1. Summaries of Doctor Theses

Effects of saline water irrigation on evapotranspiration from citrus

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Evapotranspiration (ET) is the key factor to estimate crop water requirement when irrigation should be operated. ET estimates are essential for water balance studies, irrigation and water resources planning, etc. Up to now, most available models to calculate ET under the fresh water irrigation were developed. Irrigation with saline water leads to increased soil salinity. High soil salinity conditions in the root zone hinder water uptake due to reduced osmotic potentials. Reduced water uptake by the roots results in reduced transpiration, which ultimately decreases ET. The all developed models to calculate ET under the freshwater irrigation will be unavailable. Therefore, it is very important to estimate actual ET under saline water irrigation.

A study about ET of orange trees grown in greenhouse lysimeters and effect of saline water irrigation on the ET was carried out at Arid Land Research Center, Tottori University, Japan (35º32'N; 134º13'E). This study includes three parts as following:

First part was subjected to investigate seasonal variations in daily and hourly ET. ET showed significant seasonal variations. Average ET rate exceeded 4.4 mm/day in the summer period, and dropped to 0.6 mm/day in the winter months. The average seasonal crop coefficient (K_C) was 0.91 and 0.75 during the summer and winter period, respectively. The maximum ET appeared in 09:00 for winter and 12:00 for summer. Soil evaporation (E) was 33% of ET during the winter period, while E was only 11% of ET during summer. Maximum water uptake by the trees was found at a depth of 30-60 cm, and soil water depletion was observed in the 0-120 cm depth of the profile during the summer period. However, during the winter season water depletion occurred only from 0-30 cm depth of the soil profile.

Second part was to analyze ET from orange trees under irrigation with saline water. Two lysimeters planted with an orange tree in the greenhouse were used. One lysimeter was irrigated with saline water (made using the same equivalent weight of NaCl and $CaCl_2$, and TDS = 2000 mg/L) and the other was irrigated with freshwater using drip irrigation. The applied irrigation water was 1.2 times of the ET on the previous day.

ET from orange trees was reduced after irrigation with saline water and returned to the normal level after leaching. However it takes months to exhaust the salt from the tree. To estimate the impact of irrigation with saline water on the ET from citrus trees, the reduction coefficient due to salt stress (K_S) was used in this experiment. ET under irrigation with saline water (ET_{LS}) can be calculated from ET under irrigation with fresh water (ET_{LC}) by the equation $ET_{LS} = K_S \bullet ET_{LC}$. Ks can be expressed as a function of electrical conductivity of soil-water (EC_S). The critical value of EC_S is 9.5 dS/m, beyond which adverse effects on ET begin to appear. If EC_S can be controlled below 9.5 dS/m, saline water can be safely used for irrigation.

Third part was to investigate the influence of the perforated pipe irrigation with waters having high concentration of salts (EC = 8.6 dS/m) on the ET. A short term experiment was conducted. This experiment duration was divided into three periods of about 2 weeks each and the following results were obtained.

Irrigation with saline water tended to decrease ET. The average ET value from saline water treatment

was 71% of that compared of the control. The reason for this result is due to the salinity decreasing the transpiration (T) of trees. There was no clear influence of water quality on the evaporation (E) from soil. No significant differences in water uptake pattern of trees based on water quality treatments were observed. On the other hand, the higher irrigation frequency with saline water resulted in higher ET.

The ET differences between treatments were smaller after the leaching event. The results show that leaching is an effective management strategy for sandy soil to control soil salinity when saline irrigation is used. At intervals (15 days intervals in this study), sufficient non-saline water should be applied to control salinity levels in the root zone. In our experiments the first leaching irrigation with non-saline water was very effective in reducing soil salinity levels.

Evaluation of vegetable cultivation under saline irrigation water conditions in arid areas

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Agriculture in the Sultanate of Oman is under the severe constraints posed by its natural environment. With dry and hot climate, scarcity of water forces farmers to use the saline ground water for irrigation.

To mitigate salt damages, (1) adoption of salt tolerant species and varieties, (2) adoption of improved technologies like mulching, utilization of organic matters, slow releasing fertilizers, and other measures to improve plant nutritions, and (3) construction of better irrigation system with minimum water leakage have been introduced.

