1.5 Theses of Graduate and Undergraduate Courses

(1) Doctoral Theses

Division of Climatology and Water Resources

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Modeling of interrill sediment generation and soil microtopography dynamics under variable simulated rainfall erosivity

Deformation of soil surface due to raindrop impact involve several processes have not yet been well understood. This study was attempted to measure, evaluate, and model two important processes: (1) soil microtopography change and (2) soil particle detachment due to raindrop impact. In order to understand these processes, robust techniques must be used to quantify each factor affects these processes.

Firstly, the potential use of a piezoelectric transducer to measure the rainfall impact energy under simulated rainfall conditions was investigated. The simulated rainfall kinetic energy (*KE*) and drop size distribution (*DSD*) were measured using piezoelectric transducers, modified from the Vaisala RAINCAP® rainfall sensor. The direct measurement of the kinetic energy was significantly correlated with the estimated kinetic energy using the drop size distribution data and empirical fall velocity relationships (r > 0.84, P=0.005). The effect of the rainfall characteristics produced by dripper-type rainfall simulator on splash soil erosion (D_s) was also assessed. The relationship between the rainfall intensity (I) and *KE* was found to be different from natural rainfall and the I-D_s relationship followed the same trend. This result emphasizes the importance of the *I-KE* relationship in determination of the I-D_s relationship, which can differ from one rainfall simulator to another. Accordingly, to improve the soil splash estimation by simulated rainfall the characteristics of the simulated rainfall have to be taken into account.

Secondly, the potential of using consumer-grade cameras and close-range photogrammetry procedures to quantify soil microtopography at plot-scale level (≤ 1 m^2) were assessed using simulated soil surface. The surfaces' digital elevation model (*DEM*) was generated using the photogrammetry system (*PHM*) involving a consumer-grade camera, and pin-microrelief meter (*PM*). The *DEM* generated using the *PHM* was assessed for accuracy, roughness indices (*RI*), depression area percentage (*DA* %), depression storage capacity (*DSC*), and micro-rills delineation in comparison with the *PM*. Our results suggest that a consumer-grade camera and close-range photogrammetry have high potential to quantify the soil microtopography. The method was also assessed to quantify the soil microtopography changes during rainfall. A reference surface rectification method (*RSM*) was developed to detect and eliminate the *DEM* errors prior to interpolation. The second was the parametric statistical method (*PSM*), which was used to detect and rectify the *DEM* errors after interpolation. The automated digital photogrammetric system with the rectification methods accurately generated three dimensional (*3D*) visions of the soil microtopography during rainfall.

Thirdly, two modeling approaches, empirical and physically-based, were assessed to evaluate the capability of each approach to estimate the sediment yield under hillslope condition. The empirical models tested in this study used a combination of factors which influence the sediment yield, particularly rainfall intensity, slope and runoff. The physically-based model on the other hand, used the kinematic wave method to estimate runoff and the sediment mass balance equation to estimate the sediment yield. A comparison between the empirical models and the physically-based model showed that the physically-based model, which uses the measurable soil parameters such as bulk density and hydraulic conductivity, estimates the sediment yield and runoff effectively.

Division of Biological Production

Weiqiang Li

<u>Physiological and Ecological Studies of Polymorphic Seeds of Two Halophytes: *Suaeda salsa* and *Atriplex centralasiatica*.</u>

About 0.95 billion hectares of the world's soils are saline. Salinity is one of a major environmental factor limiting plant growth and productivity in saline soils of arid and semi-arid regions. There have been some attempts to increase crop yield by enhancing salinity tolerance. However, breeding and selection for higher salinity tolerance has brought only limited successes so far. Recently, some attempts have been made to select potentially from the numerous halophytic species some economic halophytes that can be used for on a large scale production in an economically feasible manner. In the process, the saline soils used would also get amended through halophyte planting.

Suaeda salsa and *Atriplex centralasiatica* are two important annual herbaceous halophytes belonging to the family Chenopodiaceae and widely distributed in China. These two species have economic potential as a source of oil, food, vegetables and fodder and are useful for vegetation rehabilitation in saline soils. In order to use them as a crop, the first essential step is to know the germination characteristics of the seeds of these species in saline environment, as the seed germination is a critical stage for establishment of halophytic vegetation in saline areas. Previous studies have shown that *S. salsa* and *A. centralasiatica* produce dimorphic/polymorphic seeds (brown seeds and black seeds) on the same plant. However, the physiology and ecology of germination of dimorphic/polymorphic seeds under salinity is not well understand. The objectives of this study are to investigate 1) the ecological aspect namely, how environmental factors (salinity, light, storage, temperature ect.) affect germination of the two halophytes, and 2) the physiology aspect namely, how plant hormones affect seed germination and how endogenous hormones were affected by environmental factors of the dimorphic seeds. Findings from the study are given in the following sections:

