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PERFORMANCE OF BIODRAINAGE SYSTEMS IN ARID AND SEMIARID AREAS WITH SALT ACCUMULATION IN SOILS

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ABSTRACT Biodrainage is the use of vegetation to manage water fluxes through evapotranspiration. It is an alternative technique that has recently attracted interest in drainage and environmental management. Sometimes "drainage" has become a "dirty word" and its implementation has been restricted. Biodrainage is one of the alternative options. The absence of effluent makes the system attractive. However, biodrainage systems must be sustainable in the long-term. Biodrainage theory does not go back too far. The relationship between soil, climate, irrigation management and salinity is not yet well defined. In this research the SAHYSMOD mathematical model was used with two different approaches. 1) Evapotranspiration rate of plantation strips does not change because of increased salinity with the passage of time (S. Akram et al., 2009); and 2) Evapotranspiration rate decreases due to salt accumulation in the soil. While the first approach showed that in most cases the system can perform for about 15 to 20 years, the second approach showed that the life time of the system may not exceed 10 years. In the second system water table draws down during the first 3 to 4 years; however, it rises afterwards due to lower evapotranspiration rate caused by salt accumulation in the soil of plantation strips. This, however, shows that the system may not be considered sustainable in arid and semi arid areas especially where the irrigation water is saline. The result agrees with Heuperman et al. (2002) who says that it is doubtful that biodrainage can maintain soil salinity to an extent that crops could be grown economically. The result, however, does not agree with Kapoor and Denecke (2001) who indicates that biodrainage could be used in various regions ranging from humid to semi arid areas, except when the ground water EC is greater than 12 dS m-1. Hybrid system that combines bio-drainage and conventional drainage technology and/or salt removal and extra land for tree plantation may lengthen the life of the system.

Keywords: Drainage, Biodrainage, Sustainability, SAHYSMOD, Water table, Salinity.

INTRODUCTION In certain circumstances, the conventional solutions to drainage problems may not be feasible. In arid and semi arid regions usually there is water scarcity and abundant land. The lands are mostly saline. One may think of allocating water to a portion of the land and leave the rest to grow highly evapotranspirating salt tolerant trees such as Acacia, Eucalyptus, and Tamarix or high water consuming halophytes. Tree plantation strips evaporatranspirate at high rates making lower water potential beneath its root zone, hence, water in crop strips move towards the plantation strip bringing salts along. (Tomar & Gupta , 1999, S. Akram et al. 2008).

Biodrainage theory does not go back too far. So, the relationship between soil, water, and climatic parameters, in one hand, and the performance of system, in the other, is not yet well defined. S. Akram et al. (2008) attempted to study sensitive variables controlling salinity and water table control in a biodrainage system. Using a mathematical model, he found that the major constraint of biodrainage is salt accumulation in tree plantation strips in arid and semi arid regions. Maximum water salinity which could be tolerated was about 3 dS m^{-1} in medium run and sustainability may only be achieved where a salt removal mechanism such as periodical surface soil stripping and/or using a hybrid system of traditional drainage and biodrainage exists. He, however, ignored the lower ability of trees to evapotranspirate due to higher osmotic pressure caused by higher salt content.

MATERIALS AND METHODS This study attempts to investigate the effect of soil salinity on evapotranspiration rate of plantation strips located in every other strip with the crop strips, hence, lowering the water potential difference between the two adjacent strips which results in lower amount of water transmitted from crop strip into the plantation strip. In this study, the characteristics of the Eucalyptus tree are considered for the sake of simulation. In order to reach to the research goals, a mathematical model that could simulate groundwater level and salinity in both crop and plantation strips in the long run was needed. The hypothesis of the study is that accumulation of salts in plantation strips reduces their evapotranspiration; hence it might bring the water table in the crop strips higher to such an extent that crop can no longer live.

Selection Of The Appropriate Model SAHYSMOD (Spatial Argo-Hydro-Salinity Model) was used in this research. The model, is composed of two previously used models SALTMOD (agro-hydro-salinity model, Oosterbaan, 1998) and SGMP (nodal ground water model, Bootstrap and de Rider, 1981). SAHYSMOD was developed by K.V.G.K. Rao, Oosterbaan and Bootstrap (SAHYSMOD working group of ILRI, 2003). The model inputs are soil, plant and water parameters. Water and salt balance is used to simulate groundwater level and salt concentration in both crop and plantation strips in consecutive years. SAHYSMOD mathematical model is capable of forecasting soil moisture, quantity and quality of drainage water and groundwater depth in irrigated land with different geohydrological conditions. It is also able to examine different management options that can include the use of groundwater for irrigation, changing cropping pattern, etc. (Manual of SAHYSMOD, 2005).

