SUSTAINABILITY OF BIODRAINAGE SYSTEMS CONSIDERING DECLINING OF EVAPOTRANSPIRATION RATE OF TREES DUE TO SOIL SALINIZATION

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ABSTRACT Biodrainage is a natural system in which tree plantation strips absorb deep percolation losses of irrigation water applied to neighbouring crops. Loss of excess water through evapotranspiration maintains water table at a desired level. It is doubtful, however, if biodrainage can maintain soil salinity to an extent that crops could be grown economically (Heuperman et al. 2002). According to Kapoor and Denecke (2001) 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. The main constraints of biodrainage are salt accumulation in plantation strips, the need for salt removal and extra land for tree plantation. The sustainability of the system, however, is questionable except where the irrigation water is quite suitable and/or in humid regions with high annual precipitation. In saline environments, hybrid system that combines biodrainage and conventional drainage technology will be needed to achieve sustainability. The purpose of this research is to determine the sustainability of biodrainage systems in low hydraulic conductivity soils with moderate water salinity and different barrier depths. SAHYSMOD, a known drainage and ground water mathematical model was used to simulate ground water level and the soil salinity simultaneously at the end of each year. Plant evapotranspiration decreases annually due to salt accumulation in the root zone and increasing osmotic pressure. The results showed that the system life could not be more than 5 to 6 years, while it is around 10 years when the depth to the barrier increases to 10 meters. The main conclusion of the study is that biodrainage could not be considered as a sustainable technique in arid and semi arid regions without availability of good quality irrigation water and/or used in conjunction with conventional drains.

Keywords: Drainage, biodrainage, sustainability, SAHYSMOD

INTRODUCTION For optimum plant growth, it is essential that proper physical and chemical conditions within the root development zone persist. In natural conditions, hydrologic components such as precipitation, evapotranspiration, changes in soil water storage and drainage water are in equilibrium. Prolonged rainfall period may temporarily

increase the drainage flow or result in higher water level or increase of soil moisture storage. Then in the subsequent period it may return to its previous balance. In this process, the vital role of plants by evapotranspiration and soil water storage could not be ignored. When farm crops or trees planted in a particular place, because of their different evapotranspiration rates the groundwater level changes (Heuperman, 2002). This phenomenon is called "biodrainage". In this method, tree plantation strip absorbs deep percolation losses of irrigation water applied to neighbouring crop strip and dispose excess water through evapotranspiration and maintains water table at a desired level. Since the plants usually have higher evapotranspiration rates, the groundwater level falls down makes a lower potential, hence groundwater of the crop strip moves towards the plant strip (Tomar & Gupta , 1999). Salts in the soil water increases osmotic pressure which results in lower evapotranspiration. In this case additional potential is needed to extract water from the soil. In addition, some ions have toxic effects on plants reducing their metabolism, hence their growth, which results in lower leaf surface area which again reduces its evapotranspiration. Because of lower evapotranspiration of plant strips, potential difference between the two adjacent strips reduces to some extent that biodrainage cannot function properly.

MATERIALS AND METHODS This study has attempted to investigate biodrainage behaviour considering the effect of soil salinity on evapotranspiration rate of plantation strips which are laid adjacent to the crop strips. Among the highly resistant plants *Tamarix troupii*, Acacia (*Acasia tortilis* and *Acasia nilotica*) and *Eucalyptus camaldulensis* could be named. 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. In other words, the model should be able to simulate the effects of parameters such as drainage coefficient, hydraulic conductivity, depth of the barrier, initial soil and irrigation water salinity, annual rainfall and so on using water and salt balance in the years to come. Accumulation of salts in plantation strips reduces their evapotranspiration; hence it might bring the water table in the crop strips higher.

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) 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. In other words, the model simulates the effects of water and soil parameters such as drainage coefficient, hydraulic conductivity, depth of the barrier, initial soil and irrigation water salinity, annual rainfall as well as crop parameters such as evapotranspiration and growing period (Akram, 2006). 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).

THE EFFECT OF SALINITY ON EVAPOTRANSPIRATION OF TREES Salt concentration increase in the soil solution reduces osmotic potential (more negative). So, the plant will spend more metabolic energy and may use more mechanical power to extract water from the soil. In dryer soils more metabolic energy will be used and the toxic effects of salts may even make it more severe. The reaction of different plants to the soil salinity is not the same. Some plants can have an acceptable yield even in highly saline soils. The reason for this difference is that some plants can adopt themselves with lower (more negative) osmotic pressure; hence, they are able to extract water out of the saline soil.

