1. Development and evaluation of GHG absorption and fixation technology in forest ecosystems.（Abstract of the Final Report）

1a. Study of technological development for carbon fixation increase by systematic afforestation of arid lands.

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I. Overview

Feature of this study was the active use of extensive arid and semi-arid land, where agricultural use for food production was quite difficult, as carbon sink. This study consisted of 4 categories which were effective use of water, plant ecology and physiology monitoring, carbon detection and modeling for construction of platform. Each categorized study was closely cooperated aiming for carbon sequestration efficiency maximization.

Consequently, following issues were achieved. Water balance was understood and modeled in arid and semi-arid research areas. *Eucalyptus camaldulensis*, especially Silverton ecotype, was revealed optimum and promising tree species for afforestation by ecological and physiological results. Five carbon pools (above-ground biomass, below-ground biomass, litter, dead wood, soil) accounted as carbon sink in arid area were grasped and modeled. Thus, potential carbon amount was estimated. All the achievements was gathered as afforestation simulation platform, which could be generalized in other arid and semi-arid area, and then carbon sequestration potential in Western Australia or in global scale.

This study results can became great Japanese initiative in technological development when this study results were applied as global environmental policies.

II. Scientific outcome

- We investigated water balance in middle and large scale catchment area, and we evaluated runoff ratio in middle and large scale catchment area of Sturt Meadows, WA.
- We developed an original runoff model in middle scale catchment area and determined parameters of runoff in arid land.
- We developed litter and soil carbon dynamics model incorporating the physical removal of litter.

- Informative data about the mobility of leaf and woody litter for modeling of litter removal was obtained.
- Even in arid area, woody species can survive long time when acquiring root system for absorbing enough amount of water.
- hardpan blasting, initial irrigation and hardening is quite effective to improve tree growth and survival ratio
- Three tree species (*E. camaldulensis, C. cuninghamiana, C. obesa*) was revealed promising to arid land afforestation.
- Germination treatment for seeds of *Acacia* species which inherit arid area was revealed that one minute boiling was very effective
- Irrigation from under ground was accelerate tree growth since Acacia species' root system grew fast.
- The photosynthesis of *E. camaldulensis* has higher light-demanding properties among the tree species.
- The soil water potential of -1.5Mpa or more is necessary for the growth of *E. camaldulensis*.
- The better density for planting of *E. camaldulensis* is 200 trees ha^{-1} (Leaf area index <1) in arid or semi-arid regions (precipitation is 500 mm y^{-1} or less).
- *E. camaldulensis* can survive at the agricultural area with 46 mS m^{-1} of salinity in the soil.
- Woody vegetation growth of afforestation sites and of natural vegetation sites were revealed in an arid land of Western Australia
- Simple estimation equation of baseline net GHG removals by sinks was obtained, whilst their estimation has many difficulties.
- Afforestation applicable area and accountable carbon sequestration amount were calculated with numerical basis in an arid area of Western Australia
- We constructed the framework for evaluating the carbon dynamics in the whole research area which have litter removal phenomena and salt lake.
- A design guide about effective way of water retention material input for plant growth promoting was obtained.
- A simulator for predicting tree growth in arid and semi-arid lands was developed. In this simulator, simulations of surface water run-off, soil water movement, and soil moisture affected photosynthesis are performed together. The total carbon gain of the tree is calculated from the balance of photosynthesis, respiration, and litter fall, and it is distributed to each organs of tree so that the allometric relationship to be satisfied. This simulator can be applied to the open forest getting water from occasional flood.
- By incorporating simulations of tree growth, debris decomposition, and soil carbon decomposition into a carbon accounting system, estimation of total carbon storage has been achieved.
- A rough design of practical afforestation project was performed, then, total cost and CO_2 production of the project were estimated, by summing up them for all tasks within the project. Based on these values and estimated total stored carbon, efficiency and cost of carbon fixation

were estimated.

- As a tool for platform construction, a software framework for supporting the development of simulator, execution of simulator and cooperation of simulators was developed. With in this framework, data input and output of the simulators are standardized, by preparing a definition file for each simulator, which containing information such as variable name, default value, explanations. Additionally, standardized data input/output mechanism of this framework is utilized for data transfer between simulators to support their cooperation.

