BIO DRAINAGE - POTENTIAL AND LIMITATIONS[1]

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ABSTRACT

The World's irrigated area is 255 million hectares (m.ha) of which about 20 per cent is affected by waterlogging and salinity. Where the ground water is of good quality, its use by pumping (vertical drainage) can check the rise of ground water table. Horizontal sub-surface drainage in which the saline ground water is drained away through pipes and drains, is the other commonly paractised anti waterlogging measure. It is claimed that bio-drainage, in which the characteristic of the trees to transpire water is harnessed to control the rise of ground water table can be an alternative drainage measure, which would be most economical and eco-friendly. But there are doubts and reservations on the long-term sustainability of biodrainage, because of the apprehension that no salts would be removed. The paper describes why this apprehension is not wholly valid and how a sustainable 'salt balance' is achievable, when natural river water is used for irrigation. The 'potential' and 'limitations' of bio-drainage are discussed.

Keywords: Waterlogging, Salinity, Biodrainage

1 INTRODUCTION

The total irrigated area in the world is 255 million hectares (m.ha) of which more than two-third lies in Asia. About 20 per cent of the irrigated land has been rendered saline due to waterlogging. Each year, an additional area of about 1.5 million ha. of irrigated land gets affected by secondary salinisation due to waterlogging, and thereby looses its productivity.

In areas receiving good precipitation, the ground water is generally non-saline and is often used for irrigation. The infiltrating water from precipitation leaches the topsoil and pumping of ground water checks the rise of ground water table into the root zone of crops. Such regions in tropical or temperate climatic zones therefore rarely face the problem of waterlogging and salinisation. On the other hand, in arid and semi-arid zones natural precipitation is inadequate, ground water is saline, and agriculture is practised by surface irrigation by bringing water from sources outside the region. This disturbs the previously existing water balance in the region resulting in rise of ground water table, which if unchecked causes waterlogging and salinisation. The most common method of overcoming the problem is to provide horizontal sub-surface drainage to drain away the excess water through under ground pipelines, and open drains. Another practice is to make conjunctive use of saline ground water along with fresh canal water for irrigation. Vertical drainage by pumping helps to check the rise of ground water table.

The horizontal sub-surface drainage measure is quite effective and is widely practised. The disposal of saline drainage water poses pollution and environmental problems where the saline drainage water cannot be safely disposed off into the sea without polluting natural surface water bodies. The high cost of construction, maintenance and operation of the drainage system is another draw back. The vertical drainage measure has limitation because of the saline nature of the ground water. There is need of finding alternative methods of providing drainage. Biodrainage, in which the characteristic of trees to transpire water is harnessed, can be one such measure. There are differing views on whether 'bio-drainage' can or cannot be an effective measure and whether it is sustainable in the long run. A careful study of the potential and limitations of bio-drainage is needed. This paper is an attempt to do so.

2 REQUIREMENTS TO BE MET BY BIO-DRAINAGE

For biodrainage to be effectively adaptable, the following requirements must be met:

(a)	Water balance	:	The quantity of water removed from the ground water annually should equal the quantity of recharge.
(b)	Salt balance	:	The quantity of minerals removed annually should be nearly equal to the quantity of mineral import.
(c)	Area under plantation	:	Irrigation is practised primarily to promote agriculture, horticulture, dairy etc. Therefore in term of economic returns afforestation or agro-forestry should be comparable with that from other alternative uses of land. If it is not so, afforestation may still be justified, on considerations of the environmental

			and drainage benefits.
(d)	Water for plantations	:	Under ideal situation, trees in afforestation area on full development should be able to draw most of their requirement of water from the ground water table, so that surface irrigation water can be put to other productive uses. If, and so long it is not possible, plantation trees would need some irrigation water. They may also need some water periodically to leach down salts from the root zone, if and when the salinity levels approach threshold limits.
(e)	Ground water quality	:	The quality of ground water, when the water table approaches the root-zone of trees, should be such as can be tolerated by the plant species, otherwise the trees would need to be supplied irrigation water.
(f)	Effect on lowering ground water table	:	Trees can lower the ground water table directly underneath the plantation area, to a depth upto which the tree roots can extend. This can be upto 15 m from ground surface or even more. To be effective as a drainage measure, the ground water table must be lowered in the irrigated area to a minimum critical depth (say 2 m below ground level), at the farthest point from the edge of the plantation area.

