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Estimation of Biomass and Bio-fuel Production Potential by Afforestation in Arid Area of the Murchison Region, Western Australia

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Abstract: Despite recent studies on bio-fuels for carbon mitigation, biomass resource shortages in Japan continue to be a serious concern. To deal with this future problem, we evaluated whether the large amounts of biomass supplied from arid land afforestation in Western Australia could compensate for this biomass resource shortage, by estimating how much biomass as bio-fuel resource could be produced by this type of afforestation using arid areas. First, from ground truthing with tree measurement and allometirc equations, biomass production potential for bio-fuel resource was estimated at 70.5 Mg ha^{-1} in 30 years. Second, from remote sensing analysis (vegetation classification and biomass estimation), afforestation candidate areas with scarce natural vegetation were estimated at 5.41×10^4 ha. At the same time, the amount of potential biomass to be obtained from natural vegetation when creating afforestation areas was estimated at 6.47×10^4 Mg. Third, biomass production potential for bio-fuel by afforestation in arid areas of Murchison region was estimated at 3.37×10^8 Mg using the above estimated data and vegetation maps created from the Australian native vegetation assessment 2001 by the national land and water resources audit. From Life Cycle Assessment (LCA), assuming the use of this estimated biomass as bio-ethanol, bio-fuel production potential was estimated at about 1.07×10^8 m^3 in 30 years (3.56×10^6 m^3 year^{-1}). Thus, our study suggests that there is a large potential for biomass production for bio-fuel using this approach.

Key Words: Arid land afforestation, *Eucalyptus camaldulensis*, LANDSAT, Life cycle assessment, Vegetation map

1. Introduction

Over half of CO_2 emissions in Australia were derived from power generation, mainly coal fire power plants (Dicks *et al*., 2004), and the next largest CO_2 emissions (around 20%) were derived from the transportation sector (IEA, 2010). For Japan, CO_2 emissions from power generation also had the largest proportion (around 40%), and that from the transportation sector had the third largest proportion (IEA, 2010). In addition, the total CO_2 emissions derived from just the transportation sector of Japan and Australia was 306 million Mg year^{-1}. To mitigate such huge amount of carbon emission, fossil fuels should be replaced by renewable biomass as Canadel and Raupach (2008) indicated that the use of bio-fuels for the transportation sector could compensate for such large amounts of CO_2 emissions.

A recent investigation of bio-fuels in Japan raised the concern that biomass resources were insufficient to support a viable bio-fuels industry. According to a report by the Forestry and Forest Product Research Institute of Japan[A)], even utilizing all the biomass which has not yet been used for any purpose, mainly forest residues, for bio-fuel production, the produced amount of such bio-fuels corresponds to less than 1% annual petroleum consumption of Japan, which was reported as 59 million m^3 in 2010 by METI (2011). Thus, carbon mitigation by using bio-fuels in Japan is considered questionable under the present situation.

Fung *et al*. (2002) indicated that biomass from forests, especially national forests, had become the most likely renewable biomass supply, and their efficient utilization should become key for carbon mitigation inside Australia. However, due to situations like large reserves of accessible coal, natural gas and oil, low cost of electricity generated in coal-fired power plants, uncertain greenhouse and renewable energy policies of Australian government, and lack of efficient processes for producing bio-fuels, Australia has had minimal incentives for carbon mitigation using renewable energy (Richardson *et al*., 2002; Raison, 2006; Yusaf *et al*., 2011).

Considering this situation, Yamada *et al*. (1999, 2003) created a new afforestation method in arid lands of Western Australia, and Kojima and Egashira (2011) improved their large scale afforestation techniques, pointing to huge carbon mitigation potential and/or renewable biomass production potential. As Raison (2006) work supports biomass production in rural low rainfall areas, and Burrows *et al*. (2002)

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and CSIRO (2009) works also support the idea of carbon mitigation in arid areas, large scale afforestation techniques in arid areas of Western Australia (Yamada *et al*., 1999, 2003; Kojima and Egashira, 2011) were considered to cover a shortage of feasibility studies and empirical data inside Australia, and also to cover the serious shortage of renewable biomass production in Japan.

And this arid land afforestation was also considered to achieve the carbon mitigation target of Japan and Australia by Kyoto protocol and future post-Kyoto protocols. In this study, biomass production potential for bio-fuel, especially bio-ethanol, of afforested arid lands in the Murchison region of Western Australia was estimated.

