04	1.03	3.01	4.53	0	0.04	0.07	0.45	0	0	9.18
1998JIF	0.02	0.27	1.96	12.62	0	0.004	0.06	0.21	2.03	0	17.18
1998YO	0.06	0.84	1.45	0	2.18	0.05	0.03	0	0	0	4.61
1999JIF	0.03	0.69	2.57	8.32	0	0.01	0.18	0.26	0	2.32	14.37
1999YO	0.04	0.79	2.13	1.57	0	0.07	0.04	0	0	0	4.63
1998Aca [b]	0.01	0.32	0.54	0.33	0	0.002	0.04	0.11	3.17	1.86	6.38

Biomass: Mg ha^{-1}. [a] Stems less than 1.3 m high. [b] The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m.

(b) Biomass by DBH class of the planted forests (Estimated by Equation (2)).

Planted forest	Planted trees					Naturally established trees					Total
	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	Shoots [a]	≤5 cm	5–9.9 cm	10–14.9 cm	≥15 cm	
1973F	0.10	3.05	9.87	11.47	0	0.02	0.12	0	1.00	2.05	27.68
1994F	0.003	0.24	4.51	5.32	0	0.01	0	0.61	1.25	0	11.93
1995JIC	0.06	0.92	3.30	0.83	0	0.03	0.28	0.16	0	0	5.57
1996F1	0	0.18	3.40	4.59	15.37	0	0	0	0	0	23.55
1996F2	0.00	0.34	4.23	18.59	0	0.05	0.33	2.74	0.47	0	26.75
1997F	0.07	1.28	3.61	4.91	0	0.04	0.06	0.34	0	0	10.30
1998JIF	0.03	0.35	2.30	13.38	0	0.01	0.09	0.36	1.46	0	17.97
1998YO	0.09	1.00	1.54	0	1.09	0.05	0.03	0	0	0	3.80
1999JIF	0.05	0.79	2.95	10.05	0	0.02	0.21	0.25	0	1.59	15.91
1999YO	0.06	0.89	2.31	1.48	0	0.09	0.03	0	0	0	4.86
1998Aca [b]	0.01	1.04	3.96	2.14	0	0.002	0.05	0.08	2.14	1.21	10.62

Biomass: Mg ha^{-1}. [a] Stems less than 1.3 m high. [b] The planting spacing of *Eucalyptus camaldulensis* was 4 × 4 m, while that of *Acacia catechu* was 4 × 8 m.

ミャンマー中央乾燥地の人工林と人為的干渉によって維持されている低木・草本群落のバイオマス

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要 旨

熱帯で年降水量が 637mm という厳しい乾燥気候下において植林が蓄積する炭素量の程度を知るため、ミャンマー中央乾燥地で 2 つの主要な造林樹種の人工林と、被食や刈り取りなどによって維持されている低木・草本群落のバイオマスを調べた。6 ～ 11 年生の 9 つのリバーレッドガム人工林（4m × 4m 間隔植栽）のバイオマスは 3.80 から 27.68 Mg ha^{-1} の範囲内にあり、平均は 14.83 Mg ha^{-1}、定期平均成長量は 1.68 Mg ha^{-1} y^{-1} であった。7 年生のアセンヤクノキ人工林（4m × 8m 間隔植栽）のバイオマスは 10.62 Mg ha^{-1}、MAI は 1.52 Mg ha^{-1} y^{-1} であった。これらの MAI の値は、条件に恵まれた他の地域の値に比べてきわめて低い。低木・草本群落のバイオマスと堆積リターの合計重量は 2.36 から 23.14 Mg ha^{-1} で、平均は 11.00 Mg ha^{-1} であった。調査地の厳しい気候下で人工林の成長を改善し維持するには、施肥やマルチング、灌水、耐乾性樹種の利用、自然災害への対策など何らかの技術を導入する必要がある。

キーワード：アセンヤクノキ、乾燥熱帯、クリーン開発メカニズム、炭素蓄積、定期平均成長量、ベースライン、リバーレッドガム

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