Whether and to what extent the above requirements can be met, would depend upon the prevailing field conditions. Kapoor (2001) has described methods of estimating these. IPTRID (2002) has presented a knowledge synthesis report describing principles, experiences and applications of biodrainage. The Indian National Committee on Irrigation and Drainage (INCID) (2003) has brought out a status report on bio-drainage.

3 COMMON APPREHENSIONS AND DOUBTS REGARDING BIODRAINAGE

The 'apprehensions' and 'doubts' that are often expressed on the feasibility of biodrainage are described in sub paras 3.1 to 3.5.

3.1 Salt Evacuation in Irrigated Agriculture

All plants and vegetation contain some minerals, notably Calcium (Ca^{++}), sodium (Na+), Magnesium (Mg+) as cations and sulfate (SO_4), chlorides (Cl^-) etc. as anions. The composition and quantity of mineral content in bio mass depends on the plant specie and characteristics of the soil where the plant grows. The plant analysis results show that the weight of Ca^{++}, Mg^{++} and Na^+ cations in dry biomass of a plant is about 3.3 per cent of the weight of the dry biomass. When biomass is harvested and removed from the field, minerals to this extent are also evacuated from the field along with the biomass. Therefore, if the dry biomass produce (grain + foliage) be 10 tons/ha, the weight of cations of minerals evacuated along with the biomass of harvested crop would be at the rate of 0.33 tons/ha.

The commonly found soluble salts in soil solutions are salts of calcium, sodium and magnesium. The percentage gravimetric weight of the respective elements in the salt compounds are as shown in Table 1.

Table 1 Percentage (in gravimetric weight) of Element in the Salt Compound

Calcium		Sodium		Magnesium	
In Calcium Sulphate ($CaSO_4$)	29.4	In Sodium Chloride (NaCl)	39.3	In Magnesium chloride ($MgcL_2$)	25.5
In Calcium Chloride ($Ca\ Cl_2$)	36.1	In Sodium bicarbonate ($NAHCo_3$)	27.4	In Magnesium sulphate ($Mg\ SO_4$)	20.2
		In Sodium Sulphate ($Na_2\ SO_4$)	32.4		

On an overall average basis, the gravimetric weight of mineral elements (Ca, Na, Mg…) in the mineral salt compounds may be taken as about 33 percent. In other words, the total weight of mineral salts absorbed by a plant or evacuated from the soil solution is about three times the total weight of mineral elements (cations) found in the plant. The total weight of mineral compounds evacuated would be about 1.0 ton/ha. corresponding to a harvested crop biomass weight of 10 tons/ha.

The main input of salts in agriculture is through irrigation water, whose source is either rivers or ground water. James (1982) gives the composition of average river waters of the world as shown in the following table 2:

Table 2 Composition of average river waters of the world

Region	Ece[b] (μ mhos/cm at 25^0C)	Total Concentration		B (mg/l)	Ca	Mg	Na	K	Alkali[c]-nity	So_4	Cl	No_3	SAR
		mg/l	meq/l						(meq/l)				
North America	220	142	1.89	-	1.05	0.41	0.39	0.04	1.11	0.42	0.23	0.02	0.5
Europe	270	182	2.28	-	1.55	0.46	0.23	0.04	1.56	0.50	0.19	0.06	0.2
Australia	95	59	0.58	-	0.19	0.22	0.13	0.04	0.52	0.50	0.28	trace	0.3
World	190	120	1.42	-	0.75	0.34	0.27	0.06	0.96	0.23	0.22	0.02	0.4

a Adopted from Rhodes and Bernstein, 1971
b Electrical conductivity
c Alkalinity is titrable bases made up mostly of HCO^-_3 , with small amounts ofCO_3^{-2} and OH

When such natural river water (world average) is used for irrigation, the salt import on the field is at the rate of 120 mg/l in which the total cation content (Ca+Mg+Na+K) is about 28 mg/l. If 500 mm of this water were used for irrigation, the import of salt would be 0.6 ton/ha.