Introduction of crop yield function This function relates the reduction in evapotranspiration due to the soil salinity. The function is derived from the combination of two equations "salinity - yield" and "yield - evapotranspiration" (FAO paper No. 56). This, however, results in derivation of a third function which describes reduced evapotranspiration rate under different conditions of salinities.

Yield- salinity relationship When the soil salinity exceeds from a threshold value, the crop yield decreases linearly with increase in salinity, expressed as electrical conductivity of soil saturation extracts (ECe). The following equation expresses the relationship between yield and the soil salinity (FAO papers 33 and 56).

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

In this formula:

Ya: actual crop yield;

Ym: maximum crop yield;

ECe: salinity of saturated soil;

ECthreshold: threshold of crop tolerance against soil salinity (dS/m); and

b: per cent yield reduction for one unit of salinity increment after threshold of crop tolerance (% / dS/m)

Relationship between evapotranspiration and crop yield Since the b value for Eucalyptus is not presented in literature, the results of a research performed in California (S. R. Grattan, 2005) are used in this study. Eucalyptus yield reduction due to salinity is shown in diagram 1. Using the data in this chart and REGRESS software (SMADA software series) the following relationship between the relative yield reduction and salinity was obtained:

$$\frac{Ya}{Ym} = 1.02 - 0.028 \times EC_e$$

To study the effect of salinity on evapotranspiration, the above equation combined with

the relationship between yield and evapotranspiration. The following relationship was obtained:

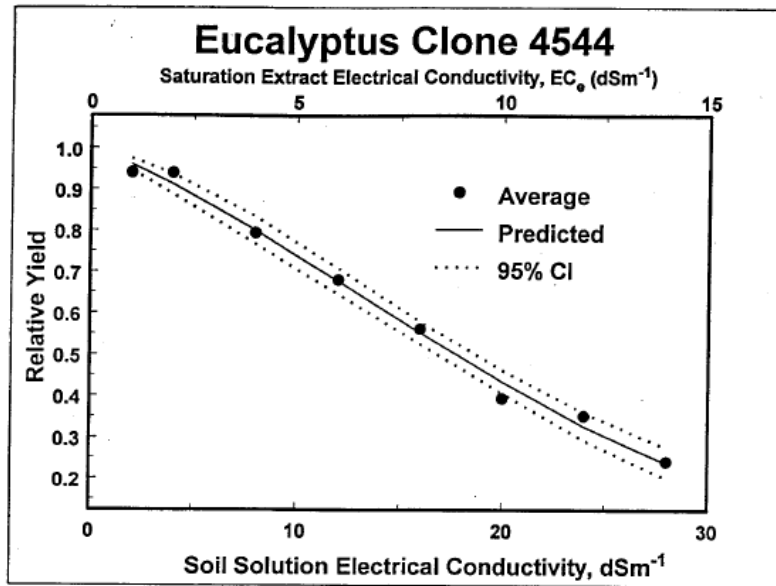$$ET_{adj} = \{1 - \frac{(0.028 \times EC_e - 0.02)}{K_y}\} \times ET$$

Figure1. Eucalyptus yield reduction due to soil salinity (Grattan et al. 2005)

PREPARATION OF AN INTERFACE PROGRAM TO evaluate the effect of salinity on plantation evapotranspiration, hence, on groundwater level of crop strips year to year, an interface program is developed to replace the salinity of the soil at the beginning of a particular year by salinity at the end of the previous year. The process continued for 20 years.