Experiments were conducted to know effective measures to obtain reasonable harvest of fruit vegetables under drip irrigation using saline water as source water in Oman. In tomato experiments, 4 varieties were evaluated their adaptability to 5 sites (Farm 3, Agricultural Research Center farm, Jimmah, Al-Kamel and Sohar) with or without mulching. In Farm 3 and ARC farm, salt concentration in irrigation water reached 11.1 and 12.7 dS/m. Under such high salinity, total soluble solid of fruit increased but growth and fruit yields decreased. Mulching was effective even under salty conditions. Salt reduced K^+/Na^+ ratio in leaves.

Similarly 5 F1 varieties of watermelon were evaluated at 4 sites (excluding Farm 3 from the previous experiment). Significant differences were observed in total soluble solids among varieties, sites, and mulching treatment. Pulp thickness, rind thickness, and fruit yields differed by genotypes, locations and mulching treatment.

Ca ion effects to mitigate Na toxity were examined using melon root elongation as indicator. The effects were generally confirmed throughout the experiments. However effects of Ca ion change by concentration of Ca ion applied, or species or varieties of plants. It may be necessary to confirm suitable Ca ion concentration according to each concrete cases.

Salt tolerance at germinating stage was examined using 14 species of plants. There were conspicuous difference among 4 tomato varieties. Halophytes showed higher tolerance at germinating stage.

From the results obtained above, several recommendations were suggested as following:

1. Drip irrigation should be introduced to coastal areas of Northern Oman to minimize the over exploitation of underground water.
2. Mulching practice should be extended in vegetable cultivation because it is effective to raise productivity.
3. More number of salt tolerant crops like cotton, barley, beet, sunflower, sapodilla, date palm and coconut palm should be examined under the saline irrigation water. Some halophyte plants such as *Salicornia*, *Salsora*, *Suaeda*, *Atriplex* and others, should be checked of their performance under the saline water.
4. The effects of calcium to mitigate sodium toxity should be examined further on their sources, particle

size and concentrations of solution.

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This paper is to study the influence of saline water irrigation under different nutrient conditions on the growth for poplar (*Populus alba L.*) in a sandy soil subjected to 4 treatments (saline water irrigation with much fertilizer, saline water irrigation with few fertilizer, fresh water irrigation with much fertilizer, fresh water irrigation with few fertilizer) from 1999 to 2000. The dynamic movements of water and nutrient in the soil and tree were also studied. These three aspects were discussed in this paper.

Firstly, we investigated the growth and biomass of *Populus alba L.* in 1999 and 2000. The results were as follows:

1) The tree height, diameter and biomass in fresh water irrigation with much fertilized treatments were larger than those in saline water irrigation with few fertilized treatments in two years.
2) Root distributions of trees in saline water irrigation treatments were shallower in depth and shorter in width than those in fresh water irrigation treatments.
3) The photosynthetic, transpiration rate and water potential of leaves in trees decreased in saline water irrigation treatments by saline water irrigation in second year (2000). The leaf area of trees in saline water irrigation treatments also decreased with increase of tree ages.
4) The growth of *Populus alba L.* was mainly affected by the amount of nutrient in 1999, and by both the amount of nutrient and salinity in 2000.

Secondly, the vertical changes in soil temperature, soil electric conductivity (EC), soil moisture, nutrient and salinity during 1999 and 2000 were also studied under saline water irrigation. The results were as follows:

1) The soil water contents and EC at depths of 10cm, 20cm and 40cm in saline water irrigation treatments were higher than those in fresh water irrigation treatments. These results might have been caused by decreases in photosynthesis, transpiration rate, leaf area and root biomass in saline water irrigation treatments.
2) The salt accumulation at the surface soil in saline water irrigation treatments was found, and the depth of salt accumulation in it increased with increasing times of saline water irrigation. High Na^+ and Ca^{2+} contents were showed in it. Significant positive correlations were showed between the Na^+, Ca^{2+} contents and EC of soil in saline water irrigation treatments. The EC values of soil might indicate the extent of salt accumulation during this period.
3) Phosphorus contents in saline water irrigation treatments decreased and potassium contents increased in the second year (2000) of the study. The increase of potassium contents in saline water irrigation treatments might have been due to the more uptake of Na^+, and less uptake of K^+ by plants under salt stress.
4) In first year (1999), the soil temperature at the depth of 10cm in saline water irrigation treatments was not different from that in fresh water irrigation treatments, but in second year (2000) it was 2 ~ 3ºC higher than in fresh water irrigation treatments which had dry sand layer. The higher temperature may have influenced the growth of *Populus alba L.* in saline water irrigation treatments.

