沙漠研究 **24**-1, 25-28 (2014)
Journal of Arid Land Studies

Tree Growth Analysis in Saline Affected Farmland in Western Australia

- Tree Species and Planting Method Selection for Agro-Forestry -

Kenyu KONDO[1)], Hideki SUGANUMA[1)], Shin-ichi AIKAWA[2)], Hajime UTSUGI[2)], Hiroyuki HAMANO[3)] and Toshinori KOJIMA*[1), 4)]

Abstract: Salinity problems caused by shallow underground water level (secondary salinity) widely occurs in the wheat belt area of Western Australia. As a countermeasure to this type of salinity problem, agro-forestry was proposed and carried out. By planting salinity tolerant trees in saline areas, underground water is used by planted trees, and then underground water level will gradually decline. In consequence, the secondary saline areas are expected to be prevented from their expansion by applying agro-forestry methods. This approach will not only mitigate the salinity problem through agro-forestry, but will simultaneously fix carbon as tree biomass by planted trees reducing carbon dioxide in the atmosphere. Then, this approach is considered as an effective countermeasure to climate change due to carbon dioxide increment. To fulfill both aims, planted trees should have high salinity tolerance, i.e. they should grow fast with high survival ratio in saline areas. We calculated pseudo site biomass [t ha^{-1}] by tree biomass and survival ratio of planted trees, and tested which tree species together with planting methods are appropriate for this type of agro-forestry.

Key Words: Agro-forestry, Groundwater, Salinization

1. Introduction

In Western Australia, salinity problems have been widespread because of extensive deforestation for agricultural land development, which has caused a gradual increase of underground water level over the years (Short and McConnell, 2000). As a result, high saline underground water level rose gradually. When underground water levels rose near soil surface, salinity problems occurred by salt accumulation (Cox and McFarlane, 1995). Such saline land was discarded and deforestation for land development was further accelerated. To stop this negative spiral, agro-forestry, which is coexistence of agriculture and forestry, should be carried out (Endo *et al*., 1988). By doing so, transpiration will be increased, and evaporation from soil surface will be decreased. Subsequently, underground water levels will decline and secondary salinity problems will be mitigated (Bell, 1995; Lefory and Stirzaker, 1999). In this study, we evaluated the survival ratio and tree growth of three tree species together with 8 planting methods in 6 experimental plots, and searched for efficient combination of species, method and place.

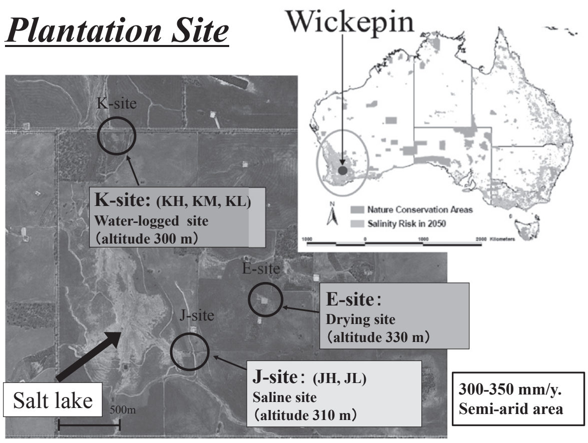

Fig. 1. Wickepin (Annual precipitation; 300-350mm: E117˚40', 32˚46'S).

2. Materials and Methods

2.1. Research area

Our research site is located in Wickepin (117˚40'E; 32˚46'S), about 250 km south-east from Perth, the provincial capital of Western Australia. This area is categorized as semi-arid area. Inside this farmland, three types of afforestation experimental sites named E-site, J-site and K-site were established (**Fig. 1**).