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 neighboring 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}). Figure 2 shows a sample layout of strips.
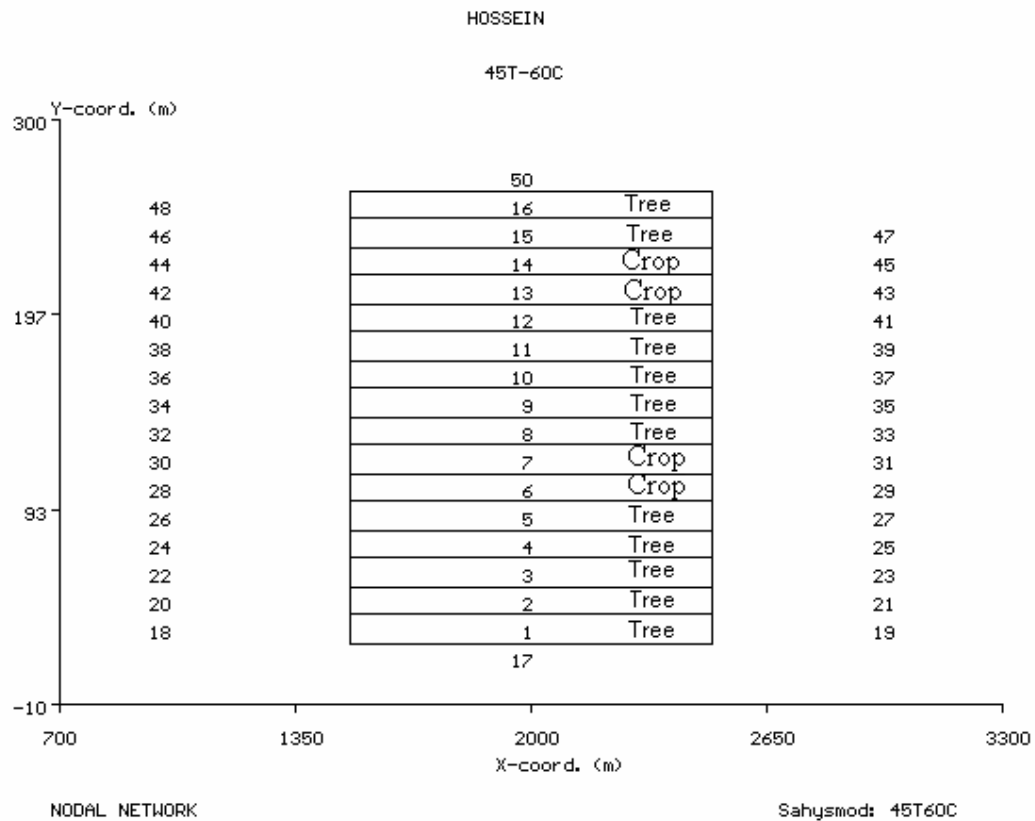
Figure 2. Layout of the hypothetical land with a ratio of 30 m to 75 m widths of crop and plantation strips, respectively

The model ran for several combinations of widths of crop strips, widths of plantation strips, hydraulic conductivities, depths to the barrier, seasonal irrigation water, and salinities of irrigation water.

RESULTS AND DISCUSSION In this study, the following symbols are used:

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

ET   =   evapotranspiration   rate, $m^3 m^{-2}$ 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, $m^3 m^{-2}$ 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, $dS\ m^{-1}$.

Effect of hydraulic conductivity on lowering the water table The trend of groundwater level change in soils with different hydraulic conductivities when the barrier depth is 4, 8, and 12 meters are shown in Figures 3, 4 ,and 5, respectively for the fifth year.

Increasing hydraulic conductivity up to about 2 m d^{-1} brings the water table higher in plantation strips. Higher hydraulic conductivities do not have real effect on the water table position. This positive trend in the higher ratios of Lt / Lc is slower and for lower ratios is faster. This means that higher ratios of plantation width to crop strip width, Lt / Lc, brings groundwater to a lower elevation in plantation strips. This is due to higher evapotranspiration of plants. Thus the underground water table falls down. This phenomenon is the same as what happens in conventional drainage systems.

 Figure 3 shows the trend of variation of water table with the changes of hydraulic conductivity when the barrier depth is 4 meters. As it can be seen in both very high and very low ratios of Lt / Lc (75t-30c, 45t-15c, 30t-15c, and 30t-90c in which t represents trees or plantation and c corresponds to crop and the figures are the widths of the strips in meters) the trend is reversed in the first 5 years. In other words with these ratios, increasing hydraulic conductivities result in lower water table depth. Perhaps this is because increasing hydraulic conductivity and high evapotranspiration rates in high ratios as well as higher volume of transmitted water in low ratios are responsible for creating a higher hydraulic gradient between crop strips and the neighbouring plantation strips.