Finally, we analyzed changes of nutrient contents in each part of *Populus alba L.* under saline irrigation during two years. The results were as follows:

1) High Na^+ contents in leaf, branch and root were showed in saline water irrigation treatments during 1999 and 2000. The value of Na^+ rates allocated in root increased, decreased in leaf. Especially in second year (2000), Na^+ rate allocated in stem was significantly higher than in first year (1999). Absorption for K^+ ion in leaf and root were prevented from increasing the amount of absorption for

Na^+ ion in saline water irrigation treatments. Uptake for Ca^{2+} ion in root also showed lower than in leaf, branch and stem. *Populus alba L.* might have and ability to accumulate Na^+ in non-photosynthetic organs (stem, branch and root) to avoid salt injury of leaf or have an ability to transport Na^+, Ca^{2+} from root to stem and branch.

2) Sodium contents of the root at depth of 0 – 60 cm were higher than these over 60cm deep in saline water irrigation treatments. K^+ contents of the root at depth of 0 ~ 60cm, 60 ~ 120cm decreased in two years. Na^+/K^+, Na^+/Ca^{2+}, Na^+/Mg^{2+} rations in root showed significant negative correlations with aboveground biomass and root biomass in second year (2000). Na^+/K^+ ratio in leaf, Na^+/Ca^{2+}, Na^+/Mg^{2+} rations in branch also showed the same results as root biomass. We concluded that *Populus alba L.* might mainly adjust the uptake of salt ion by root to adapt the salt stress.
3) Na^+/K^+ ratio of leaf, branch and root, Na^+/Ca^{2+}, Na^+/Mg^{2+} rations of root in saline water irrigation treatments were higher than those in fresh water irrigation treatments during 1999 and 2000. *Populus alba L.* might have been subjected to some salt stress under 2000ppm saline water irrigation.
4) Nitrogen and phosphorus contents of plants showed no difference among 4 treatments under saline water irrigation. It is necessary to conduct further research to understand their mechanisms.
5) Plants in the much fertilized treatment were more uptake for K^+ and less uptake for Na^+ than those in the few fertilized treatment under saline water irrigation. Na^+/K^+, Na^+/Ca^{2+}, Na^+/Mg^{2+} ratios of each part of saplings in the much fertilized treatment also were lower than those in the few fertilized treatment. These results indicate that salt stress might have been moderated with increasing amount of fertilizing under saline water irrigation.

The results presented in this study suggest that the growth of *Populus alba L.* was mainly influenced by the amount of nutrient in first year (1999), and by both the amount of nutrient and salinity in second year (2000) under 2000ppm saline water irrigation. The salt accumulation occurred at the surface of soil in saline water irrigation treatments, and depth of salt accumulation increased with increasing times of saline water irrigation. Highly positive correlations were showed between the Na^+, Ca^{2+} contents and EC of soil in saline irrigation treatments. The uptake for K^+ in *Populus alba L.* was prevented from more uptake for Na^+ under 2000ppm saline water irrigation. *Populus alba L.* might have an ability to accumulate Na^+ in non-photosynthetic organs (stem, branch and root) to avoid from salt injury of leaf. Na^+/K^+ ratios of leaf, branch and root, Na^+/Ca^{2+}, Na^+/Mg^{2+} ratios of root in saline water irrigation treatments were higher than those in fresh water irrigation treatments during this experiment. Especially in 2000, Na^+/K^+, Na^+/Ca^{2+}, Na^+/Mg^{2+} ratios of root showed significant negative correlations with aboveground biomass and root biomass. The salt stress might have been moderated with increasing amount of fertilizing under saline water irrigation. These results suggest that *Populus alba L.* might increase a potential ability by much fertilizing as a proper planting species in arid and semi-arid lands with salt accumulation.