III. Contribution to policy of global environmental issues for decision makers

- We developed runoff model in middle scale catchment area and basic of that in large scale. Those can be applied for selection of afforestation site and effective use from runoff water.
- If removal process of litter and its effect on carbon dynamics are clarified, we can enhance carbon fixation in arid land afforestation, and also can improve top soil layer in arid land, by applying the technique for prevention of litter removal.
- Since afforestation method by native species in arid and semi arid area was improved, afforestation which was aimed for carbon sequestration regarding emission trading got to be feasible with scientific basis.
- Eco-Physiological properties were clarified for the tree species suitable for carbon sequestration in arid regions. Based on the scientific information, we developed the plantation techniques and estimated the applicable area for plantation of the species in degraded area of the earth.
- When Joint Implementation afforestation will be carried out in near future, promising accountable carbon amount was estimated.
- We provided a guideline for analyzing carbon dynamics in arid land ecosystem where rain water is accumulated to and evaporated from salt lake and does not flow out of the closed area.
- We provided effective method for enhancing plant growth by using water retention material.
- Estimation of cost, efficiency and capacity of carbon fixation by arid land and semi-arid land afforestation technologies were performed. In both case, efficiency of carbon fixation is larger than unity, in other words, the amount of carbon dioxide fixed by the afforestation is larger than that emitted from the afforestation operations, and such afforestation project will actually reducing the atmospheric carbon dioxide.
- Estimated cost, efficiency and capacity of carbon fixation by arid land and semi-arid land afforestation technologies were used as a basis for comparative evaluation studies that performed in sub theme 4, together with similar estimated results of other sub theme groups.

1. Introduction

Large-scale afforestation is known as a promising measure for CO_2 sequestration; however, a land suitable for tree plantation is usually also suitable for other land use, such as agricultural food production. Considering this conflict and land use priorities, it is required to develop and to establish the afforestation techniques of arid land, where the present agricultural productivity is originally low by small precipitation or extremely reduced by salt accumulation. This research

aims to develop systems for effective use of the limited water without salt accumulation problem (sub theme-1), combined with selection of species and plantation way suitable to carbon fixation (sub theme-2). Simulation techniques will also be integrated to construct a support system for large-scale afforestation (sub theme-3). The sub theme-1 will also manage the application of the present technologies and systems developed to the actual sites with these issues as follows.

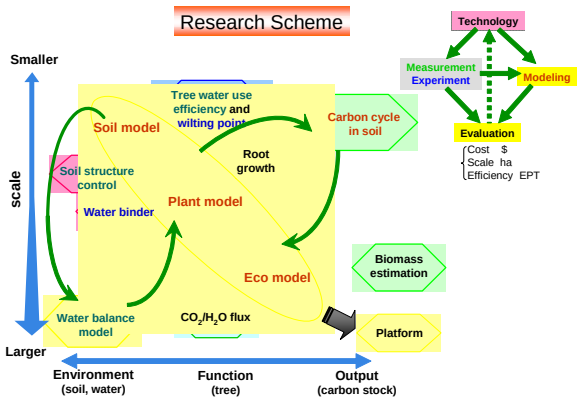

Fig. 1 Research scheme of 1a group

Fig. 1 shows the research scheme of the sub theme-1.The abscissa axis means technical root (environment – function – output as carbon fixation), and the vertical axis shows spatial scale (tree – ecosystem – global scale) of our study. We aim the individual success in their each study area and focus research goal as development of platform of carbon fixation.

