Sustainability of biodrainage systems as influenced by 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. 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, a 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 in a semi-arid region. SAHYSMOD, a known drainage and ground water mathematical model, was used to simulate ground water level and soil salinity simultaneously at the end of each year. Plant evapotranspiration decreases annually due to salt accumulation in the root zone and osmotic pressure increases. The results demonstrated that the life system could not be more than 5 to 6 years, while it was around 10 years when the depth of the barrier increases to 10 metres. The main conclusion of the study is that biodrainage could not be considered as a sustainable technique in arid and semi-arid regions without the availability of good quality irrigation water and/or it must be used in conjunction with conventional drains.

Key words : Biodrainage, drainage, SAHYSMOD, sustainability

INTRODUCTION

The use of plants for pumping excessive sub-surface water is popularly known as ‘Biodrainage’ (Heuperman, 1992, 2000). Biodrainage is an eco-friendly technique for combating waterlogging and salinity (Jeet et al., 2008). Biodrainage is a natural system in which tree plantation strips absorb deep percolation losses of irrigation water applied to neighbouring crops. Loss of excessive water through evapotranspiration maintains the 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). Designing efficient biodrainage plantations based on tree transpirative capacity to enhance the discharge of shallow ground water tables demands a careful specie selection (Khamzina et al., 2005).

Due to high transpiration capacity and an ability to extract water from deeper layers containing saline ground water, trees can control rise in water table in irrigation command areas and prevent formation of waterlogged and eventually can prevent the saline wastelands (Chhabra and Thakur, 1998). 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 was greater than 12 dS/m. The main constraints of biodrainage are salt accumulation in plantation strips, the need for salt removal and extra land for tree plantation. 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

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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. Farm crops and trees, due to their different evapotranspiration rates, have the ability to change the ground water level (Heuperman et al., 2002). This phenomenon is called “biodrainage”.

In this method, a tree plantation strip absorbs deep percolation losses of irrigation water applied to its neighbouring crop strip and disposes excessive water through evapotranspiration and maintains water table at a desired level. Since the plants usually have higher evapotranspiration rates, the ground water level decreases and makes a lower potential, hence the ground water of the crop strip moves towards the plant strip. Salts in the soil water increase osmotic pressure which results in lower evapotranspiration. In this case additional potential is needed to extract water from the soil. Also, some ions have toxic effects on plants by reducing their metabolism, consequently their growth is effected which eventually results in lower leaf surface area that again reduces its evapotranspiration. Because of lower evapotranspiration of plant strips, potential difference between the two adjacent strips reduces to the extent that biodrainage cannot function properly.

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 in a semi-arid climate.

**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 the research goals, a mathematical model that could simulate ground water 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 increase the water table in the crop strips.

**Selection of the Appropriate Model**

SAHYSMOD model (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 ground water 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. SAHYSMOD mathematical model is capable of forecasting soil moisture, quantity and quality of drainage water and ground water depth in irrigated land with different geohydrological conditions. It is also able to examine different management options that can include the use of ground water for irrigation, changing cropping pattern, etc. (SAHYSMOD Working Group of ILRI, 2005).

The effect that salinity shows on evapotranspiration is viewed by the increase in salt concentration in the soil solution, consequently causing reduction in 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 is related to 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 by Richard *et al.* (1998)). 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 a threshold value the crop yield decreases linearly with increase in salinity. This is expressed as electrical conductivity of soil saturation extracts (ECe). The following equation (1) expresses the relationship between yield and the soil salinity (FAO Paper No. 56 by Richard *et al.* (1998)).

\[
y_a/y_m = 1 - \frac{(ET_e - ET_{e\text{ threshold}})}{b/100} ...(1)
\]

Where,
- \(y_a\) : Actual crop yield,
- \(y_m\) : maximum crop yield,
- \(ET_e\) : Salinity of saturated soil,
- \(ET_{e\text{ threshold}}\) : Threshold of crop tolerance against soil salinity (dS/m) and
- \(b\) : yield reduction per cent 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 (Grattan *et al.*, 2005) are used in this study. Eucalyptus yield reduction due to salinity is shown in Fig. 1. Using the data in Fig. 1 and REGRESS software (SMADA software series) the following relationship (2) between the relative yield reduction and salinity was obtained:

\[
y_a/y_m = 1.02 - 0.028 \times ET_e ...(2)
\]

To study the effect of salinity on evapotranspiration, the above equation was combined with the relationship between yield and evapotranspiration. The following relationship (3) was obtained:

\[
ET_{adj} = \left(1 - \frac{(0.028 \times ET_e - 1.02)}{K_y}\right) \times ET ...(3)
\]

**Preparation of an Interface Program**

In order to evaluate the effect of salinity on plantation evapotranspiration on ground water level of crop strips from year to year, an interface program was 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 Models**

In this study, several combinations of widths of crop strips to widths of plantation strips, were used, which crop strips were laid adjacent to plantation strips. The hypothetical land was a rectangle. 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. Nine ratios of crop to plantation were considered. The minimum width of a crop strip was considered to be 30 m. 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 was assumed to be very small (0.01 m/day).

