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Selection of Afforestation Methods for *Eucalyptus sargentii* as a Countermeasure to Climate Change and Salinity Problem

-A Case Study of Wheat Belt Area in Western Australia-

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Abstract: There exist serious problems such as increase of underground water level and secondary salinity problem in wheat belt in southern Western Australia. So we here propose agro-forestry, which is a remedy of water logging and salinity problems by planting trees in a part of the farmland. Planted trees use surplus underground water by transpiration from the deep soil. At the same time, planted trees capture CO_2 from atmosphere, so we attempt to use this agro-forestry method as a global warming countermeasure.

To investigate agro-forestry effect on water logging and global warming, some afforestation sites were established in the semi-arid region (Wickepin) in Western Australia. We tested three types of field modification technologies, two types of soil modification technologies and three types of tree species. From statistical analysis on survival ratio and tree growth, we selected the suitable combination of modification technology and tree species in various salinity and water logging intensity.

Key Words: Afforestation, Salinity, Semi-arid area, Statistical analysis, Water logging

1. Introduction

In Australia, farmland has been cultivated by cutting large scale of *Eucalyptus* native forest from European immigration. Transpiration water amount of the crop land is lower than that of the native forest, and the crops can't extend their roots deep in the soil compared to the trees, and then all the rainwater was not used by crops. Thus surplus water was supplied into the deeper underground water, and underground water level has gradually risen with long time. In addition, the surplus water dissolved salt naturally contained in the soil and plenty of salt has been gathered into the underground water, which became saline water. In consequence, shallow underground water level brought water logging which also brought soil salinity and salt accumulation on soil surface since saline capillary water reached soil surface and evaporated. This problem has been widely observed in the decades in Australia and agricultural production was gradually declined because of this problem. Part of crop land became desolate area.

So agro-forestry has been carried out as a countermeasure against these problems (Endo *et al*., 1998; Marcar and Crawford, 2004). Furthermore, afforestation also has role of fixing CO_2 and planted trees will be used for producing biomass energy. Then our team established agro-forestry trial area at a farmland of Wickepin in Western Australia and various trials were conducted to develop afforestation technologies (Kojima and Egashira, 2011). In the present study, we will report the experimental results for improving soil environment of root zone to increase survival ratio of seedlings and to accelerate their growth. .

2. Materials and Methods

2.1. Research area

Our agro-forestry trial area at Wickepin locates at 200 km south-east from Perth, the provincial capital of Western Australia. In the trial area, there are several test sites. But in this study, we will report the results of three sites; E-site（S 32°43'58", E 117°40'48.1", elevation 330 m), J-site (S 32°43'14.1", E 117°40'23.4" , elevation 310 m) and K-site (S 32° 43' 14.2", E 117° 40'1.2" , elevation 300 m). E-site has drought stress but can be still used for wheat cultivation. J-site has strong secondary salinity problems becouse of its location (next to a salt lake) and can not be used for wheat cultivation. This J-site consists of sub-sites named J-high (JH) and J-low (JL) according to their difference in altitude. K-site has strong water-logging stress with a little secondary salinity problem because of its location near a water channel and can not be used wheat cultivation. This site also consists of three sub-sites named K-high (KH), K-middle (KM) and K-low (KL).

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2.2. Plantation methods of seedlings

We tested eight types of plantation methods in all sites. First method was no modification. This was just planting seedlings on original soil directly and it was assumed control method. It was called "Control". Second method was that soil surface layer was scratched like ditch with about 60 cm depth by heavy equipment and seedlings are planted along the ditch. This method also adopted mounding. Both treatments may improve root growth and air permeability (Marcar and Crawford, 2004). This method was called "Ripping". Third method was that vertical holes with 1 m depth and 10 cm diameter were drilled up by boring machine, and original soil was put back, and then tree seedlings were planted in the hole. This method also adopted mounding and this method may avoid water-logging. This method was called "Hole's original". Fourth and fifth methods were similarly Hole's original but used two additional soils. Additional soils were Kanuma-soil and potting mix. Kanuma-soil was commonly used soil for gardening in Japan and improved water retention characteristics and water permeability. Potting mix was leaf mold used for gardening in Australia. These methods were called Hole's Kanuma and Hole's potting mix, respectively. Sixth method was that PVC (poly-vinyl chloride) pipe with 9 cm diameter and 1.2 m length was inserted in the same hole of "Hole method" drilled by boring machine, and original soil was put back inside the pipe. This method was called "Pipe's original". Seventh and eighth methods were called "Pipe's Kanuma" and "Pipe's potting mix" that were used the same pipes of "Pipe's original" but used the same above mentioned additional soils instead of original soil.