1. Germination behavior of dimorphic seeds of *Suaeda salsa* under saline conditions

It is very important to examine the effect of storage, environmental factors and hormonal treatment on germination of *S. salsa* in salinity. Therefore, the effect of storage, cold-wet stratification (4 ^{o}C for two days after water imbibition), application of gibberellins (GA_1 and GA_4) and temperature regimes (5/15, 10/20, 15/25, 20/30, 25/35 ^{o}C) on germination of dimorphic seeds of *Suaeda salsa* was investigated under NaCl stress conditions. The results showed that after one year of storage under room temperature, germination percentage of brown seeds decreased while that of black ones increased both in distilled water and in saline solution (300mM NaCl). Stratification and GA_4 treatments improved black seeds' germination, but showed little effect on the germination of brown seeds. However, treatment with GA_1 failed to promote seed germination of both kinds of seeds. Salinity, temperature and their interaction significantly affected the germination of both kinds of seeds. Brown seeds under all the conditions showed higher germination percentage than black seeds. Maximum germination percentage was noted in distilled water at 15/25^{o}C and 20/30^{o}C temperature regime for both kinds of seeds. The highest rate of germination was obtained in distilled water at

20/30^{o}C for brown seeds, and at 15/25^{o}C for black seeds.

2. Germination characters of dimorphic seeds of *A. centralasiatica* under saline conditions

The effect of light, temperature, fruit type (presence of bracteoles), seed color, storage, cold-wet stratification, seed coat scarification and plant hormones on germination of polymorphic seeds of *A. centralasiatica* was investigated under saline conditions. Results showed that the effect of fruit types was not significant on seed germination. Multi-factorial analysis of variance revealed significant differences in the effects of seed color, temperature, salinity, light and their interactions on seed germination. Maximum germination occurred in distilled water, and an increase in NaCl concentration progressively inhibited germination in all the four types of seeds. A temperature regime of 15/25^{o}C resulted in the maximum germination. Brown seeds had a higher germination percentage than black seeds in mild temperature regime and high salinity; while black seeds had a higher germination percentage than brown seeds in higher temperature and lower salinity. Germination of black seeds was sensitive to light in NaCl solution but not of brown seeds. Attached bracteoles inhibited the germination of both black and brown seeds. The black seeds were more sensitive to presence of bracteoles than brown ones. After one-year storage, germination percentage of brown seeds decreased significantly; while that of black seeds increased in salinity stress. Cold-wet stratification promoted seed germination rate, however, it did not affect final germination percentage of both seeds. Seed coat scarification and fluridone (Abscisic acid, ABA biosynthesis inhibitor) treatments improved germination of both black and brown seeds under salinity stress. Gibberellins, 1-aminocy-cloproane-1-carboxylate (ACC, the immediate precursor of ethylene), 6-benzyladenine (BA) showed little effect on the germination of both kinds of seeds under salinity. ABA and paclobutrazol (inhibitor of gibberellin biosynthesis) did not affect seed germination in distilled water, however, ABA inhibited germination in the presence of salinity. Inclusion, by differential germination of the polymorphic sees, *A. centralasiatica* showed a bet-hedging ecological strategy, that ensure the establishment of plant stands under highly variable environmental conditions. ABA was the main plant hormone that affected seed germination under salinity stress.

3. Effect of salinity on levels of endogenous gibberellins and abscisic acid during germination of dimorphic seeds of *S. salsa*

In order to clarify the role of hormones in regulating germination of *S. salsa* dimorphic seeds under salinity, we investigated the effect of salinity on gibberellins (GAs) and abscisic acid (ABA) profiles during germination. Content of endogenous ABA in dry brown seeds was about 2.7 times that of black seeds, and after imbibition it decreased faster in the brown seeds than the black seeds. Salt (NaCl) stress slightly prevented decrease of ABA content in germinating seeds and fluridone (ABA biosynthesis inhibitor) alleviated seed germination in the presence of salinity stress. Bioactive GAs (GA_4/GA_1) and their biosynthetic precursors (GA_{12}, GA_{15}, GA_{24}, GA_9, GA_{53}, GA_{44}, GA_{19}, GA_{20}) were higher in brown seeds than black seeds both under dry condition as well as when germinating in water and salt solution. However, deactivated GA forms (GA_{51} and GA_{34}) were higher in black seeds than brown seeds when dry and also when germinating in water and salt solution. The dimorphic seeds showed significant difference in biosynthesis and inactivation of bioactive GA_4, which might result in difference in germination in water and salinity. In early stage of germination, GA_4 declined in response to salinity in both types of seeds. In the presence of GA biosynthesis inhibitor (paclobutrazol), GA_4 was more active than GA_1 in promoting seed germination. Salt also decreased sensitivity of both seeds to GA_4, brown seeds were more sensitive to GA_4 than black seeds. Salinity might affect on one hand the content of GA_4 by inhibiting its biosynthesis and promoting its deactivation and by affecting sensitivity to GA_4 and on the other hand biosynthesis of ABA, which affected seed germination.