2. Research Objective

- Observation of hydrological data in middle (20 km^2) and large scale (12,000 km^2) at Sturt Meadows (mean rainfall: 211mm/yr), WA.
- Development of original runoff model for selection of the best afforestation place and effective use from runoff water in middle scale catchment area.
- Our principal objective in this section were to develop pipe applying afforestation methods for saline land that control the growth of root system.
- Secondly, we identified suitable species for the afforestation method.
- To choose tree species suitable for planting on arid area and semiarid area, which have drought resistance, salt tolerance and property of fast growth.
- To improve and establish afforestation system on arid area and semiarid area, by investigating and removing the factors which prevent the growth of trees.
- To establish nursery technology on *Acacia* species which widely grow on Western Australia
- *E. camaldulensis* is shown to be effective for plantation in arid regions. In this section, we research the single leaf photosynthetic properties of *E. camaldulensis*, and show the index of the soil moisture conditions in which the species can be planted, and we clarify the suitable tree density for planting from the model analysis. The afforestation possibility for *E.camaldulensis* is considered in the agricultural area along the shore which damage from saline discharge.
- Sequestrated carbon amount by afforestation must be accounted according to UNFCCC guideline. Thus, we aimed developing a method estimating carbon amount change of tree above-ground and below-ground biomass.
- Estimations of afforestation applicable area and of carbon amount accounting by afforestation were set as objectives in this research area, and in the arid region around this research area.
- Developed of middle scale model for accurate speculation of the parameters in the large scale

model.

- To clarify litter and soil carbon dynamics in the research area
- To investigate effective way of water retention material input for plant growth promoting
- As a part of platform, an integrated simulator of forest tree growth was implemented. To express arid and semi-arid conditions, this simulator is using photosynthesis model, which considering the effect of water stress, and its final goal is to predict tree growth. The results were compared with observed data from afforestation experiments.
- To make comparative evaluation of arid land and semi-arid land afforestation technologies with other technologies, estimated cost, efficiency and capacity of carbon fixation were estimated.
- As a tool for platform construction, a software framework for supporting the development of simulator, execution from web interface and cooperation of simulators was developed. Within this framework, input and output of the simulators are standardized and this mechanism is utilized for data transfer between simulators to support their cooperation. Additionally, a mechanism for automatic check of equations in the model of simulator after each calculation was prepared.

3. Research Method and Results

(1) Development of systems for effective use of the limited water without salt accumulation problem

1) Investigation and control of water balance, construction of water and salt cycle model in middle / large-scale catchment model in an arid land

- We observed hydrological properties of Sturt Meadows (WA, Australia) with gauges of rainfall, soil water content, flow rate to pond (Jims pool) and salt lake, water level of the pond and salt lake in middle and large scale catchment area. There was correlationship between amount of rainfall and runoff in the middle catchment area. Runoff ratio in large-scale catchment area to rainfall in November 2003 was evaluated 1.11%.
- We constructed a original runoff model of middle catchment area (20 km^2) for estimate effective use to afforestation trees from runoff water. We developed the model and determined parameter. We run the model in some conditions of mesh size of the model and determined optimum mesh size. Those results will be used for optimization of the model and employment for hydrological model of large scale catchment area.
- Water and salt movement in Sturt Meadows was analyzed by modified runoff model. There was correlation between calculated water age and measured salt concentration of soil at some investigated sites. Creek water was estimated significant ratio in runoff water by the model, and creek water was determined as the better harvesting water than surface water for afforestation site because that salt concentration in the creek water was evaluated low in the model.

2) Analyzing and modeling of soil environment

a. Litter and soil carbon dynamics in arid land

- Knowing litter and soil carbon dynamics is one of the key factors for evaluating carbon dynamics in forest ecosystems. In order to clarify the litter and soil carbon dynamics in the

research area, we analyzed the litter and soil carbon flows at study sites by using a model, and experimentally investigated the physical removal of litter by floods and winds from the forest floor, and then the fate of removed litter.

- It was estimated that a significant amount of litter, ranging 59 to 75% of input litter, was removed from the sites physically, that is, by flooding of water, winds, and other mechanism.
- In-depth information regarding litter removal on the forest floor in the study site was obtained from this research .
- We constructed a framework for analyzing carbon dynamics in the whole research area, incorporating the effect of physical litter removal.

b. Controlling the water movement by using water retention materials.