Another model was needed to simulate actual evapotranspiration of trees due to increased salt concentration in plantation strips which which causes salt transfer from the crop strip into the neighbouring plantation strip. The model could be a combination of two equations "salinity - yield" as described in FAO Irrigation and Drainage Paper No. 33 and "yield - evapotranspiration" as stated in FAO Irrigation and Drainage Paper No. 56. This, however, results in a third formula which describes reduced evapotranspiration rate under different salinities.

Yield - salinity relationship When the soil salinity exceeds a threshold value, which varies for different crops, the crop yield decreases linearly with increase in salinity, expressed as electrical conductivity of the soil saturation extract (ECe). According to FAO Irrigation and Drainage Papers 33 and 56, one can find the following equation:

$$\frac{Y_a}{Y_m} = 1 - \left(EC_e - EC_{e\,threshold}\right)\frac{b}{100} \quad (1)$$

In which: Ya= actual crop yield; Ym= maximum or potential crop yield under normal condition; ECe= electrical conductivity of the soil saturation extract (dS $m^{-1)}$; ECthreshold= threshold of crop yield reduction due to soil salinity (dS m^{-1}); and b= per cent yield reduction for one unit of salinity increment after threshold of crop tolerance (% / dS m^{-1}).

Yield - evapotranspiration relationship The b value for Eucalyptus could not be found. So, the results of a research performed in California (S. R. Grattan, 2005) are used in this study (Liaghat et al. 2010). Eucalyptus yield reduction due to salinity is shown in Figure 1. The best fit curve shows the following relationship between the relative yield reduction and salinity (Liaghat et al. 2010, Grattan et al. 2005):

$$\frac{Ya}{Ym} = 1.02 - 0.028 \times EC_e \quad (2)$$

Salinity - evapotranspiration relationship To study the effect of salinity on evapotranspiration, the equations (1) and (2) combined with each other. The following relationship was obtained:

$$ET_{adj} = \{1 - \frac{(0.028 \times EC_e - 0.02)}{K_y}\} \times ET \quad (3)$$

In which:

ET_{adj}= adjusted or actual evapotranspiration due to the effect of soil salinity;

ET= theoretical electrical conductivity of the soil saturation extract in normal condition; and K_y = crop yield reduction factor.

An interface program facilitated evaluation of the effect of salinity on plantation evapotranspiration year to year. Then, the core program, SAHYSMOD, simulated groundwater level of crop strips.

Study Area In this study, several crop strips were laid adjacent to plantation strips. Nine crop to plantation ratios were considered. The hypothetical land was considered a rectangle. The minimum width of crop strip considered to be 30 meters. Both crop and plantation strips were very long (1000 m) but narrow (15 m) polygons. Thus, it can be assumed that water transfer only occurs between the neighbouring crop and plantation strips. Furthermore, in order to eliminate the effect of water and salt transfer to the outer side of the strips, the hydraulic conductivity at these sides assumed to be very small (0.01 md^{-1}). The model ran several times and the collected outputs analysed.

Notation In this study, the following symbols is used:

Lt / Lc = the ratio of crop strip width to plantation strip width, m m^{-1};

ET = evapotranspiration rate, m3 m-2 season-1;

Sl = depth of the barrier depth, m;

Dwu = groundwater depth in plantation strips, m;

Dwa = groundwater depth in crop strips, m;

Hwu = elevation of water level in plantation strips compared to a reference datum, m;

Hwa = elevation of water level in crop strips compared to a reference datum, m;

Ia = depth of irrigation water, m3m-2 season-1;

K = soil hydraulic conductivity, md^{-1};

Cic = irrigation water salinity, dS m^{-1};

Co = soil salinity, dS m^{-1};

Cru =soil salinity in the plantation root depth, dS m^{-1}; and

Cra = soil salinity in the crop root depth, dS m^{-1}.

RESULTS AND DISCUSSION The trends of changes of water table depth as well as the soil salinity in both crop strips and plantation strips are important factors affecting the performance and the life cycle of the system.

Two general conditions were assumed; 1) salinity does not affect the evapotranspiration rate of plantation strips, and 2) salinity affects the evapotranspiration rate of plantation strips. It seems, however, in the second case because of assumption of salt deposit in the plantation strips, the osmotic potential increases, hence, the evapotranspiration rate reduces in plantation strips, and thus the water table cannot fall down anymore which results in waterlogging of the crop strips and the failure of biodrainage system.