4. Conclusion

Based on the above results, it can be concluded that the dimorphic/polymorphic seeds of *S. salsa* and *A. centralasiatica* exhibit distinct differences in dormancy, germination, dispersal strategies and storage characteristics. Brown seeds are more tolerant than black seeds during germination under salinity. Brown seeds showed higher dispersal performance than black seeds, and would germination in spring; black seeds showed seed bank features and would germinate in summer, next year or later. This is a kind of bet-hedging ecological strategy and permits the two species to successfully inhabit the harsh saline habitats. In practice, it is suitable to sow brown seeds in spring and black ones in summer, as well as to use black seeds for storage. Plant hormones (ABA and GAs) are involved in regulation of seed germination and dormancy of dimorphic/polymorphic seeds of the two halophytes. ABA inhibited seed germination of both kinds of seeds under salinity, while GAs (especially GA_4) could alleviate salinity stress in some cases. The results also indicated that salinity stress inhibited seed germination mainly through affecting GA biosynthesis and ABA catabolism. The reason for difference in germination behaviors of the black and brown seeds of *S. salsa* under salinity could in part to be the difference in biosynthesis and deactivation of active GAs (GA_1 or GA_4) and catabolism of ABA in the two kinds of seeds.

Division of Afforestation and Land Conservation

Shogo Imada

<u>Studies on growth characteristics of *Populus alba* under different water table depths and salinity levels</u>

Soil salinization is one of the major causes of desertification. The spread of soil salinity has resulted in large reductions in plant productivity worldwide. In several areas salinization is due to shallow water tables. To combat soil salinization and ameliorate salinized soils, various biological and engineering methods have been used. A biological method using native deep-rooted perennial plants has drawn attention because of low initial investment and sustainability. In this method, the plantation of perennial plants, particularly woody plants, is expected to lower shallow water table and soil salinization through water uptake by deep and extensive root systems. However, there is some evidence that some plants may also increase levels of soil salts, so it is necessary to select appropriate species.

In order to select the right species, the growth characteristics in regions where selected species would be planted needs to be understood. Saline environments are generally characterized by shallow groundwater tables and large amounts of salts in the soil. Therefore, for successful amelioration, the response of a species under water table depth and soil salinity conditions should be examined. Furthermore, changes in the soil after planting the species in saline environments also need to be evaluated.

In this study, the effects of three constant water-table depths (45, 30, and 15 cm depths from soil surface) and a fluctuating water table regime (fluctuating between 45 and 30 cm depths) on the fine-root growth and whole-plant biomass of 1-year-old rooted *Populus alba* cuttings were determined. Fine-root growth varied with water-table depth and soil water profiles: fine roots were scarce in the soil layers below the water tables because of soil O_2 depletion and proliferated in the layer just above the water table where the conditions were favourable for exploiting water. The total biomass and root length in each treatment were positively correlated and the relationship did not differ significantly among treatments, suggesting an important role of fine roots in controlling whole-plant growth under different levels of soil water availability.

The relationship among different growth components at the whole-plant level was also examined. Both net assimilation rate and leaf area ratio correlated with relative growth rate (RGR). While leaf mass ratio (LMR) and specific leaf area positively correlated with RGR, the correlation was stronger in the case of LMR. The variation in LMR was mainly attributed to variation in root biomass allocation. The root biomass allocation strongly and negatively correlated with the proportion of fine-root biomass not only at whole root system level but at each soil depth layer. These results suggest that such root growth responses may relate to whole-plant growth along a soil moisture gradient.

To examine, in detail, the growth and mortality of fine roots of *P. alba* in fluctuating water tables, shoot cuttings were exposed to a constant water-table depth (45 cm) and two fluctuating water-table conditions (fluctuating between 45 to 30 cm and between 45 to 15 cm). Fine-root biomass was similar among the treatments, while the proportion of fine-root necromass increased in the fluctuating water-table depth treatments. Despite the increase in gross fine-root mass, the water-table fluctuations did not influence the whole-plant growth and biomass allocation among the plant parts. These results suggest that the increase in gross fine-root mass would be an important mechanism of *P. alba* in adapting to fluctuating water tables.