Determination of biodrainage life time In biodrainage both water and soluble salts move from crop strip into the neighbouring plantation strip. In the absence of either natural or artificial drainage, salts accumulate in plantation strips. So, the salinity of plantation strips increase year by year, hence the evapotranspiration of plants decrease which results in lower water transfer from crop into the plant strip, and the biodrainage system fails to function.

Using this rationale, the evapotranspiration is calculated year by year for 20 years and for different ratios of Lt/Lc. A sample result is shown in Figure5 which clearly indicates that the plant evapotranspiration for all ratios of Lt/Lc decrease sharply due to salinity increase in plantation strips.
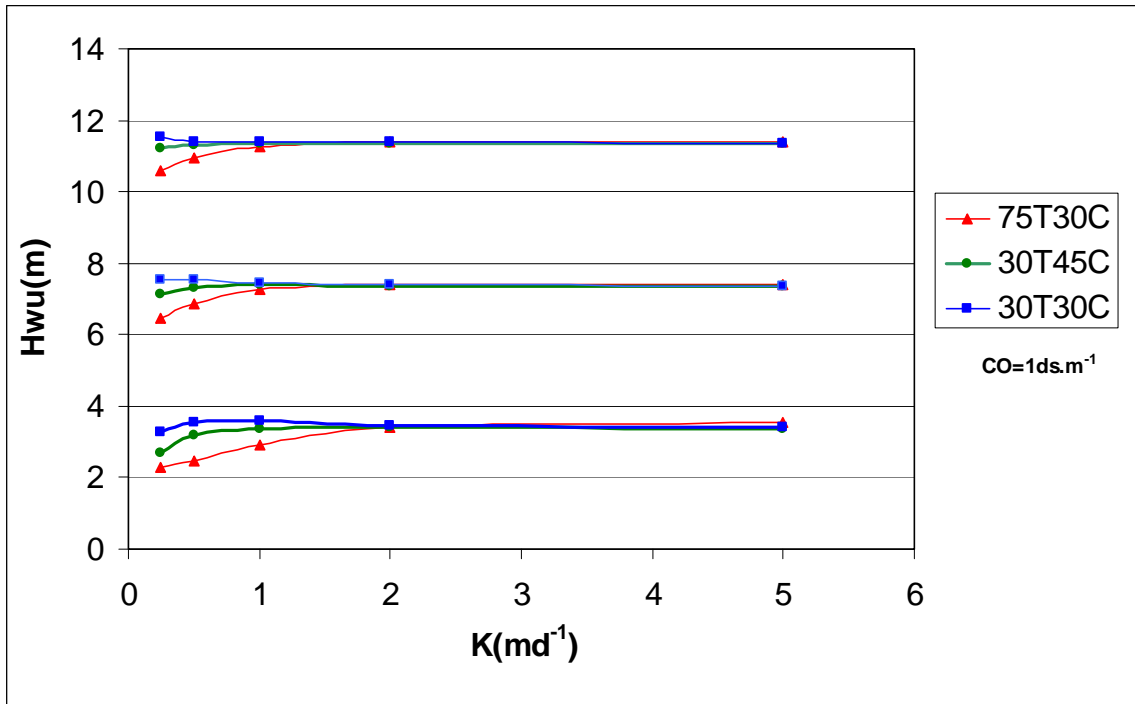
Fig3 - Ground water level changes with increased hydraulic conductivity when the barrier is located at 4 and 8 and 12 m
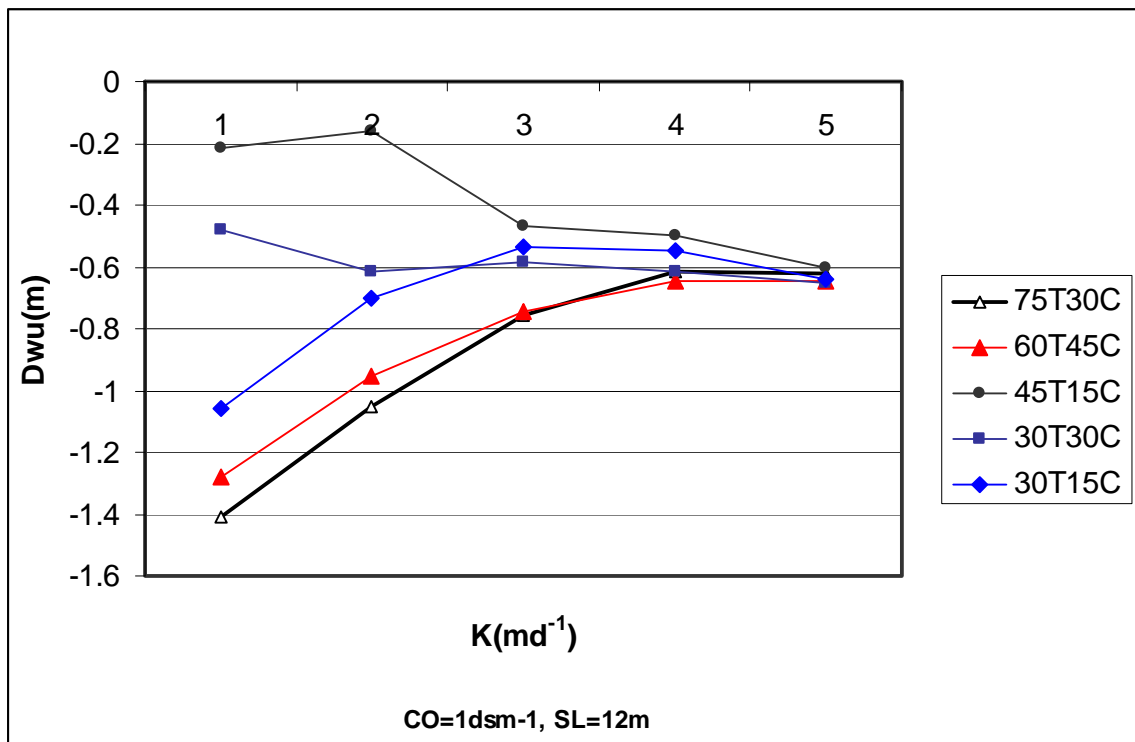