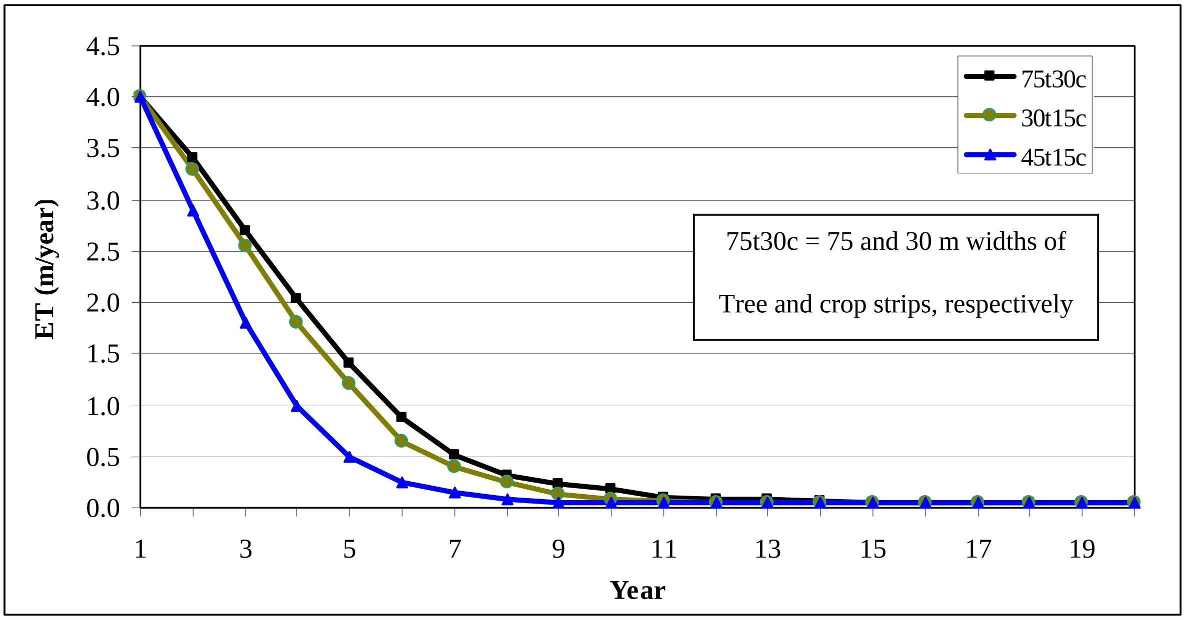

Figure 1. The trend of evapotranspiration changes due to salt deposits in the plantation strips.

Figure 1 shows that the trend of evapotranspiration of eucalyptus trees decreases year to year. As it can be seen, evapotranspiration decrease is faster when the ratio of LT/LC is higher. In other words when LT/LC =3 the evapotranspiration decrease is sharper than when LT/LC = 2.

Water table changes in tree strips over time Water table variation in tree strips for both cases i.e. with and without salinity effect, are shown in Figure 2. All parameters such as the soil hydraulic conductivity, drainage coefficient, depth of the barrier, etc. assumed to be identical except the LT/LC ratio.

The assumption of ignoring the influence of salinity on evapotranspiration rate of trees, the water table drops sharply in the first year or two to a depth of 1.4 to 1.6 meters below the soil surface and then it rises with a mild slope. This means that the salinity control could have profound effect on the life cycle of the system. On the other hand, in the first one or two years the trend of water table fall is the same for both cases but it rises very rapidly afterwards and reaches to about 50 centimeters from the soil surface after 5 to 7 years. So, one can expect that eucalyptus plantation could not be able to continue its life. The greater the LT/LC ratio, the life of the system is longer. The difference, however, is not very significant. Of course shallower root plants such as halophytes may be able to survive provided that the evapotranspiration rate of these plants is not lower than eucalyptus.