Fig. 2 shows strips, hydraulic...
conductivities, depths to the barrier, seasonal irrigation water and sample layout of strips. The study area was assumed in a semi-arid zone which has 350 mm precipitation by 70% effective rainfall.

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Fig. 3 shows the variation of salinity during years of biodrainage for three different irrigation depths. It reveals that in the first five years of biodrainage time, increase in soil salinity by the increase of irrigation depth had no significant difference and all were approximately the same. After that, the small water depth caused bigger soil salinity.

The effect of increase in irrigation water depth on biodrainage and soil salinity of root zone was investigated by applying three irrigation water depths of 1.0, 1.47 and 2.2 m/year; and calculations were done to achieve salinity and water table level during a period of 20 years. The resulted values are presented in Figs 3 and 4 for the ratio of 75c30t (the most suitable ratio in this study).

It can be explained that bigger irrigation water depth had bigger percolation rate which caused more leaching of the salts in the soil profile and prevented salt accumulation. As a result, a bigger irrigation water depth on one hand controlled the salt in soil which increased biodrainage system life time, and on the other hand caused rise in water table near to ground surface.

The effect of applied water depth on water table during 20 years can be seen in Fig. 4. It is evident that increase in applied irrigation water depth in the first four years had no significant difference in water table level. As can be seen in Fig. 3 about the 5th to 7th years the salinity of root zone soil dramatically increased.

As mentioned before increase in salinity had direct effect on decrease of evapotranspiration which came to account by FAO formula in calculations. To survey this decrease in ET due to salinity, the variation for a period time of 20 years was calculated and plotted for plantation (tree) root zone. It reveals that during the first 4-6 years of biodrainage period the evapotranspiration decreased rapidly which could be due to accumulation of salt in the root zone (as seen before in Fig. 3). The subsequent result of decrease in ET was the rise in water table level which came near to ground surface (which was
evident after the sixth year in Fig. 4).

In biodrainage both water and soluble salts moved from crop strip into the neighbouring plantation strip. In the absence of either natural or artificial drainage, salts accumulated in plantation strips. So, the salinity of plantation strips increased year by year, hence the evapotranspiration of plants decreased which resulted in lower water transfer from crop to the plant strip, and as a result the biodrainage system failed to function.

Using this rationale, the evapotranspiration was calculated year by year for 20 years and for different ratios of Lt/Lc. A sample result is shown in Fig. 5 which clearly indicates that the plant evapotranspiration for all ratios of Lt/Lc decreases sharply due to salinity increase in plantation strips.

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 were reviewed during 20 years (Fig. 6).

From this graph it is clear that the increased evapotranspiration of trees increases the salinity to such an extent that the plant can no longer continue its life.

Effect of salinity due to evapotranspiration was calculated based on the FAO formula. According to Fig. 6 in all ratios of Lt/Lc, salinity increased year by year during the 20 years simulated. After the cropped area was waterlogged, the roots of the plants could not actually continue to live and biodrainage system failed.

Annual change of evapotranspiration rate of plantation area will affect water table in both crop and plantation strips. Figs. 7 and 8 show that for the first few years the water table in plantation strips fell down but then started to rise. This was because after a few years the evapotranspiration rate fell to such an extent

Fig. 5. Evapotranspiration decrease due to soil salinity during time for different ratios.

Fig. 6. Variation of plantation root zone salinity during time by two different primary evapotranspirations for ratio of 30t75c.

Fig. 7. Effect of evapotranspiration on variation of water table level during time in plantation root zone for ratio of 35t75c.
that it could not compensate the deep percolation of the crop strips.

**CONCLUSIONS**

Increase in soil salinity by the increase of irrigation depth had no significant difference in the first five years of biodrainage time. After that, the small water depth caused bigger soil salinity.

Due to increasing salinity during the years, evapotranspiration efficiency of the tree strips reduced to such an extent that it actually would lose its applicability. Biodrainage, in fact, might last for 5 to 6 years.

After this period, the water table could be dropped down either by means of pumping drainage water or a traditional drainage combined with biodrainage in plantation strips. Biodrainage in humid areas could be feasible because the initial soil salinity was usually lower and rainfall had 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 the system was able to be rather sustainable. While the hydraulic conductivity was more than 1 m/day the higher the barrier depth, the deeper to the equilibrium the water table reached. Combined biodrainage system and traditional drains with wider spacing seemed to control both salinity and water table satisfactorily. This issue, however, can be the subject of a separate research.

**REFERENCES**