We planted three species of seedlings with above eight methods respectively. Seedlings are *Eucalyptus camaldulensis*, *E. salubris* and *E. sargentii*. In this study we focused *E. sargentii* which grows around naturally in Western Australia and has salt tolerance and has a characteristic of expanding roots sideways.

2.3. Tree height measurement and biomass estimation

First we have conducted measurements of tree height of planted seedlings twice a year since September 2006. And we also recorded survival ratio. Some died samples at early stage were replaced by new seedlings but were excluded from our analysis.

Second we cut down some samples in September 2010 and made an allometric equation. The allometric equation was used for dry-biomass weight (Y) estimation from tree height (X). And we conducted regression analysis by a power function as $Y = bX^a$. Using this estimated biomass data and planting density, we also calculated biomass density in Mg ha^{-1} unit.

2.4. Statistical analysis of tree growth

We conducted statistical analysis called multiple comparison ($\alpha = 0.05$, Bonferroni) of average tree height and survival ratio to the data of September 2010. Statistical order with significant difference is given as $a < b < c$. Then we made scatter plots giving survival ratios for Y-axis and average tree height or average biomass for X-axis, reflecting the results of statistical analysis. From this result, we determined which plantation method is suitable for in each site.

3. Results and Discussion

Figure 1 shows a scatter plot and statistical analysis results for KH-site with average tree height on the X-axis and survival ratio on the Y-axis. Continued four plots represent annual data from the first to fourth year. The biggest plots indicate the data of the fourth (last) year. In this figure, statistical analysis was applied to the data of fourth year. Longitudinal dotted lines represent significant difference in tree height and lateral dotted lines represent significant difference in survival ratio. The digits next to the fourth year plots represent the survival numbers of planted trees.

In KH-site, Ripping and Pipe's potting mix gave the best results for survival ratios, while all data of growth were statistically indistinguishable except Pipe's Kanuma and Pipe's original. Thus from survival ratio significance, Ripping was judged as the best planting method for KH-site

On the other hand, in **Figure 2** with biomass on the X-axis instead of tree height, Hole's original shows statistically significant high value of biomass. From survival ratio evaluation, Ripping and Pipe's potting mix were better than Control, and from growth analysis evaluation, Hole's original was better than Control. Then we compared these results by using biomass density in Mg ha^{-1}. According to this analysis, Ripping, Hole's original and Control gave 9.0, 8.2 and 7.5 Mg ha^{-1}, respectively. So planting *Eucalyptus sargentii* in areas which have water-logging problem like KH-site, Ripping was revealed the best planting method.

Similarly, results of KL-site are shown in **Figures 3** and **4**. In KL-site, Ripping was the best planting method of all the evaluation indices which were survival ratio, average tree height, biomass and biomass density.

The results for the *E. sargentii* planted in the other sites are also summarized as follows using similar methodology.

In KM-site, there was no significant difference of survival ratio and growth, statistically.

In E-site, comparatively high survival ratio was found. Among the various methods, Ripping and Hole's potting mix were revealed the best planting method.

In JH-site, there was no significant difference in survival ratio and growth.