- In arid land afforestation, the engineering challenges lie in how we can enhance the water use efficiency to make good use of scarce precipitation. We investigated the effect of different placement of porous water retention material on the drying rate and retention capacity of water in soil column experiment.
- The quasi-steady state water content, which corresponds to the enhanced amount of water retention, were higher in the soil columns with porous media placed in as a layer than those with porous media placed evenly throughout the column.
- We also found that the reduction in drying rate of soil are different by depth of placement of the porous media layer.

3) Countermeasure technology and development of afforestation against salinity crisis in semi-arid land

a. Afforestation with control pipe and selection of afforestation tree species

- To develop the pipe applying afforestation methods, we cultivated some tree species with various size of pipe that control the growth of root system.
- *E.camaldulensis* showed a highest growth rate among the deep-rooted species and showed high plasticity in biomass allocation to pipe applying methods.
- *Pinus radiata* showed a lower growth rate and sensitivity to a narrowness of their underground space than those of *E. camaldulensis*.

b. Investigation of water balance in middle catchment area in a semi-arid land

- Water balance were calculated by setting flow meter with watershed boundary set from digital elevation model. Water supply by rainfall was measured in Wickepin Station (32.53˚S, 117.46˚E). Transpiration by afforestation trees (4 species) were estimated by tree census and by tree sap flow calculated from TDP (Thermal Dissipation Probe) data (Archebald et al., 2006).
- From water balance investigation, relationship between cumulative surface run-off water and cumulative rainfall was grasped. Therefore, afforestation available water and afforestation spreadable area were got to become estimated.
- From tree census data and tree sap flow, the tree difference of potential transpiration amount were grasped. From above mentioned data, available water and effective plant species for afforestation against salinity problem were revealed.

(2) Study on technological development of environmental adjustable afforestation and soil control techniques for systematic afforestation in arid area.

1) Proposing tree species selection method and afforestation method based on environmental condition evaluation affecting tree growth.

a. Tree species selection method and afforestation method

- As results of analysis on the growth of planted trees in site C and site T, *Eucalyptus camaldulensis*, *Casuarina obesa*, *C. cunninghamiana* have high survival rate and big growth increment.
- As a result of comparing the growth in the planting holes which were penetrated the hardpan or not, the survival rate and the growth of the trees are good in the former planting hole which penetrates the hardpan.
- As a result of analyzing on the growth of planting trees under different irrigation methods, *E. camaldulensis* which was done hardening for drought shows good growth.
- Two species of *Casuarina* have shallow root system, so their growth needs continuous irrigation or planting in areas where have shallow water table.
- As results of germination test and cultivation experiment of the four *Acacia* species, the followings are clarified, that the treatment soaked in the 1 minute boiling water is optimum for their germination and that the method for supplying the water from bottom of the pot is suitable for growth of root system.

b. Environmental condition evaluation affecting tree growth

- We measured the photosynthesis and transpiration properties for *E. camaldulensis* silverton in three study sites (precipitation ranges from 200 to 500 mm). And we planted 9 tree species including three varieties of *E. camaldulensis* in 5 study area along the shore (precipitation ranges from 350to 500mm). *E. camaldulensis* showed the higher photosynthetic ability and the plasticity of stomatal conductance against changes in soil water condition in the model analysis (Amthor 1996[1)]). *E. camaldulensis* could maintain the surplus photosynthetic production in soil water potential of -1.5Mpa or more. Regardless of a planting number, *E. camaldulensis* could yield 5 $Mgha^{-1}y^{-1}$ of stem and branch production. *E. camaldulensis* could survive at the agricultural area with $46mSm^{-1}$ of salinity in the soil.

2) Study on establishing tree biomass variation detecting method in regional scale in arid afforestation area.

- 12 afforestation sites among 22 site, and also 12 natural vegetation sites among 45 sites were selected as biomass increment monitoring sites. From tree census results, Mean annual Increment (MAI) of above- and below-ground biomass in these afforestation sites was calculated as 2.19±1.25 Mg ha^{-1} $year^{-1}$. MAI in these natural vegetation sites was also calculated as -0.3～4.44 Mg ha^{-1} $year^{-1}$.
- Regression analysis between baseline (natural vegetation MAI) and canopy coverage revealed that both variables has strong correlation. Thus applying this correlation to digitized aerial

photograph could estimate baseline distribution in this research area.