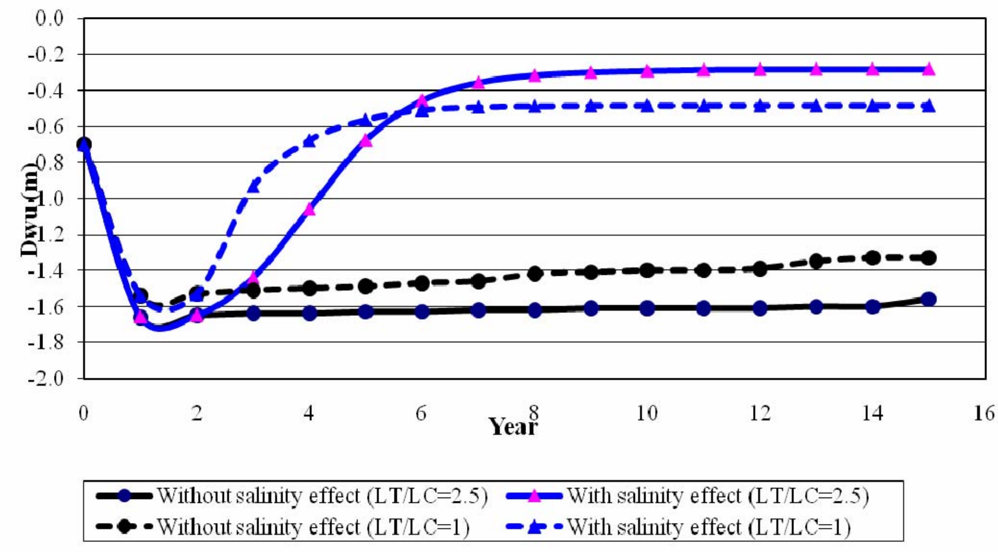

Figure 2.Water table fluctuation in plantation strips with different ratios of LT/LC

Water table changes in crop strips over time Water table variation in crop strips for both cases i.e. with and without salinity effect, are shown in Figure 3. All parameters such as the soil hydraulic conductivity, drainage coefficient, depth of the barrier, etc. assumed to be identical except the LT/LC ratio.

The trend of these curves are the same as the corresponding curves for plantation strips. This is because the salt and water movement from crop strip into plantation strip depends on the potential difference, or water table elevation difference, between the two adjacent strips. So, by rising water table in plantation strip, the same will happen in the crop strip as well.

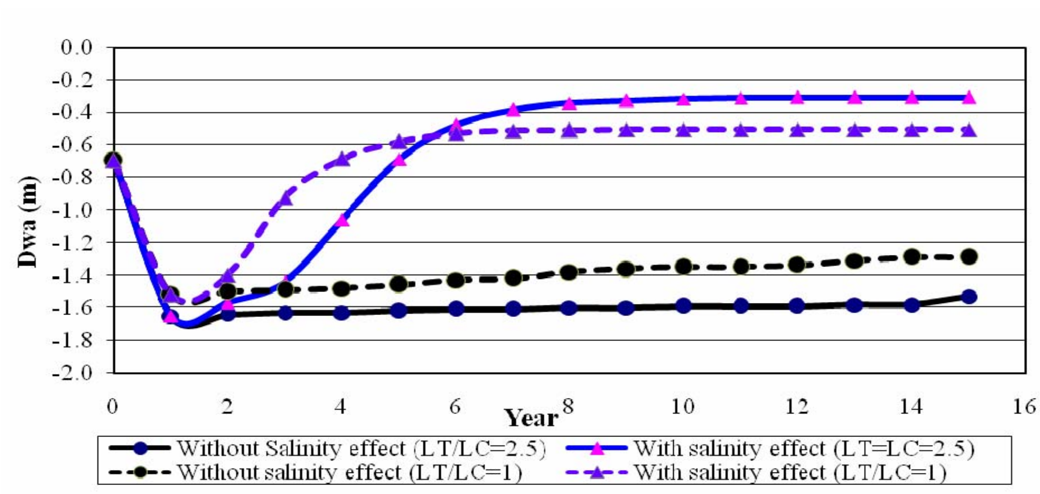

Figure 3 .Water table fluctuation in crop strips with different ratios of LT/LC

Salinity changes beneath the root zone of tree strips over time Salinity variation in tree strips for both cases i.e. with and without salinity effect on evapotranspiration, are shown in Figure 4. All parameters such as the soil hydraulic conductivity, drainage coefficient, depth of the barrier, etc. assumed to be identical except the LT/LC ratio.

The assumption of ignoring the influence of salinity on evapotranspiration rate of trees, the salinity rises gradually and almost steadily over time until it reaches to a value which trees cannot tolerate anymore and eventually die. In case where it could be assumed that eucalyptus dies when the EC of the soil extract reaches to 32 dS m^{-1} the life of the system would be around 20 years.

This means that the salinity control could have profound effect on the life of the system. On the other hand, in the first one or two years the trend of water table fall is the same for both cases but it rises very rapidly afterwards and reaches to about 50 centimeters from the soil surface after 5 to 7 years. So, one can expect that eucalyptus plantation could not be able to continue its life. The greater the LT/LC ratio, the life of the system is longer. The difference, however, is not very significant. Of course shallower root plants such as halophytes may be able to survive provided that the evapotranspiration rate of these plants is not lower than eucalyptus.