Therefore, when natural river water is used for irrigation, there should be no adverse salt balance. When ground water is used for irrigation the salts are merely recycled and there is no change in the overall salt balance status. Salt imbalance would occur only when saline surface water is used for irrigation.

3.2 Survival of Trees Under Saline Conditions

Different species of trees have different capacity to survive and grow under saline conditions. Salt tolerant species like Tamarix Troupii, Prosopis jaliflora, Acacia farnesiana give satisfactory growth upto salinity level of 35 dS/m. Acacia nilotica, A.tortilis, Eucalyptus camaldulensis etc. give satisfactory growth upto salinity level of 25 dS/m.

When trees transpire water, salts are left behind in the soil. It is apprehended that if this continues to happen continuously for many years, the salt content in the soil may exceed the tolerance limit of the trees and plantations may not survive.

The concentration of salts in the soil in this manner occurs in the 'capillary zone' which may be about 1.0 m thick. When ground water table is shallow and within the reach of the roots of the trees, they would be able to draw their water requirement from the ground water table. The trees would survive so long as the salinity of ground water (below the ground water table) does not increase beyond the threshold limit. The rise of salinity in the capillary zone does not mean that it would also necessarily increase correspondingly under the ground water table. Survival of trees would be threatened only when the salinity level in the capillary zone as well as in the ground water table both exceed the tolerance limits.

3.3 Ground Water Salinity

Ground water salinity under irrigated agriculture lands may or may not increase with passage of time. In the early years, after irrigation is introduced the ground water salinity gets diluted due to recharge from relatively less saline water that infiltrates down from the fields and the conveyance system. This continues to be so with the rise in ground water table until the ground water table stabilises under the new equilibrium conditions. Thereafter, the ground water salinity would not increase if natural river water (unpolluted) is used for irrigation. It would also not increase if ground water is used for irrigation, regardless of whether it is saline or non-saline.

However, if polluted river water (containing salts, say more than 200 mg/l) is used for irrigation, the salinity of ground water may show an increasing trend. The rate at which ground water salinity may increase would depend upon the salinity level and quantity of recharge water, the depth to the barrier layer under the ground water table and the porosity of the sub-strata. Kapoor (2001) estimates that the rate of rise of ground water salinity is likely to be too slow to be a matter of concern in most situations. Transpiration rate from tree plantations decreases with increase in ground water salinity. In case of Eucalyptus plantations the rate may reduce to about one-half of that under non-saline conditions, when the ground water salinity reaches a level of 12 dS/m.

3.4 Impact of Bio-Drainage on Depressing the Ground Water Table

Bio-drainage would lower down the ground water table underneath the plantation area. But the objective is not to lower down the ground water table only underneath the plantation area, but to do so under the entire irrigated area. The lowering down of ground water table underneath the plantation area should be to such depth , that the draw down effect extends up to the farthest point from the plantation area, and the ground water table, no where under the irrigated area rises above the critical depth (say 2.0 m) to cause waterlogging. Besides achieving water balance and salt balance, the plantations should be able to generate effective ground water movement from all around under the irrigated area towards the plantation area. The quantity of subsurface water drainage towards the plantations should be adequate to prevent rise of water table above the critical depth any where and everywhere under the irrigated area. To achieve this, the plantation areas would have to be suitably planned and dispersely located over the irrigated area.