- Combining MAI in afforestation site, baseline distribution and biomass distribution, afforestation applicable area and accountable sequestrated carbon amount were calculated. Afforestation applicable area estimation results varied from 1,850 to 2,557 km^2, corresponding to 70.9% to 98.0% of this research area, depending on afforestation period (5 to 20 years). Accountable sequestrated carbon amount also varied from 582.9 to 4,225 kt-C.
- Since Murchison bio-geographic region has the same vegetation and meteorological type to this research area, under the assumption that this Murchison region has the same afforestation applicable area ration and the same accountable carbon amount per unit area, afforestation applicable area was estimated about 197,000 km^2 and accountable sequestrated carbon amount as estimated 320,000 kt-C in the Murchison region.

(3) Implementation of a simulation framework for platform of arid land afforestation technology

- As a part of the tree growth simulator for arid and semi-arid conditions, a process based simulation of photosynthesis process under water stressed conditions was developed. Based on the standard model of photosynthesis process, the effect of water shortage is taking into account as a controlling factor for stomatal conductance, and its response to the environmental conditions were formulated using some experimental data. Growth rate of the tree was estimated from balance between photosynthesis, debris production, stem respiration and tree growths.
- Simulators for surface water and soil moisture transport were developed for modeling the water behavior in open forests. Simulator for soil water was developed and water infiltration and evaporation were calculated. A simplified model was also prepared to reproduce these data in good precision with very low calculation efforts. This simplified model was combined into the surface water model as a sub-model. Then, the water movement from rainfall to surface water and soil water can be treated by the simulators.
- Prediction of total carbon storage change for long time scale was attempted, based on the simulators for water movement and tree growth. A carbon accounting system was used as a framework for this prediction, and some models for carbon pools, i.e. debris and soil carbon, were treated by established models.
- A rough design of practical afforestation project was performed, using experimental observations and simulation result of carbon storage. Then, cost and CO_2 production by the project were estimated. Using these results, cost of CO_2 fixation and its efficiency was calculated.
- For arid land afforestation, estimation of candidate area for afforestation was performed using global database of climate and land condition. And estimation of carbon fixation capacities were attempted for Western Australia and all over the world.
- As a tool for platform construction, a software framework for supporting the development of simulator was constructed. In this framework, a definition file is prepared for each simulator before development. This definition file contains information such as variable name, default

value and variable explanation. This file is automatically converted to fragments of source code of the simulator, which implement standardized data input/output mechanism. Additionally, a mechanism for automatic check of equations in the model of simulator after each calculation was prepared.

4. Discussion

(1) Development of systems for effective use of the limited water without salt accumulation problem

1) Investigation and control of water balance, construction of water and salt cycle model in middle / large-scale catchment model in an arid land

- In arid land (Sturt Meadows) of WA, water balance in middle and large scale catchment area were investigated with some gauges in the field, and runoff ratio against rainfall in the area was evaluated by gauges data.
- Runoff and water-salt movement model was constructed with the investigation data, and that model could be applied for demonstration of selection of afforestation site in Sturt Meadows. Runoff model was applied for afforestation site in semi-arid land (Wickepin), and that was used for analyze of water balance in afforestation site.

2) Analyzing and modeling of soil environment

a. Litter and soil carbon dynamics in arid land

- We conclude that in this type of ecosystem, which is susceptible to the run-off of water and strong winds, taking into account of the physical removal of the litter is essential for analyzing the carbon dynamics in the ecosystem.
- To contain effectively water retention material for plant growth promoting, it is necessary that enough water reach the water retention material and that water retention material has enough ability of water retention.