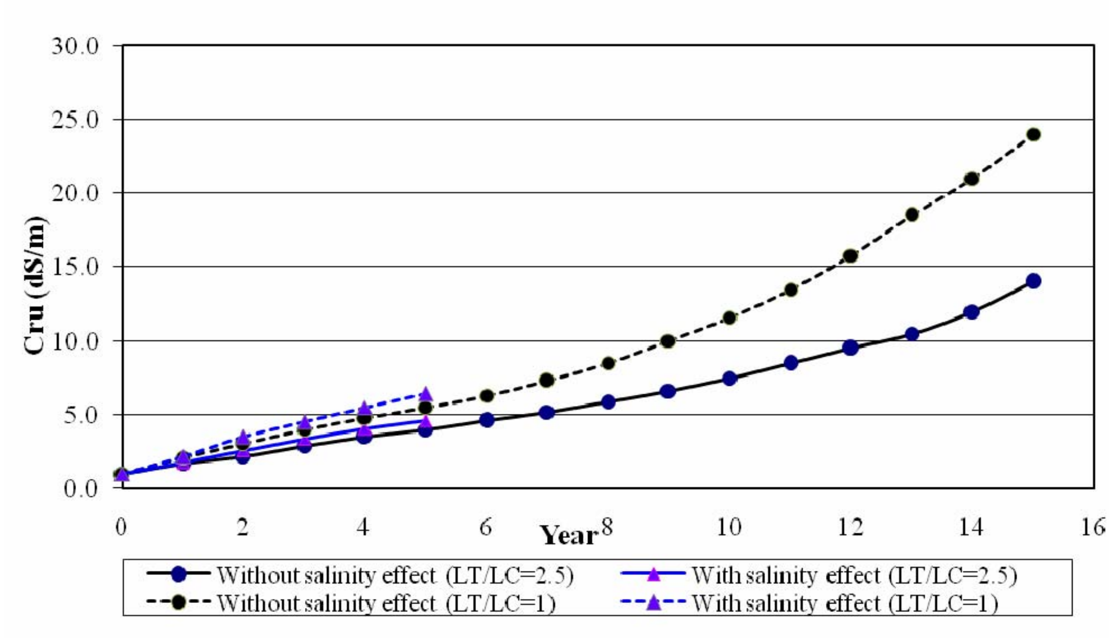

Figure 4.Salinity fluctuation in plantation strips with different ratios of LT/LC

Life of the system In the case of ignoring the influence of salinity on evapotranspiration the biodrainage system generally cannot continue its life more than about 15 years. It is obvious that the life time mostly depends on the irrigation water salinity. The result, however, does not agree with the results reported by Kapoor and Denecke (2001) which indicates that the biodrainage system is sustainable when the irrigation water salinity is less than 12 dS m^{-1}.

No doubt that salt accumulation is responsible for non-effectiveness or even the failure of the system. Most authors believe that biodrainage is able to maintain water table in a position not to be hazardous to the crop. However, some are doubtful about its sustainability from the point of view of soil salinity and believe that unless some type of salt removal mechanism such as foliage harvesting, salt scraping from the soil surface, and/or leaching facility exists, the system cannot remain sustainable. Scraping salts accumulated in the soil surface is rather a common measure in pistachio orchards in south eastern part of Iran as it can be seen in Picture 1. Periodic disposal of soil salinity through combination of biodrainage and traditional drainage system with a wider spacing also can ensure the disposal of parts of the salts received to the plantation strips. It seems that this period may change from drainage in non irrigated period of the year for brackish waters to a continuous drainage with wide spacing laterals for saline irrigation water. This can be an important and appropriate topic for research. This agrees with suggestions of combination of biodrainage and a conventional one first made by Heuperman et al. (2002) and Heuperman (2003).

Picture 1. Salts in the middle of the rows of pistachio plantation ready to be harvested

In the case of considering the influence of salinity on evapotranspiration, the biodrainage system cannot continue its life more than about 5 to 6 years.
In both fixed and variable evapotranspiration, the ratio of tree strip width to crop strip width should not be less than 2.

CONCLUSIONS In short, biodrainage does have a high sensitivity to salinity in regions with arid and semi arid climates. If one wishes to find a solution to this problem when the irrigation water is too saline, biodrainage cannot be a good alternative to conventional drainage systems.

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