2. Materials and Methods

2.1. Research area

The research area of this study is Sturt Meadows (28˚40'S, 120˚58'E) near Leonora, located about 600 km from Perth, the provincial capital of Western Australia. The range of our research area is approximately 45 km east and west, and 50 km north and south. The annual rainfall was calculated as 211 mm (Yasuda *et al*., 2001), and potential evapo-transpiration was observed as 3400 mm y^{-1} (Yamada *et al*., 1999). This research area belongs to the Murchison region of Interim Biogeographic Regionalization of Australia (IBRA) Version 5.1 (Environment Australia, 2000). The Murchison environment was described as having Mulga (*Acacia aneura*) low woodlands, often rich in ephemerals, on outcrop hardpan wash plains and fine-textured quaternary alluvial and eluvial surfaces mantling granitic and greenstone strata (Environment Australia, 2000).

2.2. Estimation procedure for biomass production potential

First, to estimate biomass production potential per unit area (Mg ha^{-1}), the measurement data (2000 to 2012 period) of 76 *Eucalyptus camaldulensis* trees, deemed as the appropriate tree species for arid land afforestation method invented by Yamada *et al*. (1999, 2003), and allometric equations (Suganuma *et al*., 2006) were used to estimate the mean annual increment (Mg ha^{-1} $year^{-1}$) of their trunk and branches, parts which can be used for bio-ethanol production. For the calculation, three assumptions were set as follows. 1) Afforestation was a monoculture of *E. camaldulensis* trees, 2) an afforestation period, or tree production cycle, was 30 years, and 3) felling loss was set as 10%.

Second, to estimate afforestation candidate areas and obtained biomass from natural vegetation inside the research area, vegetation classification results and biomass estimation results of Suganuma *et al*. (2010), who used four LANDSAT 5TM/7ETM+ images (path 110, row 80), were used. Afforestation candidate areas were chosen from three land cover types (*Acacia* woodland, bare ground and their transition area) with biomass value of less than 130 Mg ha^{-1}.

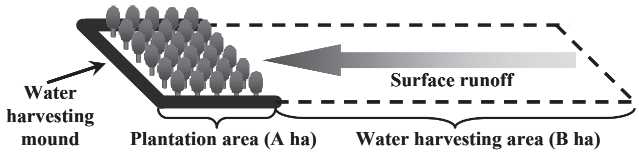

Fig. 1. Afforestation site layout. Ratio of A : B was set as 1 : 3.

This biomass criteria (less than 130 Mg ha^{-1}) was smaller than the biomass production value of *E. camaldulensis* in 30 years by afforestation method of Yamada *et al*. (1999, 2003), and also smaller than the maximum observed biomass value of natural forest of *E. camaldulensis* inside the research area (Suganum *et al*., 2006).

The actual tree plantation area was 25% of the total afforestation candidate areas, with the other 75% left as original land cover, used for water harvesting (**Fig. 1**). By applying the afforestation methods of Yamada *et al*. (1999, 2003), original vegetation inside the research area had to be clear cut before creating the plantation areas. Trunk and branches parts from the cleared biomass provided an estimate of biomass from natural vegetation.

Third, the combined data from these first two procedures were used to estimate the biomass production potential for bio-fuel inside the research area.

Fourth, to estimate the biomass production potential for bio-fuel in the Murchison region, the vegetation maps made by National Land and Water Resources Audit (2002) were used for extracting vegetation distribution areas, which contained vegetation types similar to those in the research area. Two assumptions were also made. Assumption 1 was the environmental conditions in the Murchison region were nearly the same as those of the research area, this assumption was supported by on-site ground observations and meteorological data [B)]. Assumption 2 was the Murchison region had the same proportion of afforestation candidate area and biomass distribution to the research area. This was considered reasonable because the research area was located inside Murchison region and both areas have almost the same vegetation and climate conditions. By calculating how many times larger the extracted vegetation distribution area was compared to the research area, biomass production potential for bio-fuel in the Murchison region was directly estimated.

Last, to estimate the amount of potential bio-ethanol production from the Murchison region, above mentioned results and life cycle assessment (LCA) results by Tahara *et al*. (2009) and Kojima *et al*. (2012) were used. Bio-ethanol production per unit biomass (L Mg^{-1}) was calculated from

Table 1. Summary of results.