Finally, the effects of saline irrigation on the growth, Na partitioning, and Na dynamics of the cuttings were studied. The plants were grown in lysimeters and were watered with either field water (control) or solutions containing either 2000 or 5000 mg L^{-1} of a mixture of NaCl and $CaCl_2$ (low- and high-salt treatments, respectively). The cuttings in the low-salt treatment exhibited growth similar to that of the control after 1 year of start of the treatment. In the low-salt treatment the addition of Na to the soil by irrigation for 1 year (1831 kg ha^{-1}) was similar to the levels of Na that accumulated naturally in saline soils in *Populus deltoides* forests. But, the addition of Na to the soil in the high-salt treatment (4568 kg ha^{-1}) was much higher and it caused a significant growth reduction and 20% mortality for the plants. Strong Na partitioning was observed in the roots (about 90%) in the control and low-salt treatment, suggesting that this is an important salt tolerance mechanism in *P. alba*. The Na accumulated in the biomass after 1 year in the low-salt treatment was about 88% of the total uptake, resulting from low rate of return to the soil. The percentage of Na taken up by the cuttings from the total amount added to the soil by irrigation, however, was very low (2% in the low-salt treatment), suggesting that this tree can not reduce salt concentration in soil through its ability to accumulate salts in the body.

These findings suggest that *P. alba* can grow well under shallow and fluctuating groundwater tables, and can tolerate soil salinity commonly occurring in saline environments where natural forests of *Populus* grow. In addition, the results of Na dynamics indicate that *P. alba* may have little risk of increasing levels of soil salts after planting this species in saline soils since the tree biomass can accumulate a high proportion of total Na taken up by the plants. Thus, *P. alba* can be a good candidate for afforestation in saline soils where the tree can tolerate moderate salinity levels and is expected to lower water tables by pumping out water through its extensive root system.

Yuki Tamura

Studies on improvement of salt accumulated areas using *Tamarix* spp

Salt accumulation in the soil is a serious problem in the dryland regions of China. To improve these salt-accumulated areas, several methods have been examined, including leaching. In this study, we examined the efficacy of biodrainage, which involves planting trees to remove excess salt and water. Before applying this method to a salt-accumulated area, one must assess whether the plants to be used for revegetation will be effective in improving the area. In salt-accumulated areas, the water table is also high, meaning that the plants used for revegetation should be tolerant of salt and flooding. In this study, we focused on several species of *Tamarix*, which are native to China and have high tolerance to both salt and flooding, and evaluated their availability to improve salt-accumulated areas.

As described in Chapter II, we also assessed the optimal growth conditions for *Tamarix*.

The effects of changes in the depth of the water table on *Tamarix* were studied using cuttings immersed in 0.1% salt water under various water table conditions: a constant depth of 35 cm from the soil surface [WTC_{35}], a constant depth of 25 cm from the soil surface [WTC_{25}], a depth of 15 to 35 cm from the soil surface [$WTC_{15\text{-}35}$], and a depth of 25 to 35 cm from the soil surface [$WTC_{25\text{-}35}$]. The amount of available water in the high water table treatments (WTC_{25} and $WTC_{15\text{-}35}$) was greater than in the low water table treatments (WTC_{35} and $WTC_{25\text{-}35}$). The growth of the *Tamarix* plants tended to be higher under the high water table conditions.

The effects of high salt and water table depth on *Tamarix* were studied using cuttings exposed to various amounts of salt (0, 1, 2, 4, and 6%) and water table depths (0, 10, 20, and 30 cm from the soil surface). Nutrient absorption by the *Tamarix* plants under the high water table depth conditions was lower than that under the low water table depth conditions. *Tamarix* was unable to grow under high salt and water table depth conditions. Based on these data, we identified three conditions necessary for the successful cultivation of *Tamarix*.

A water table depth of 20 cm from the soil surface and a soil Ca^{2+} content of 2,500 mg kg^{-1} soil, even if the Na^{+} content is 2,000 mg kg^{-1} soil, will support the growth of *Tamarix*.

A water table depth of 0 cm from the soil surface and a soil Ca^{2+} content of 2,000 mg kg^{-1} soil, even if the Na^{+} content is 1,500 mg kg^{-1} soil, will support the growth of *Tamarix*.

A Na^{+} content greater than 3,000 mg kg^{-1} soil may prevent the successful growth of *Tamarix* regardless of the Ca^{2+} content or water table depth.