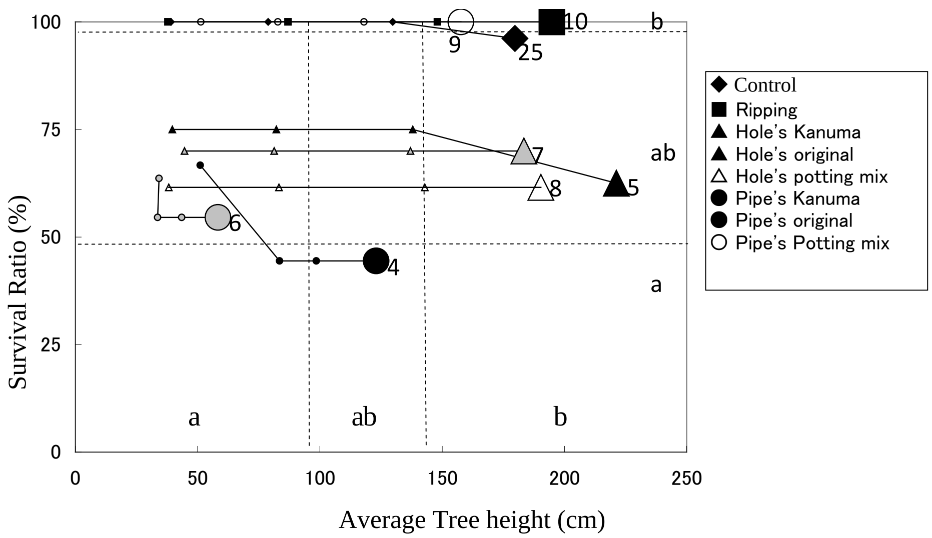

Fig. 1. Tree height and survival ratio of planted trees on KH-site.

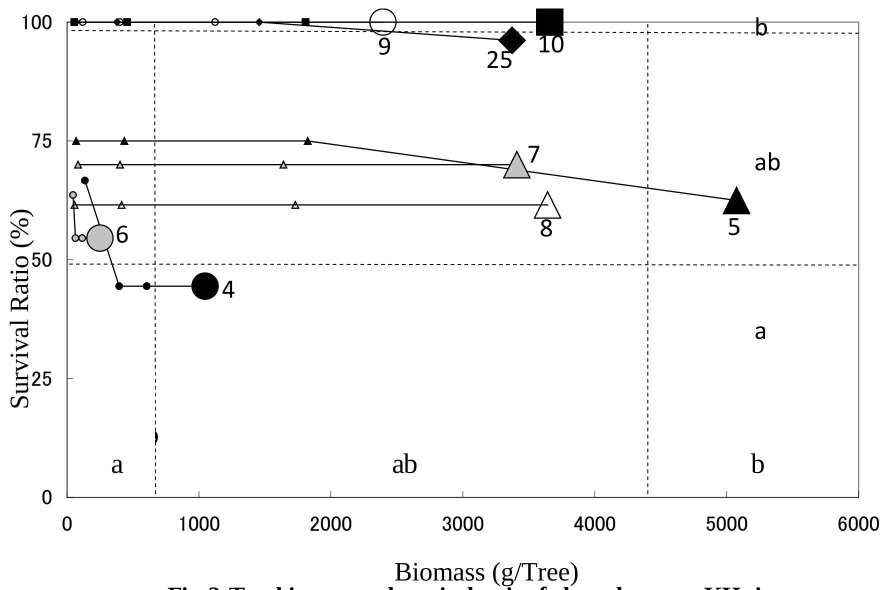

Fig. 2. Tree biomass and survival ratio of planted trees on KH-site.

