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 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 allometric 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 5.41×10⁸ ha. At the same time, the amount of potential biomass to be obtained from natural vegetation when creating afforestation areas was estimated at 6.47×10⁸ Mg. Third, biomass production potential for bio-fuel by afforestation in arid areas of Murchison region was estimated at 3.37×10⁹ 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 1.07×10² m\(^3\) in 30 years (3.56×10⁶ 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 CO₂ emissions in Australia were derived from power generation, mainly coal fire power plants (Dicks et al., 2004), and the next largest CO₂ emissions (around 20%) were derived from the transportation sector (IEA, 2010). For Japan, CO₂ 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 CO₂ 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 CO₂ 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\(^{4}\), 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)
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 STM/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\(^{-1}\). 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 (Suganuma 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. 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
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 2.17×10⁵ 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 (5.41×10⁴ 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 6.47×10⁴ 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 3.91×10⁶ Mg, which was quite a large amount.

From the vegetation map created by the National Land and Water Resources Audit (2002), 1.97×10⁶ 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 3.37×10⁸ Mg.

From estimated potential biomass of 3.37×10⁸ 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 1.07×10⁸ m³ in 30 years (0.71~1.46×10⁸ m³), which was equivalent to 3.56×10⁶ m³ 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 5.9×10⁷ m³ (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

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Table 1. Summary of results.

<table>
<thead>
<tr>
<th>Tree species</th>
<th>Eucalyptus camaldulensis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree density</td>
<td>178 trees ha⁻¹</td>
</tr>
<tr>
<td>Afforestation period</td>
<td>30 years</td>
</tr>
<tr>
<td>Mean annual increment</td>
<td>4.41 Mg ha⁻¹ year⁻¹</td>
</tr>
<tr>
<td>Ratio of trunk and branches</td>
<td>0.533</td>
</tr>
<tr>
<td>Mean annual increment of trunk and branches</td>
<td>2.35 Mg ha⁻¹ year⁻¹</td>
</tr>
<tr>
<td>Research area</td>
<td>2.29×10⁴ ha</td>
</tr>
<tr>
<td>Afforestation candidate area</td>
<td>2.17×10⁵ ha</td>
</tr>
<tr>
<td>Plantation area</td>
<td>5.41×10⁵ ha</td>
</tr>
<tr>
<td>Biomass of natural vegetation from plantation area</td>
<td>9.87×10⁴ Mg</td>
</tr>
<tr>
<td>Ratio of trunk and branches</td>
<td>0.66</td>
</tr>
<tr>
<td>Trunk and branches biomass of natural vegetation</td>
<td>6.47×10⁵ Mg</td>
</tr>
<tr>
<td>Potential biomass production inside research area</td>
<td>3.91×10⁵ Mg</td>
</tr>
<tr>
<td>The same vegetation distribution inside Murchison region</td>
<td>1.97×10⁵ ha</td>
</tr>
<tr>
<td>Potential biomass production inside Murchison region</td>
<td>3.37×10⁸ Mg</td>
</tr>
<tr>
<td>Bio-ethanol production (upper)</td>
<td>436 L Mg⁻¹</td>
</tr>
<tr>
<td>Bio-ethanol production (lower)</td>
<td>213 L Mg⁻¹</td>
</tr>
<tr>
<td>Bio-ethanol production (average)</td>
<td>320 L Mg⁻¹</td>
</tr>
<tr>
<td>Felling loss</td>
<td>0.10</td>
</tr>
<tr>
<td>Bio-ethanol production potential inside Murchison region</td>
<td>1.07×10⁸ m³</td>
</tr>
</tbody>
</table>

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the natural environment of arid land afforestation and calculating many carbon mitigation scenarios introducing different bio-energy types.

Note

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