Fig 4- Underground water depth changes with increased hydraulic conductivity in different ratios of Lt/Lc
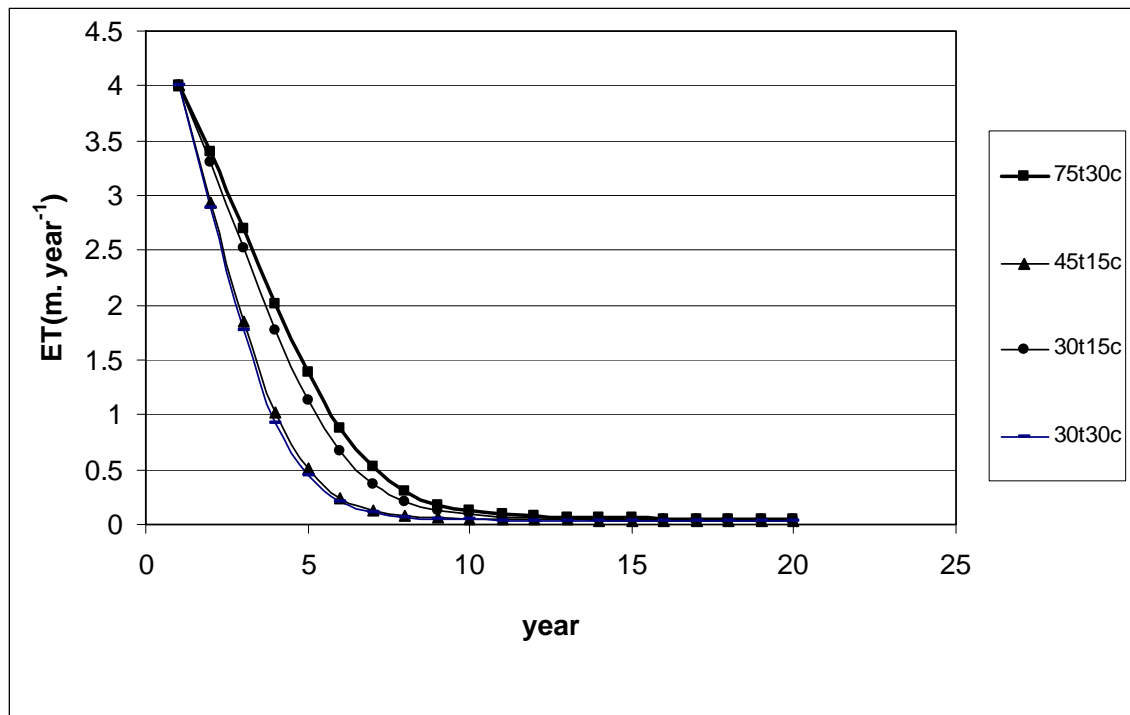
Figure5. Annual variation of evapotranspiration in plantation strip due to salt accumulation for different ratios of Lt/Lc