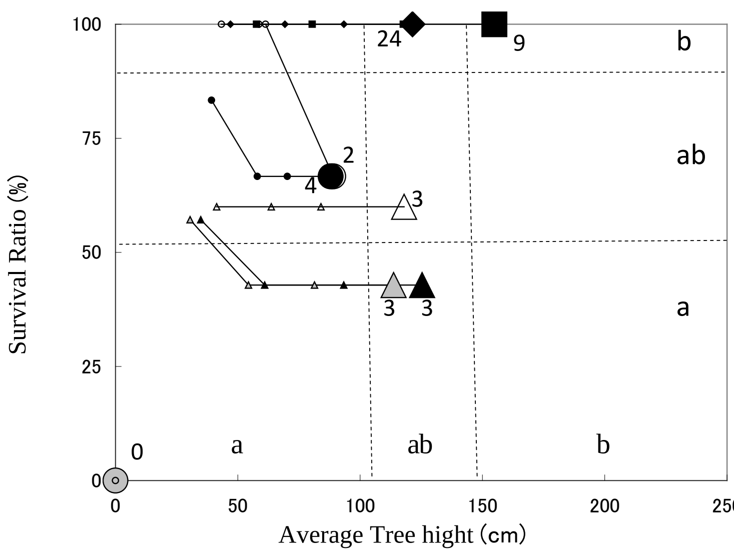

Fig. 3. Tree height and survival ratio of planted trees on KL-site.

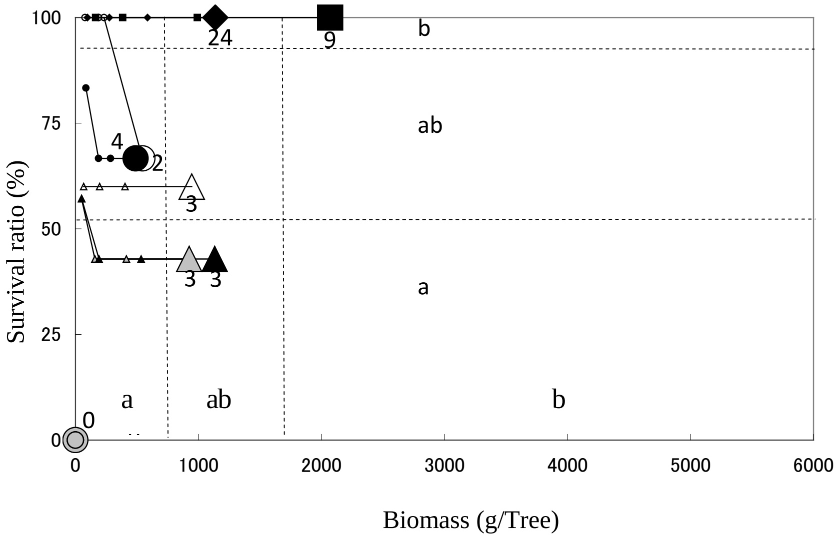

Fig. 4. Tree biomass and survival ratio of planted trees on KL-site.

Table 1. Estimated total biomass density for all methods of all sites.

Site name	Biomass (Mg ha^{-1})
E	2.22
JH	0.49
JL	0.61
KH	2.89
KM	1.53
KL	1.02

In JL-site, significant difference in growth was found and Pipe's potting mix was the best planting method while all methods gave indistinguishable results of survival ratio.

From these results,when the farmland which can be used for wheat cultivation, such as E-site, was used for afforestation sites, Ripping or Hole's potting mix was considered to give better results compared to Control. When the land with salinity problems, such as J-site, was used for afforestation sites, Pipe's potting mix was considered to give better results compared to Control. When the land with water-logging, such as K-site, was used for afforestation sites, Ripping was considered to give better results compared to Control.

Finally the estimated results of total biomass density of all sites are shown on **Table 1**. According to Table 1, the yield of KH-site was found remarkably high. It was considered that there was almost no stress for *E. sargentii* in KH-site because KH-site which located the higher elevation had less water-logging effects than the other K-sites. In addition, *E. sargentii* has the characteristic of expanding its roots horizontally. Considering the difference in biomass amount among the various methods in various sites, by selecting the most suitable methods according to the characteristics of each site, higher yield was expected in water-logging site for afforestation using *E. sargentii*.

4. Conclusion

When the farmland which can be used for wheat cultivation, such as E-site, was used for afforestation sites, Ripping or Hole's potting mix was considered to give better results compared to Control. When the land with salinity problems, such as J-site, was used for afforestation sites, Pipe's potting mix was considered to give better results compared to Control. And When the land with water-logging, such as K-site, was used for afforestation sites, Ripping was considered to give better results compared to Control.

Considering the difference in biomass amount among the various methods in various sites, by selecting the most suitable methods according to the characteristics of each site, higher yield was expected in water-logging site for afforestation using *E. sargentii*.

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