E-site (117˚40'48.1"E, 32˚43'58.0"S, altitude 330 m) is located on a hill and has deep groundwater level, so this site was set as a control site. This area can be still used for agriculture. J-site (117˚40'23.4"E, 32˚43'14.1"S, altitude 310

* Corresponding Author: kojima@st.seikei.ac.jp, kojimaseikei@gmail.com
3-3-1, Kichijoji-Kitamachi, Musashino, Tokyo, 180-8633, Japan
1) Department of Materials and Life Science, Seikei University
2) Forestry and Forest Product Research Institute
3) Japan Science and Technology Agency
4) Centre for Ecosystem Management, School of Natural Sciences, Edith Cowan University, Australia

(Received, September 14th, 2013; Accepted, December 27th, 2013)

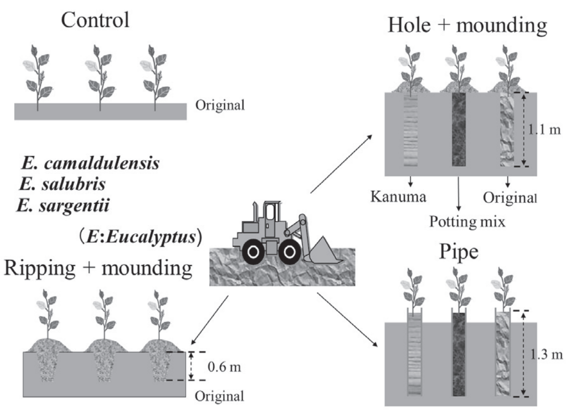

Fig. 2. Planting methods in Wickepin.

m) is located near the salt lake and has shallow ground water level and is affected by salinity problem. K-site (117°40'1.2"E, 32°43'14.2"S, altitude 300 m) is located near a wadi and has very shallow ground water. This site is frequently affected by water-logging. J-site and K-site cannot be used for agriculture.

In addition, depending on altitude differences within J-site and K-site, sub-sites named JH-site and JL-site in J-site and KH-site, KM-site and KL-site in K-site were set, since lower altitude areas are most affected by larger environmental stress (salinity and water-logged).

2.2. Planting methods

We conducted test plantation methods in E-site, J-site and K-site in Sept. 2006 as shown on **Figure 2**. Seedlings of three tree species (*Eucalyptus camaldulensis*, *E. sargentii* and *E. salubris*) were planted with 8 types of planting method inside each site. Adopted 8 types of planting methods were as follows; control, ripping, hole with original soil, hole with kanuma soil, hole with potting mix soil, pipe with original soil, pipe with kanuma soil and pipe with potting mix soil. Control method means just planting trees directly to the land and was considered as the reference planting method. Ripping and hole methods were adopted to improve soil conditions (Barrett-Lennard, 2003). Pipe method was adopted to improve soil condition and also to prevent roots area of tree seedlings from intruding saline water. The tree density of E-site, J-site and K-site were 2858 trees ha^{-1}, 2766 trees ha^{-1} and 3124 trees ha^{-1}, respectively.

2.3. Analysis procedure

Inside each afforestation site, height and survived individual numbers of all tree species were measured every year from 2006. The measurement data of 18 patterns (3 tree species × 6 sites, E, JH, JL, KH, KM and KL-site) were used for following analyses. We analyzed the data of surviving samples in 2012. First, survival ratio and averaged tree biomass [kg tree^{-1}] of survived trees for each planting method were calculated in 18 patterns, and used for latter described statistical analyses. We also calculated pseudo site biomass using the equation (1).

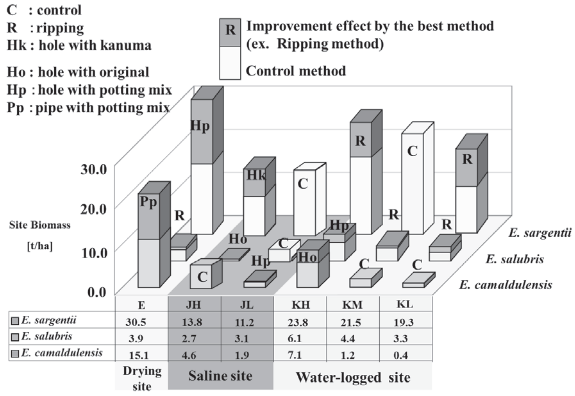

Fig. 3. Summary of pseudo site biomass (6th year).

$$B_{pse} = B_{ave} \times Sr \times D \times 1/1000 \quad (1)$$

; where B_{pse} is pseudo site biomass [t ha^{-1}]; B_{ave} is average biomass [kg tree^{-1}]; Sr is survival ratio [-]; D is tree density [tree ha^{-1}]; 1/1000 is conversion factor from kg to metric ton. After the pseudo site biomass calculation, we evaluated which tree species combined with planting method were appropriate for agro-forestry in this area.