It should be noted that after the area was waterlogged, roots of plants cannot actually continue to live. Annual change of evapotranspiration of the tree strips affects salinity of the root zone. Tree root zone salinity changes reviewed during 20 years and Figure 6 is resulted. From this graph it is clear that the increased evapotranspiration of trees increases the salinity to such an extent that plant can no longer continue its life.

Effect of salinity on evapotranspiration was based on the FAO formula. According to Figure 6 in all ratios of Lt / Lc, salinity increases year by year during the 20 years simulated.
After waterlogging of the cropped area roots of plants cannot actually continue to live and biodrainage system fails. Annual change of evapotranspiration rate of plantation area will affect water table in both crop and plantation strips. Figures 7 and 8 show that for the few first years the water table in plantation strips falls down but then after it starts to rise. This is because after few years the evapotranspiration rate falls to such extent that cannot compensate the deep percolation of the crop strips.
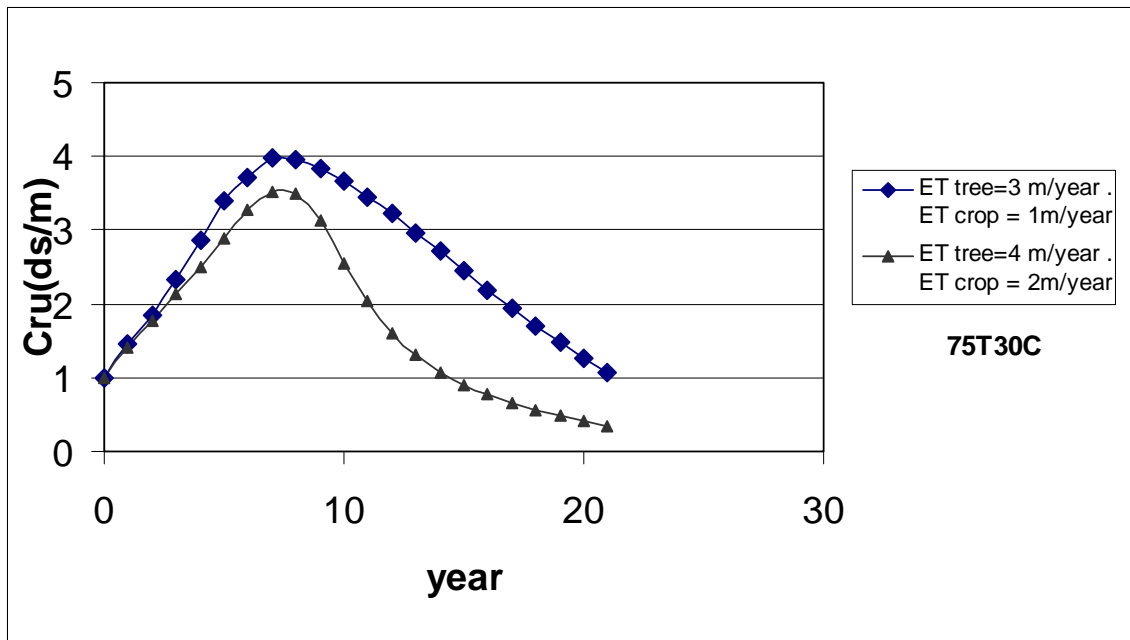
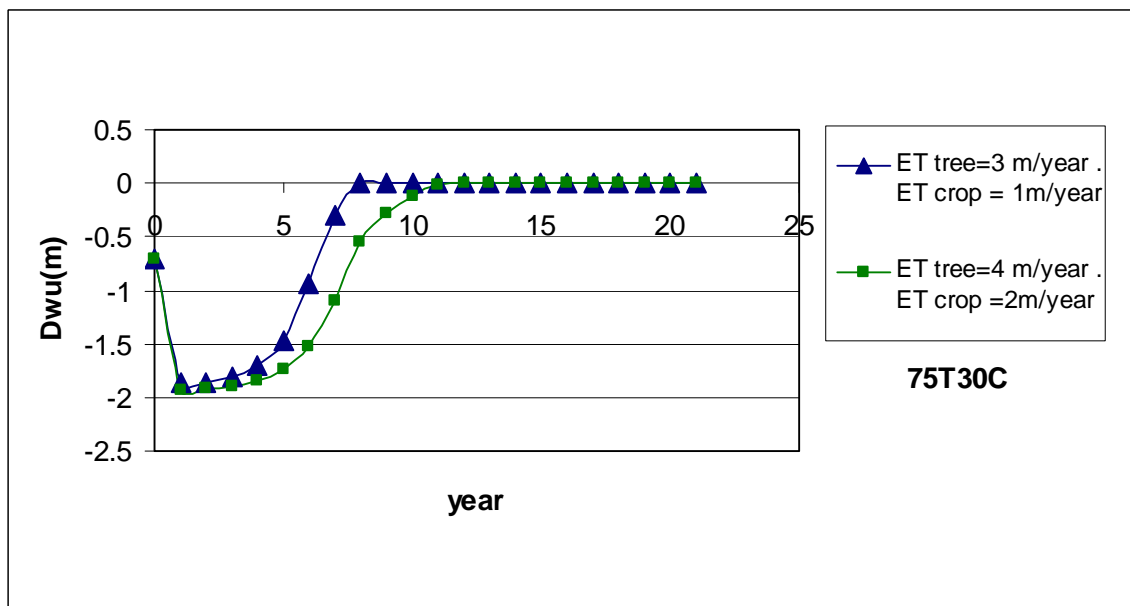Figure 6. Annual variation of salt concentration in plantation strip due to