If plantation areas are separated by distance L, the depression of water table underneath them would result in ground water flow behaviour similar to that as in case of flow towards parallel ditches penetrating a unconfined aquifer. On equilibrium, the position would be as shown in Figure-1 and the relationship between depression of ground water table, rate of recharge, hydraulic conductivity, depth to barrier layer and distance between plantations can be expressed by Donnan equation :

$$L^2 = \frac{8KY_0h}{R} + \frac{4Kh^2}{R}$$

$L \rightarrow distance\ between\ plantations.$

$R \rightarrow rate\ of\ recharge$

$Y_0 \rightarrow height\ of\ water\ level\ above\ barrier\ layer\ underneath\ plantatior$

$K \rightarrow hydraulic\ conductivity$

$h \rightarrow head\ difference$

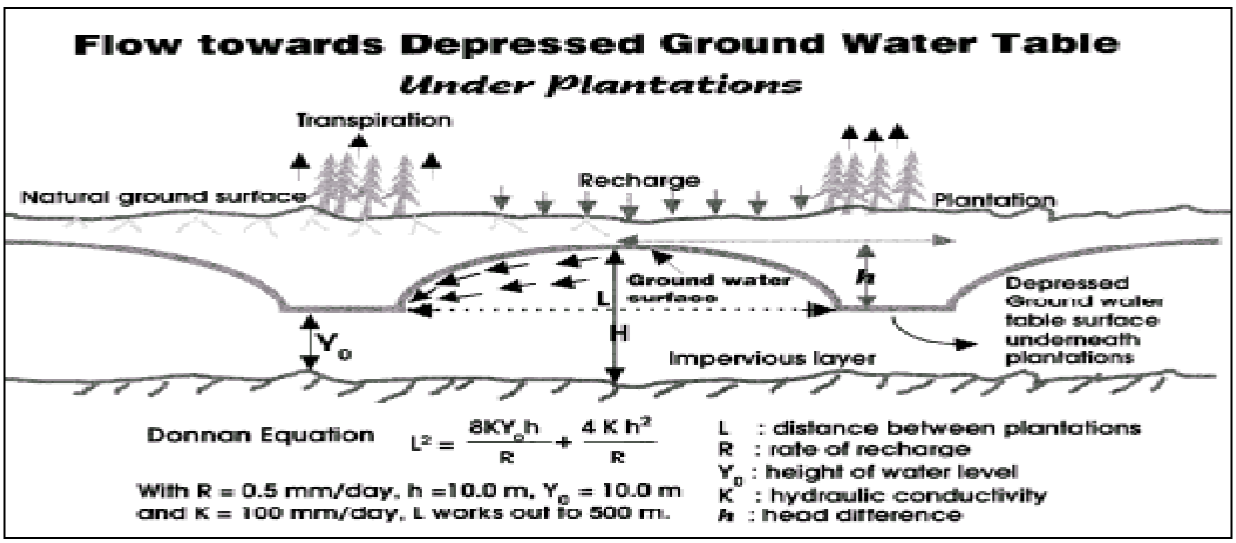

Figure 1 Flow towards depressed ground water table.

It is seen that plantations would be able to provide effective bio-drainage to farther distances in permeable soils (in comparison to impermeable soils) and when barrier layers are sufficiently deep. With a rate of recharge (R) equal to 0.5 mm/day, head difference (h) of 10.0 m, depth to barrier layer under plantations (Yo) as 10.0 m and hydraulic conductivity value of 100 mm/day, plantations can be spaced 500 m apart. With hydraulic conductivity values of 1000 mm/day and 10 mm/day, the distance between plantations would work out to 1500 m and 150 m respectively.

3.5 Land required for bio-drainage plantations

Land under command in irrigation projects is generally used for agriculture by farmers who own the lands or hold tenancy rights. Sometimes these holdings are quite small in densely populated countries and regions like in India. It is feared that it may not be possible to persuade the farmers to part with their lands or to change its use from agriculture to forestry.