3) Countermeasure technology and development of afforestation against salinity crisis in semi-arid land

a. Afforestation with control pipe and selection of afforestation tree species

The structure of root systems were revealed in afforested species and the plasticity of them were tested by our experiment. It is essential for the afforested species to avoid high concentration of salt that is accumulated to the surface soil. E. camaldulensis had high growth rate and biomass fixation ability in the dryland afforested stand. This species also showed the favorable traits to grow in saline areas, as follows: 1)does not decrease in growth rate if it was grown in the pipe of 10 cm in diameter, 2) showed higher growth rate than the other species, 3) quickly elongate their roots to the deeper soil layer, 4) showed greater plasticity in root growth pattern. These results suggested that E. camaldulensis was the promising species for afforestation not only in drylands but also salt-affected lands. On the other hand, P. radiata showed lower growth rate than E. camaldulensis, however, the growth rate did not decrease even if it was grown in 2.5 cm pipes. Therefore, the usage of this species enable to save labor for afforestation.

b. Investigation of water balance in middle catchment area in a semi-arid land

- From water balance investigation data, the possibility for removing excess water by afforestation were indicated. In this agro-forestry area, about 40% of rainfall supplied water will be removed by transpiration by only 20% afforestation area.
- In this research, since soil water movement (water content and evaporation) was not investigated, complete water balance was not investigated in strict meaning. However, our investigation become basic data to evaluate available water for afforestation, to discuss restraining effect for water-logging or salinity problem and to consider realizability of agro-forestry afforestation in semi-arid land.

(2) Study on technological development of environmental adjustable afforestation and soil control techniques for systematic afforestation in arid area.

1) Proposing tree species selection method and afforestation method based on environmental condition evaluation affecting tree growth.

a. Tree species selection method and afforestation method

- Tree planting on areas having hardpan seems to be impossible until now, however, afforestation on the areas became possible by hardpan blast in order to ensure the sufficient soil layer.
- Planting holes need not only sufficient size but also penetrating the hardpan, for planting trees can use more much rain water and under ground water.
- *E. camaldulensis* which was done hardening for drought shows good growth and high survival rate and two species of *Casuarina* which have shallow root system show good growth under continuous irrigation or shallow water table.
- The treatment soaked in the 1 minute boiling water is optimum for germination of the four *Acacia* species and the method for supplying the water from bottom of the pot is suitable for growth of root system of *Acacia aneura*.

b. Environmental condition evaluation affecting tree growth

- *E. camaldulensis* was known to be drought-tolerant species because of its natural distribution in inland of Australia. It has been understood that *E. camaldulensis* is strong light-demanding species in this research. Then sparse plantation density is suitable for planting of *E. camaldulensis* in order to avoid the mutual shading of leaves. The better planting density is 200 trees ha^{-1} (Leaf area index <1) in the area with a precipitation of 500mm or less. The afforestation of *E. camaldulensis* is suitable for rehabilitation of degraded crop land because of its saline-tolerant ability.

2) Study on establishing tree biomass variation detecting method in regional scale in arid afforestation area.

- Mean Annual Increment (MAI) in afforestation sites was calculated as 2.19±1.25 [Mg ha^{-1} $year^{-1}$]. Comparing MAI in other Australian or Brazilian afforestation sites (Forrester et al., 2004[2)]; Stape et al., 2004[3)]) in tropical zone, MAI in this research area was quite low value. However, MAI per 100mm unit rainfall was almost the same level between this research area and other tropic area. MAI in natural vegetation (baseline) varied from -0.3～4.44[Mg ha^{-1} $year^{-1}$], which was almost the same range compared to an semi-arid area of north eastern Australia (Burrows et al., 2002[4)]).

- From the significant correlation between canopy coverage and baseline, baseline got to be estimated by a simple function. Thus, a regional baseline distribution in this research area was estimated using digitized aerial photograph with remote sensing techniques.
- By combining MAI in afforestation site, baseline distribution and biomass distribution, afforestation applicable area and accountable sequestrated carbon amount were estimated. From these results, it was revealed that the more afforestation period got long, the more afforestation applicable area got large. When afforestation period will be set as 20 years, the accountable sequestrated carbon amount was estimated as corresponding about 1/3 of carbon amount in Australian temperate forest biomass. When afforestation period will be set as 50 years, the accountable sequestrated carbon amount was estimated as corresponding about the same carbon amount in Australian temperate forest biomass (Dixton et al., 1994[5)]).
- This research area belongs to the Murchison bio-geographic region (National Land and Water Resources Audit, 2002[6)]). Assuming that the Murchison region has the same ratio of afforestation applicable area and the same carbon sequestration amount per unit area to this research area, it was revealed that quite huge amount of carbon (2800 - 3200 kt-C) would be accounted as carbon credit. However, since this research neglect water balance, soil type, species variety, actual accountable carbon amount should not be obtained so simply. In future analysis, we must consider about especially water balance and other factors to obtain robust estimation value of afforestation applicable area and accountable sequestrated carbon amount.