Figure 7. Effect of evapotranspiration decrease on groundwater level in tree root zone
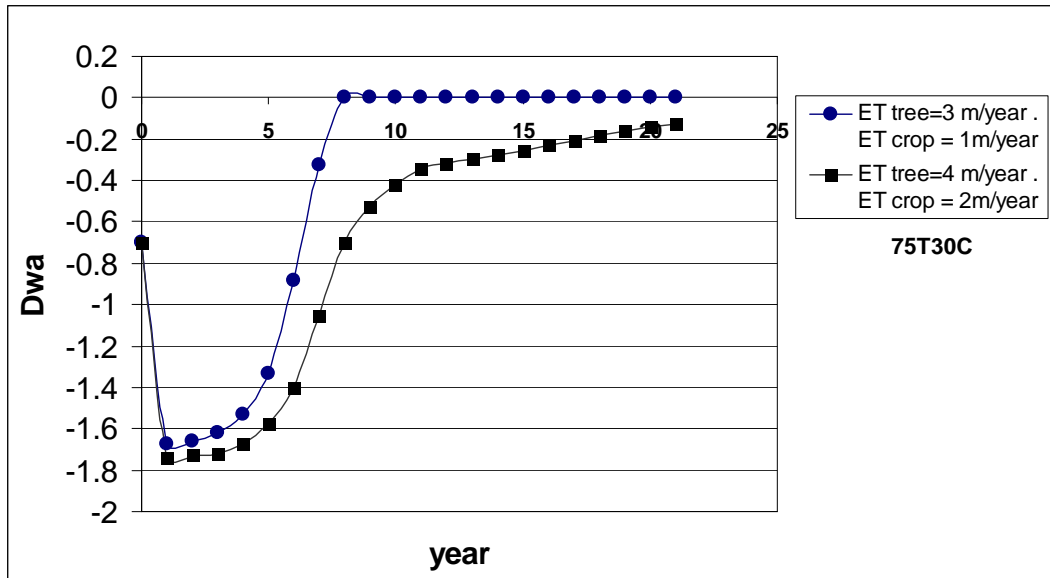
Figure 8. Effect of evapotranspiration decrease on groundwater level in drop root zone

GENERAL RESULTS

Effective parameters for improving biodrainage According to discussions conducted, it seems that biodrainage life in lower hydraulic conductivities and depths of barrier cannot exceed more than 5 to 6 years. This is because it cannot control ground water level in both crop and plantation strips anymore. Restoration of the land will be very expensive. With increasing the initial soil salinity the sustainability of the system is even harder.