Land is no doubt scarce in densely populated areas. But fresh water is even scarcer. Leaving aside a few exceptional cases, water is relatively much more scarce than land. In dry arid regions, the disparity is so marked that land without water has little value. With limited quantity of available water, it is rarely possible to make full productive use of all land. It is very common to leave part of land fallow every season because there is not enough water to irrigate the whole land. In large tracts of irrigated commands in India and Pakistan, irrigation water is available to hardly meet the crop water requirement over half area during each of the winter and summer season. The rest of the land either remains fallow or produces much less than its potential. Therefore, it would not be right to say that land cannot be made available for forestry.

Generally, farmers receive their share of irrigation water on some rationing basis. The returns to a farmer depend more on the volume of his share of water rather than on the size of his land holding. That being the position, it should not be very difficult to persuade the farmers to divert a part of their lands for tree plantations by assuring them that there would be no reduction in their share of water.

In any case, loosing a part of land for tree plantations should be a much better proposition than allowing the land to be destroyed by waterlogging and salinity.

4 POTENTIAL AND LIMITATIONS OF BIO-DRAINAGE

Bio-drainage, like other drainage measures, has potential and limitations. All irrigation regions are not alike. They differ in physiographic and climatic conditions. Bio-drainage may be very suitable, partly by suitable or unsuitable depending upon the prevailing conditions. The important characteristics of a region that would govern whether bio-drainage is appropriate or not are whether the region is humid or dry and what is the salinity level of the ground water. Brief description on four possible regional scenarios follows:

4.1 Humid region with ground water of good quality

Generally, humid regions have soils and ground water of good quality. The natural precipitation washes down the salts in soils which are drained away naturally. The top soils and ground water are of a reasonably good quality to enable irrigated agriculture. Natural precipitation may not occur uniformly throughout the year to match with the crop water requirements and therefore supplemental irrigation may be needed. This can be done by storing surface water and making it available for irrigation when needed or by pumping ground water and using it.

In case, use of stored surface water for irrigation results in rise of ground water table and there is a threat of waterlogging the best course would be to make conjunctive use of ground and surface water. This would enable best possible use of the water resource and at the same time check the rise of the ground water table. However, if this is not possible for some reasons, like abundance of surface water or non-availability of dependable power for pumping ground water (a situation that is common in developing countries), then plantation of trees on part area can provide the needed drainage.

4.2 Humid regions with saline ground water

There are very few regions which receive good precipitation and yet have saline ground water. This condition can occur in localised pockets where the ground sub-strata has salt incrustations. The infiltrating water dissolves and carries the salts to the ground water table. In a situation like this, it should be possible to make conjunctive use of surface and ground water. Bio-drainage through tree plantations can also be a viable option.

4.3 Semi-arid and arid regions with ground water of good quality

In dry regions, water is generally scarce and irrigation is often practised by bringing surface water from outside regions. Recharge from irrigation disturbs the previously existing ground water balance and the ground water table (often perched water table) starts rising. The ground water can be pumped and put to conjunctive use along with the surface water for irrigation. This should be the best way to prevent waterlogging. However, there are many examples of excessive use of surface water for irrigation and little use of ground water inspite of its good quality. The reasons of this anomalous position are surplus availability of surface water during early operative years of a project or low cost of surface water to the farmer in comparison to the cost of ground water. The situation should be remedied by appropriate management measures.

The second best alternative to prevent or over come the threat of waterlogging should be to plant trees on part area to provide bio-drainage.

4.4 Semi-arid and arid region with saline ground water

This is the commonly prevailing situation in most semi-arid and arid regions. The need of irrigation water is maximum in such regions. Water is the scarce resource. Land, mostly waste land, is in abundance.

Waterlogging and secondary salinisation is a common problem when lands are brought under irrigation by bringing water from outside sources. Horizontal sub-surface drainage would be the most suitable and effective measure, where saline drainage water can be safely disposed off into the sea or in evaporation tanks at affordable cost without polluting natural water bodies and/or causing environmental problems. Conjunctive use of ground water can be possible to a limited extent.