(3) Implementation of a simulation framework for platform of arid land afforestation technology

- To predict tree-growth in arid and semi-arid land conditions, a simulator of photosynthesis, which explicitly modeling the effect of water stress was developed. Using the data of gas exchange experiment of a tree, (*Eucalyptus camaldulensis* in arid land, Leonora, Western Australia) parameter fittings of this simulator was attempted. It can reproduce the hourly change of photosynthesis rate observed in gas exchange experiments, but further adjustment of parameters was required to reproduce daily change of transpiration rate estimated by sap-flow measurement.
- As for tree-growth simulation based on this photosynthesis simulator, calculated result fits well to the observed tree growth though the data was limited to the growing stage of the tree's life cycle. Final size of the tree estimated by the simulator could not be compared to the observed data, but it is a value appropriate as size of trees around the observed tree. It is concluded that, this tree growth simulator is effective to predict tree behavior in arid land.
- About simulators on water movements, amounts of water loss by surface run-off were estimated using soil water simulation by comparing change of the water content in the soil and rainfall. Another estimation of surface run-off water amount was predicted by surface water simulator, and agrees well.
- A simulation of surface run-off, dealing with area of around 100m size, was sufficient to predicting surface run-off water amount in ordinary rain events. However, in extremely large run-off events, water flow larger than this size was observed. The result of this simulation is

considered to be a minimum estimation of water supply of the planted tree.

- Although partial evaluation of the combined simulator for carbon storage were attempted in Leonora, Western Australia, evaluation of long-term simulation not performed because of the limited time scale of the project. Therefore, soil carbon and debris were not taking into account in estimation of carbon fixation amount.
- A rough design of practical afforestation project was performed. Then total cost and CO2 production of the project were estimated. Although the capacity of carbon fixation is very large, estimated cost is somewhat expensive. This estimation is based on the cost and CO2 emission data of present, but such data will be changed with energy source shift and economical conditions. Especially, uncertainty of the land and human labor cost is significant, and revision of estimated cost will be required after some time intervals.
- As a tool for platform construction, a software framework for supporting the development of simulator, execution of simulator and cooperation of simulators was developed. Its usability was tested in development and calculation of simulators described in this section. When a calculation is executed using this framework, check of equations in the model of simulator were automatically performed. This mechanism was designed only for debugging process in simulator development, but it was turned out that this mechanism is also checking the soundness of model equations under rare combination of input values.

Table 1 shows carbon fixation potential evaluated by our research results. The amount of carbon sequestration in WA from atmosphere to biomass of afforestation trees by the techniques of our study project were 700 and 4-27 Mt-C $20yr^{-1}$, respectively. In global scale, the amount of carbon sequestration of arid and semi-arid land were 19,000 and 210-1,400 Mt-C $20yr^{-1}$, respectively. Our research results can be applied to huge area of arid and semi-arid land, and those should be one of initiative in environmental policies of global scale.