Tree species	*Eucalyptus camaldulensis*
Tree density	178 trees ha^{-1}
Afforestation period	30 years
Mean annual increment	4.41 Mg ha^{-1} $year^{-1}$
Ratio of trunk and branches	0.533
Mean annual increment of trunk and branches	2.35 Mg ha^{-1} $year^{-1}$
Research area	2.29×10^5 ha
Afforestation candidate area	2.17×10^5 ha
Plantation area	5.41×10^4 ha
Biomass of natural vegetation from plantation area	9.87×10^4 Mg
Ratio of trunk and branches	0.66
Trunk and branches biomass of natural vegetation	6.47×10^4 Mg
Potential biomass production inside research area	3.91×10^6 Mg
The samge vegetation distribution inside Murchison region	1.97×10^7 ha
Potential biomass production inside Murchison region	3.37×10^8 Mg
Bio-ethanol production (upper)	436 L Mg^{-1}
Bio-ethanol production (lower)	213 L Mg^{-1}
Bio-ethanol production (average)	320 L Mg^{-1}
Felling loss	0.10
Bio-ethanol production potential inside Murchison region	1.07×10^8 m^3

these results. As bio-ethanol production per unit biomass can be very variable due to many conditions, such as fuel conversion methods and utilization methods, average data were used for this study.

This value was multiplied by the potential biomass production for bio-fuel in the Murchison region estimated by the previous procedure, and thereby the potential bio-ethanol production in this region was estimated.

The first, second and third procedures were based on the authors' works of field measurement and analyses, and the fourth and last procedures were simple estimations based on the data from other earlier works.

3. Results and Discussion

All the data from this study are summarized in **Table 1**. The biomass production potential in 30 years from *E. camaldulensis* monoculture plantation was estimated at 132.3 Mg ha^{-1}. This potential biomass production value was lower than the 149 Mg ha^{-1} observed as the maximum biomass value of a *E. camaldulensis* natural forest (Suganuma *et al*., 2006), so this potential value was considered feasible. From this potential biomass, the trunk and branches biomass to be used for bio-fuel production was estimated at 70.5 Mg ha^{-1}.

The afforestation candidate area was estimated at 2.17×10^5 ha, and which was classified as *Acacia* woodland, bare ground and their transition area (Suganuma *et al*., 2010), and 25% of this candidate area was estimated as plantation area (5.41×10^4 ha). This meant that most of the area inside the research area excluding the salt lake and *Eucalyptus* forests can be used for afforestation. In addition, biomass (trunk and branches) from natural vegetation was estimated at 6.47×10^4 Mg. Since afforestation has less offset impact to surrounding environment (Harper *et al*., 2007), 75% of this area was conserved as original land cover, and *E. camaldulensis* was the native species to this research area, this afforestation method (Yamada *et al*., 1999, 2003; Kojima and Egashira, 2011) can reduce the environmental impact to this area to a minimum.

Potential biomass production for bio-fuel from this research area was estimated at 3.91×10^6 Mg, which was quite a large amount.

From the vegetation map created by the National Land and Water Resources Audit (2002), 1.97×10^7 ha of the Murchison region was judged to have the same vegetation as in the research area, and corresponded to 86 times larger area than the afforestation candidate plot in our research area. The potential biomass production for bio-fuel in the Murchison region was estimated at 3.37×10^8 Mg.

From estimated potential biomass of 3.37×10^8 Mg and bio-ethanol conversion from biomass estimated by Tahara *et al*. (2009) and Kojima *et al*. (2012), potential bio-ethanol production from Murchison region was estimated at 1.07×10^8 m^3 in 30 years ($0.71\sim1.46\times10^8$ m^3), which was equivalent to 3.56×10^6 m^3 $year^{-1}$. This potential bio-ethanol production is quite a large value, however, it is not a sufficient production compared to the petroleum consumption amount of Japan and Australia. The Japanese annual petroleum consumption was reported as 5.9×10^7 m^3 (METI, 2011), and the Australian one was estimated at 1/3 of that in Japan (IEA, 2010). Thus, the potential bio-ethanol production in the arid Murchison region corresponds to about 4-5% of the combined Japanese and Australian petroleum consumption.

4. Conclusion and Limitations

From this study, a large potential for biomass and bio-ethanol production was estimated for the arid region of Murchison, Western Australia. Although this potential bio-ethanol production was sufficient for E3 petroleum, this production was not considered sufficient for substantial carbon mitigation of the transportation sectors of Japan and Australia. Improvements in afforestation methods and combinations of carbon mitigation methods are necessary for actual and future carbon mitigation practices.

In addition, future application of large scale arid land afforestation should have some negative impact to the natural environment, such as water quality derived from water balance change, species composition of native vegetation and wildlife, and so on. And biomass could be used for not only bio-ethanol but also power generation and other liquid type fuels. Moreover, there is some uncertainty regarding policy making of Australian government. Thus, further studies in the future are necessary, such as assessing negative impact to the natural environment of arid land afforestation and calculating many carbon mitigation scenarios introducing different bio-energy types.

Note

A)http://www.ffpri.affrc.go.jp/pubs/mori/documents/mori-170.pdf

B) http://www.bom.gov.au/climate/averages/maps.shtml

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