Bio-drainage can be a feasible option. Availability of land should not be a problem. Transpiration rates are quite high. The limitation would be the salinity level of the ground water. Where the salinity in ground water at shallow depths reaches 12 dS/m, the transpiration rate falls down to about one-half. If and when it reaches to a level of say 25 dS/m, the tree plantations may become ineffective.

The position of potential and limitations of bio-drainage and relative suitability with other drainage measures is summarised in the following table:

Table 3 Potential and limitations of biodrainage and relative suitability of drainage measures.

<table>
<tr><th rowspan="2">Characteristics of the region</th><th colspan="3">Potential and limitation of bio-drainage</th><th rowspan="2" colspan="2">Relative ranking of drainage measures</th></tr>
<tr><th>Feasibility</th><th>Merits</th><th>Demerits/ Limitation</th></tr>
<tr><td rowspan="2">Humid region with ground water of good quality</td><td rowspan="2">Feasible</td><td rowspan="2">Least cost, environment friendly</td><td rowspan="2">Land needed for tree plantation</td><td>Region with surplus water</td><td>Region with no surplus water</td></tr>
<tr><td>1.Bio-drainage
2.Horizontal sub-surface drainage
3.Vertical drainage</td><td>1.Vertical drainage with conjunctive use
2.Bio-drainage
3. Horizontal sub-surface drainage</td></tr>
<tr><td rowspan="2">Humid region with ground water of poor quality</td><td rowspan="2">Feasible where salinity of ground water is not excessive (say, more than 12 dS/m)</td><td rowspan="2">Least cost, environment friendly</td><td rowspan="2">Land needed for tree plantation</td><td>In coastal region</td><td>In inland regions</td></tr>
<tr><td>1.Horizontal sub-surface drainage
2.Bio-drainage
3.Vertical</td><td>1.Bio-drainage
2.Vertical drainage
3.Horizontal Sub-surface drainage</td></tr>
<tr><td>Semi arid and arid regions with ground water of good quality</td><td>Feasible</td><td>Least cost, environmental friendly</td><td>Hardly any</td><td colspan="2">1.Vertical drainage with conjunctive use.
2.Bio-drainage
3.Horizontal sub-surface drainage.</td></tr>
<tr><td rowspan="2">Semi arid and arid regions with ground water of poor quality</td><td rowspan="2">Feasible where salinity of ground water is not excessive (>12dS/m)</td><td rowspan="2">Least cost, environment friendly</td><td rowspan="2">Natural river water (unpolluted) is used for irrigating crops</td><td>In coastal regions</td><td>In inland regions</td></tr>
<tr><td>1.Horizontal sub-surface drainage
2.Bio-drainage
3.Vertical drainage</td><td>1.Bio-drainage
2.Vertical drainage
3.Horizontal sub-surface drainage</td></tr>
</table>

5 SUMMARY AND CONCLUSIONS

Bio-drainage can be a feasible option for controlling waterlogging and salinity in irrigated lands. Its main merits are economy in cost and environment improvement. The limitations are requirement of land for tree plantations, limited evacuation of salts from the system and vulnerability of trees to high saline conditions.

The requirement of land for tree plantations may be about 10 per cent of the area, which should be no problem, particularly in semi-arid and arid zones.

All biomass contain some minerals which are evacuated, when the crops are harvested and removed from the field. When natural river water (unpolluted) is used for irrigation, the mineral evacuation by biomass may equal the net import of minerals with the irrigation water, enabling a reasonable salt balance.

Tree growth and transpiration rate is affected by ground water salinity. There are many species of trees that are salt tolerant and grow satisfactorily upto salinity levels of 12 dS/m or more. There are quite large irrigated areas, that have ground water salinity of less than 12 dS/m, Bio-drainage should be feasible in such areas.

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