Table1 Evaluation of carbon fixation potential

item	Afforestation in arid land	Partial afforestation against expanding of saline area in wheat belt of semi-arid land
arid land / harvesting area (km^2)	**2,500** (research site) **1.71M** (WA -300 mm/y) **47M** (global scale)	**40,000** (WA) **2.1M/14M** (global scale)
carbon fixation potential ($Mt\text{-}C\ 20yr^{-1}$)	**700** (WA 200-300 mm/y) **19,000** (global scale)	**4～27** (WA) **210～1,400** (global scale)
recital	*WA: Arid-land area (average of annual rainfall: 200-300 mm) of WA is 1,120,000 km^2 (Bureau of Meteorology 1990) and this technology was assumed to be applied to the whole area. *global: Fraction of arid land where this technology can be applied was assumed to be same as in WA. *Carbon-fixation was assumed to be 10,000 $t\text{-}C / km^2$ considering the temperate grassland is converted to forest (Kojima 1994). *25% of precipitation of 250 mm/y was assumed to be concentrated to be 1000 mm/y to make temperate forest.	*Salt affected land in WA was assumed as 10-70% (FAO data, Oldeman et al. 1991). *Global salt affected land was assumed as 10% of crop land or wheat field. *Afforestation area necessary for improving salt affection was assumed as 20% of crop land. (the figure was given from our growth rate data, water balance estimation and predicted salt affection for 50 years.) *Expanding rate of area under salinity hazard are our research and ANRA data. *Carbon-fixation was assumed to be 5,000 $t\text{-}C / km^2$ / 20y from our experimental results with introduction of our technology. (without our technology, the growth rate/carbon fixation will be half)

References

1) Amthor J.S.: Photosynthesis Res., 39, 321-350 (1996) “Scaling CO2-photosynthesis relationships from the leaf to the canopy”
2) Forrester, D.I., Bauhus, J., Khanna, P.: For. Ecol. Manage. 193, 81-95 (2004) “Growth dynamics in a mixed-species plantation of *Eucalyptus globulus* and *Acacia mearnsii*.”
3) Stape, J.L., Ryan, M.G., Binkley, D.: For. Ecol. Manage. 193, 219-234, (2004) “Testing the utility of the 3-PG model for growth of *Eucalyptus grandis* x *urophylla* with natural and manipulated supplies of water and nutrients.”
4) Burrows, W.H., Henry, B.K., Back, P.V., Hoffman, M.B., Tait, L.J., Anderson, E.R., Menke, N., Danaher, T., Carter, J.O., McKeon, G.M.: Global Change Biology, 8, 764-784, (2002) “Growth and carbon stock change in eucalypt woodlands in northeastern Australia: ecological and greenhouse sink implications.”
5) Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C. & Wisniewski, J.: Science, 263, 185-190, (1994) “Carbon pools and flux of global forest ecosystems.”
6) Australia's native vegetation-A summary of the national land and water resources audit's Australian native vegetation assessment 2001-. 27pp, (2002) National Land and Water Resources Audit.

Major publications

1) K. Shiono, Y. Abe, H. Tanouchi, H. Utsugi, N. Takahashi, H. Hamano, T. Kojima and K. Yamada: Journal of Arid Land Studies, 17-1, 11-22 (2007) “Growth and Survival of Arid Land Forestation Species (*Acacia aneura, Eucalyptus camaldulensis* and *E. salubris*) with Hardpan Blasting”

2) T. Kojima, H. Hamano, Y. Abe, H. Tanouchi, Y. Egashira, M. Saito, J. Law, N. Takahashi

and K. Yamada: J. of Arid Land Studies, 16-3, 167-174 (2006) “Basic Data of Research Project on Large Scale Afforestation of Arid Land for Carbon Fixation near Leonora in Western Australia”

3) H. Tanouchi, H. Utsugi, N. Takahashi, H. Hamano, S. Kawarasaki, T. Kojima and K. Yamada: J. of Arid Land Studies, 15-4, 267-270 (2006) “Water Use Efficiency of Trees in Arid Lands: Plasticity to Water Conditions”

4) K. Yamada, T. Kojima, Y. Abe, Y. Egashira, H. Tanouchi, N. Takahashi, H. Hamano and K. Tahara: Energy and resources, 26-6, 435-441 (2005) “Establishment of a CO_2 fixation system by afforestation on arid land”

5) Y. Egashira, D. Tomii, K. Ueyama, N. Takahashi, T. Kojima、Y. Abe、M. Saito and K Yamada: Journal of Chemical Engineering of Japan, 36-4 383-390 (2003) “Development of integrated simulator of water transport and plant growth as an evaluation tool of arid land afforestation for CO_2 fixation”

(Team 1a has 56 publications. Only the five representative articles are listed. All publications are listed into detailed report (in Japanese).