If the soil salt content and water table depth in the salt-accumulated area comply with these conditions, the planting of *Tamarix* should be successful.

It is also necessary to know whether *Tamarix* can improve salt-accumulated soil when it is used to revegetate a salt-accumulated area. Therefore, in Chapter III, we report the salt dynamics in a naturally regenerated *Tamarix* forest in Inner Mongolia (Dalateqi, China). The salt levels in bare soil, forest soil, plants, litter, throughfall, and stemflow at the site were investigated. Our data indicate that Na^{+} accumulated in the woody parts of the plants (stems, branches, and roots), and to a lower extent in the soil (litter, throughfall, and stemflow). In addition, the litter, throughfall, and stemflow contained greater amounts of K^{+}, Ca^{2+}, and Mg^{2+} than the woody parts. This contributed to an increase in K^{+}, Ca^{2+}, and Mg^{2+} at the soil surface in the forest. The Na^{+} content in the forest soil was lower than that in bare soil. This might be because evaporation from the surface soil was inhibited by the forest vegetation. It has been reported that vegetation inhibits the movement of water and salt to the soil surface. Therefore, the Na^{+} content of forest soil might be lower than that of bare soil. Furthermore, leaching by rainfall might contribute to the small amount of Na^+ in forest soil. The growth of *Tamarix* forests is believed to increase the amount of nutrients and decrease the amount of salt in the soil by increasing the accumulation of salt in tissues and inhibiting the upward movement of salt through the soil; therefore, *Tamarix* forests may improve salt-accumulated areas.

The salt in the throughfall and stemflow was derived from secreted salt. Therefore, to analyze the salt dynamics in a *Tamarix* forest, it is important to understand the characteristics of salt secretion. To this end, in Chapter IV, we describe a series of experiments designed to investigate the characteristics of salt secretion.

The effects of the soil salt composition on the plants and the secreted salt composition of *Tamarix* were examined using cuttings exposed to salt water containing various ion ratios: a 1% solution of 2:2 Na^+:Ca^{2+}, a 0.75% solution of 2:1 Na^+:Ca^{2+}, and a 0.75% solution of 1:2 Na^+:Ca^{2+}. As the amount of Ca^{2+} in the soil increased, the absorption of Na^+ by the plants decreased (*i.e.,* the Na^+ content of the plants and the amount of salt secreted dropped). In addition, *Tamarix* secreted a larger amount of Na^+ than Ca^{2+}. Therefore, *Tamarix* may selectively secrete excess Na^+ from salt glands to the plant surface.

We conducted experiments in both a naturally regenerated *Tamarix* forest and a growth chamber in order to detect hourly and daily changes in salt secretion in *Tamarix* plants and the effects of temperature and humidity on salt secretion. As the relative humidity increased, the amount of salt secreted from *Tamarix* increased significantly. Thus, rainfall and night dew may promote salt secretion in *Tamarix*.

In Chapter V, we assessed whether the planting of *Tamarix* in a salt-accumulated area would be successful based on the three sets of conditions outlined in Chapter II. When the ground water depth and soil salt met these conditions, the cultivation of *Tamarix* was successful. In addition, the effects of *Tamarix* on the removal of soil salt, the effects of salt secretion by *Tamarix* on the inflow of salt into the soil, and the beneficial effects of *Tamarix* forests on salt-accumulated soil were evaluated based on the results in Chapters III and IV, and the salt and flood tolerance of *Tamarix* was compared with that of other plants native to China. *Tamarix* was found to have higher salt and flood tolerance than the other plants, it was able to grow in a salt-accumulated area, and it was found to contribute to the removal of soil salt and the inhibition of the upward movement of soil salt. In addition, *Tamarix* may contribute to the accumulation of soil nutrients. Thus, *Tamarix* may be used to improve salt-accumulated areas.

(2) Master's Theses

Division of Climatology and Water Resources

Komatsu, Y.

Heat budget between atmosphere and land-surface during snowmelt season in eastern Mongolia

Division of Biological Production

Sano, K.

Effects of temperature and atmospheric CO2 concentrations on the photosynthesis and water use efficiency of *Jatropha curcas* L.

Division of Afforestation and Land Conservation

Kaneuchi, T.

Effect of artificial zeolite on resistance to water erosion of sodic soil

Muromachi, K.

Growth of NERICA under saline irrigation

Tanaka, I.

Effects of salt stress on the ectomycorrhizal symbiosis of pine trees

Taniguchi, S.

Improvement of soil environment using Zeolite Cotton and its effect on plant growth

Tojo,M.

Effects of S-ABA application on growth and drought tolerance of woody plants