2.4. Statistical analyses

In this research, all planting methods were also ranked by multiple comparisons method (Bonferroni method) according to their survival ratio, where the significant level (α) was set as 0.05. The software used for statistical analysis was Excel statistics Ver. 6.0 (Esumi Co. Ltd.). Tree samples less than three surviving individuals were excluded from statistical analysis and expressed as "x" in the result. From this statistical analysis, averaged tree biomass and survival ratio were ranked based on alphabetical order (a<b<c), *i.e.* b is better than a.

3. Results and Discussion

3.1. Summary of pseudo site biomass

Figure 3 summarizes all the best methods in each site for each tree species. X axis indicates each site, and Y axis indicates tree species and Z axis indicates the calculated pseudo site biomass. In bar chart, faint color shows the pseudo site biomass by the control method and deep color shows pseudo site biomass by the best method in each condition. This figure was created to see the difference in growth between the best method and control, clearly. In this figure, *E. camaldulensis* had good growth performance in normal land condition such as E-site, but had bad growth

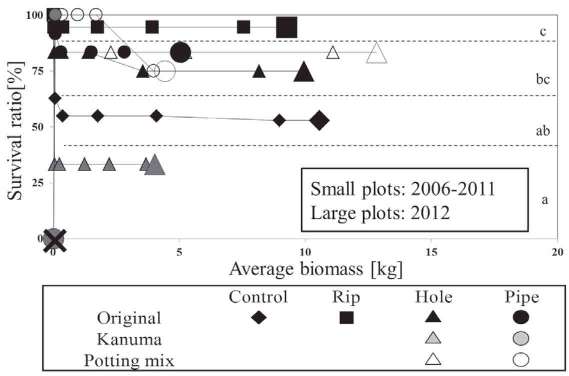

Fig. 4. Average biomass and survival ratio of each plantation method of E-site, *E. sargentii*.

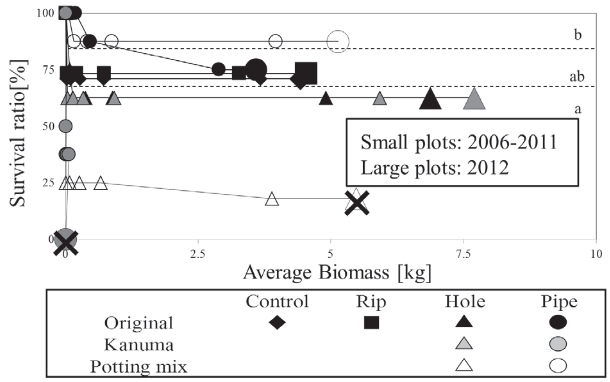

Fig. 6. Average biomass and survival ratio of each plantation method of JH-site, *E. sargentii*.

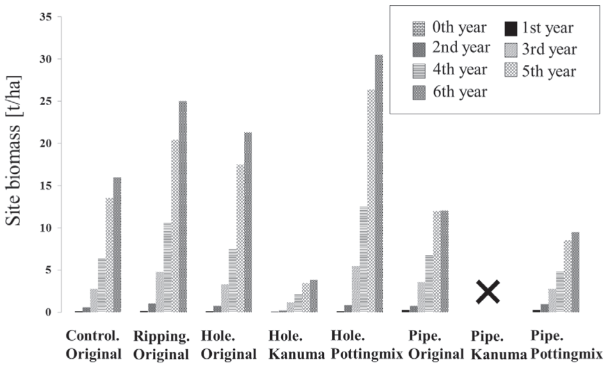

Fig. 5. Pseudo site biomass of E-site, *E. sargentii*.