Increased hydraulic conductivity and/or increased barrier depth causes drop of water table in the first years, while after 5 to 7 years it reaches to a depth of 50 to 80 centimeters which remains rather constant afterwards. The same happens when the hydraulic conductivity ranges between 2 and 5 m d^{-1} and the barrier depths between 8 to 12 meters regardless of the salinity. In higher ratios of Lt / Lc (especially in the ratios of 2, 2.5, and 3) water table stabilises in rather lower levels. In general it can be concluded that the Lt/Lc ratios of 75t-30c (2.5) and 30t-15c (2.0) and 45t-15c (3.0) are in better conditions. In these conditions one can expects that the life time of the biodrainage could be higher.
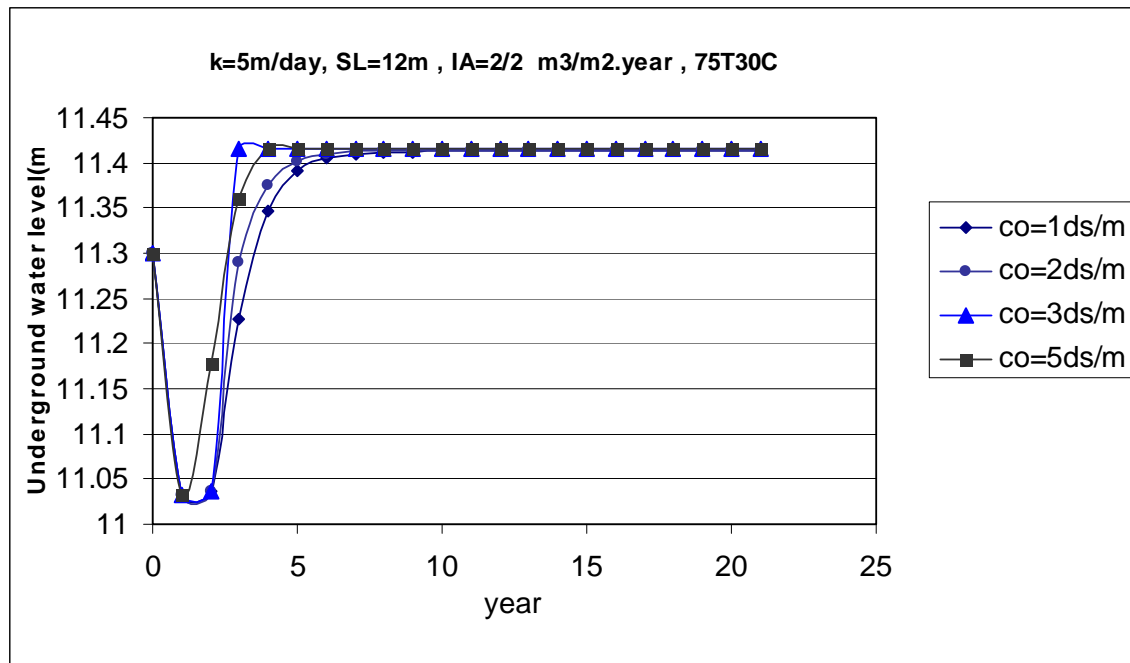
Figure9. Effect of different amounts of salinity in underground water level change over time

Biodrainage sustainability Due to increasing salinity during the years, evapotranspiration efficiency of the tree strips reduces to such an extent that actually will lose its applicability. Biodrainage, in fact, might last for 5 to 6 years even when the initial salinity is low and the hydraulic conductivity is less than 1 m d^{-1}. After this period, the water table can be dropped down either by means of pumping drainage water or a traditional drainage combined with biodrainage in plantation strips. Biodrainage in humid areas can be feasible because the initial soil salinity is usually lower and the rainfall has a good effect on lowering soil salinity.

Combined biodrainage and traditional drainage could be used in different climatic conditions. In this case, even with the initial salinity of 5 dS m^{-1} the system is able to be rather sustainable. While the hydraulic conductivity is more than 1 m $^{-1}$ the higher the barrier depth, the water table reaches deeper to equilibrium. Combined biodrainage system and traditional drains with wider spacing seems to control both salinity and water table satisfactorily. This issue, however, can be the subject of a separate research

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