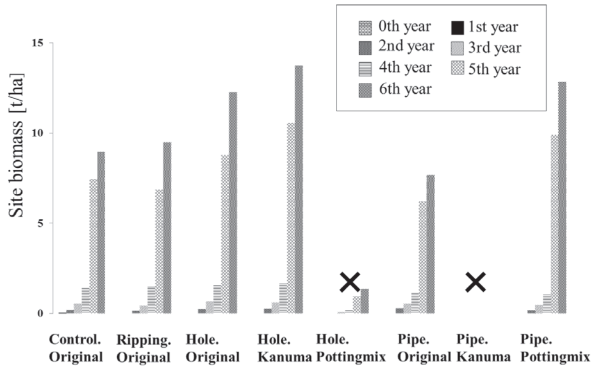

Fig. 7. Pseudo site biomass of JH-site, *E. sargentii*.

performance in harsh environmental condition such as J-site and K-site. And *E. salubris* had bad growth performance in all sites, thus this tree species was considered not suitable for agro-forestry. And *E. sargentii* was considered obviously the best tree species in all the environmental condition because it had good growth performance compared with other tree species.

3.2. Result of tree growth and site biomass

Since *E. sargentii* was revealed as the most appropriate tree species for agro-forestry in this research area, detailed investigated results were shown as follows. **Figure 4** shows the result of the averaged biomass and the survival ratio of *E. sargentii* in E-site. X axis indicates averaged tree biomass [kg] and Y axis indicates survival ratio [%]. Dotted lines indicate the significant rank boundaries of survival ratio according to the statistical analysis (multiple comparisons method, Population rate, Bonferroni). Smaller plots indicate first to fifth year's data and the bigger plots indicates 6th year's one. Plots locate in the upper right side indicate better planting method. From this figure, we could not clearly know which method was greater than control method, thus pseudo biomass calculation results were used for evaluation.

Figure 5 shows the result of pseudo site biomass of each planting method of *E. sargentii* in E-site. X axis indicates planting method and Y axis indicates pseudo site biomass. Columns indicate first to sixth year's data from left to right, respectively. In both figures, data of each method calculated from less than three surviving individuals are marked by cross.

In E-site, hole method with potting mix soil was considered as the most suitable method, especially in biomass growth, though statistical difference of average tree biomass was not observed between this method and control method. And ripping method was considered to second suitable method, especially for improving survival ratio.

The same analyses results of JH-site are shown in **Figures 6** and **7**. Pseudo site biomass was much smaller than that of E-site. However, pipe method with potting mix soil improved survival ratio significantly compared to the control method. And hole method with kanuma and original soil were considered to improve growth of *E. sargentii*, though this was not statistically proven.

The same analyses results of KH-site are shown in **Figures 8** and **9**. Ripping method was considered as the most suitable planting method in terms of survival ratio improvement, but not so much biomass difference was observed among planting methods excluding pipe with original and kanuma soil. Though *E. sargentii* was reported to have high salinity tolerance and high water-logging tolerance (Marcar and Crawford, 2004), this tree species showed poor growth in saline area. But in water-logging area, *E. sargentii* showed good tree growth. The pseudo site biomass of KH-site was 75% of that of E-site. Thus, *E. sargentii* was considered as

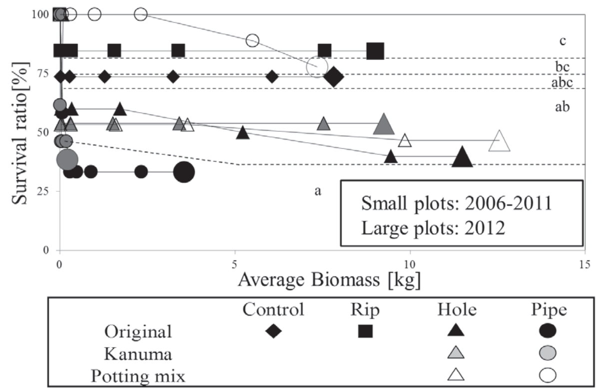

Fig. 8. Average biomass and survival ratio of each plantation method of KH-site, *E. sargentii*.

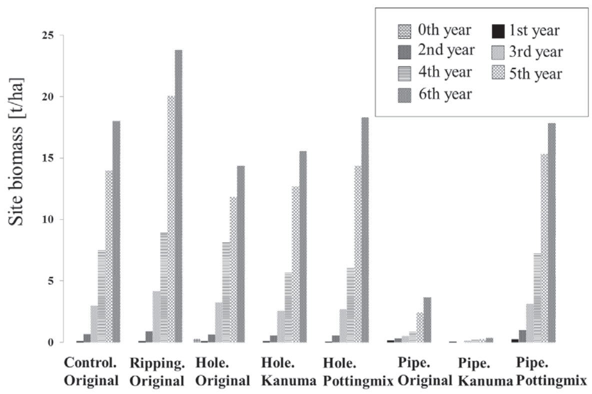

Fig. 9. Pseudo site biomass of KH-site, *E. sargentii.*

appropriate for planting normal land and water-logging land.

The result of the averaged biomass and the survival ratio of *E. salubris* and *E. camaldulensis* were much lower than that of *E. sargenti*. *E. camaldulensis* has high drought tolerance and grows rapidly and widely observed in Australian continent (Marcar and Crawford, 2004), but had bad growth performance in high water-logged area such as KM and KL sites. *E. salubris* is native species of Wickepin, however, it had bad growth performance in this research.

Only a few tree species survived in high saline area and water-logged area such as JL-site and KL-site. So these sites could not be used for agro-forestry. But slightly water-logged area such as KH-site was considered to be used for agro-forestry with *E. sargentii* trees. From our study, E-site was considered as the best site of tree growth because it had good growth performance compared with other sites. But as indicated by Flugge and Abadi (2006), applying agro-forestry to agricultural land introduces large proportion of opportunity loss, and then not so much area can be used for afforestation.

4. Conclusion

From this study in Wickepin, the most suitable tree species for agro-forestry was considered as *E. sargentii*. This tree species showed high survival ratio and fast tree growth in arable area (E-site) and water-logging areas (KH-site, KM-site and KL-site). Efficient planting methods for *E. sargentii* were considered as ripping and hole with potting mix, but even control method showed relatively high survival ratio and fast tree growth of *E. sargentii*. Other combinations of planting methods and tree species showed low survival ratio and slow tree growth, thus they were not appropriate for agro-forestry. In addition, no method showed good performance in saline area (JH-site and JL-site), thus such areas should not be used for agro-forestry.

In future studies, cost of each planting method and opportunity cost of agro-forestry should be compared, and then appropriate agro-forestry methods should be investigated. Because using arable area for agro-forestry increases opportunity cost to the land owners and/or farmers, using other than control method increases initial cost of agro-forestry. Thus, the data of survival ratio and growth rate are insufficient for actual decision making of agro-forestry.

Acknowledgements

This work was supported by grants from the Mitsui & Co., Ltd. Environment Fund and from the Global Environment Research Fund of The Ministry of the Environment (GHG-SSCP Project).

References

Barrett-Lennard E.G. (2003): *Land, Water and Wool Sustainable Grazing on Saline Lands Sub-program, Saltland Pastures in Australia: A Practical Guide Second Edition*. p.125.

Bell D.T. (1999): Australian trees for the rehabilitation of waterlogged and salinity-damaged landscapes. *Australian Journal of Botany*, **47**(5): 697-716.

Cox J.W., McFarlane D.J. (1995): The causes of water logging in shallow soils and there drainage in southwestern Australia. *Journal of Hydrology*, **167**: 175-194.

Endo I., Abe Y., Kojima T. (1988): *Desert engineering*. Morikita Publishing, p.182-187.

Flugge F., Abadi A. (2006): Farming carbon: an economic analysis of agroforestry for carbon sequestration and dryland salinity reduction in Western Australia. *Agroforestry Systems*, **68**: 181-192.

Lefory E.C., Stirzaker R.J. (1999): Agroforestry for water management in the cropping zone of Southern Australia. *Agroforestry Systems*, **45**: 277-302.

Marcar N.E., Crawford D.F. (2004): *Trees for saline landscapes*. RIRDC, Canberra, Australia, pp.246.

Short R., McConnell C. (2000): *Extent and Impacts of Dryland salinity -Project 1A-DAW29-*. National Land and Water Resources Audit.