TESTING OF A MULTI-LEVEL SUBSURFACE DRAINAGE SYSTEM FOR IMPROVING DRAINAGE WATER QUALITY[1]

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ABSTRACT

Irrigation development throughout Australia has seen a significant change in the natural hydrological cycle and groundwater systems over the past 50 –100 years. A significant part of all irrigation areas in Australia now have watertables within 2m of the soil surface creating waterlogging and salinisation problems.

In many cases the problems associated with shallow watertables have been controlled by the installation of subsurface drainage systems. Already within the Murray Darling Basin there is approximately 90 000 ha of subsurface drainage, mostly in irrigated perennial horticulture and pasture. The existing subsurface drainage has a significant impact on the salt load in streams and rivers. For example, in the Murrumbidgee Irrigation Area only 7% of the area has subsurface drainage but this contributes 30% of the salt load leaving the area. In today's social climate the search to manage our natural resource base sustainably and allow equity for future generations dictates that exporting environmental problems is no longer acceptable and we must aim to minimize off site environmental impacts as much as possible.

This paper describes a multi-level drainage system, which aims to improve drainage water quality, presenting results from a field scale land reclamation experiment implemented in the Murrumbidgee Irrigation Area of New South Wales. The mutli-level drainage system consisted of shallow closely spaced drains (3.3m spacing at 0.85m depth) underlain by deeper widely spaced drains (20m at 1.75m depth).

Comparisons of water and solute movement between the multi-level drainage system and a single level drainage system are presented in the paper. Significant differences in the performance of the multi-level and single level drainage systems have been found in the watertable regime, drain water salinity and soil salinity.

Keywords: Drainage Design, Multi-Level Drainage, Drainage Salinity, Semi-Arid Drainage

1 INTRODUCTION

In a review of subsurface drainage systems (Christen, Ayars and Hornbuckle, 2001), in irrigation areas in Australia, it was shown that in many cases the drainage salt loads are 5-10 times greater than that applied through the irrigation, even after reclamation of the rootzone was completed, indicating that such systems typically remove stored geologic salt as well as that applied with the irrigation water, Figure 1. Often this stored salt may be from below the root zone and its removal offers little benefit to the crop.

Figure 1 Salt applied and salt drained based on studies undertaken in Australia in 10 irrigation areas, Christen, Ayars & Hornbuckle (2001)

Hornbuckle and Christen (1999) reviewed assessments of salinity in irrigated soils for the Murrumbidgee Irrigation Area (MIA) in SE Australia. They found that soil salinity showed a general increase with depth. Figure 2 shows a typical soil salinity profile for horticultural soils found in the MIA. This shows that generally within the MIA there is considerably less salt stored in the upper soil layers.

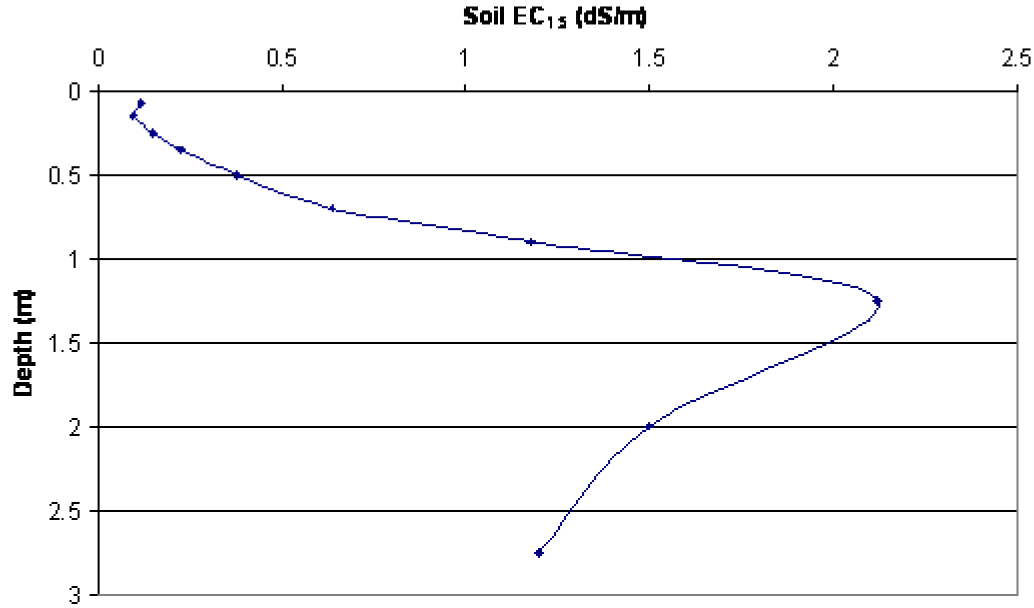


Figure 2 Typical soil salinity profile taken from Hornbuckle and Christen for irrigated red-brown earths of the MIA

For the soil profile shown in Figure 2 the approximate amount of salt stored in the upper soil profile (0-1m) and lower soil profile (1-2m) is 25 and 91 t/ha respectively, hence it can be seen that at depths greater than 1m there is considerably more salt stored than at shallower depths.

Flow paths to drains have been shown to have a large effect on the quality of drainage water (Jury 1975a,b) and flow path depths are a function of the drain depth and spacing. The shallower and more closely spaced the drain the shallower the depth of flow paths. Considering this, shallow drains placed in areas with soil salinity profiles such as those found in the MIA, should have much reduced drain water salinities and hence present less of a drainage water disposal problem.

The use of a shallow drainage system, has been show in the past to be effective in waterlogging protection, but controlling soil salinisation is less certain (Christen and Skehan 2001, Hermsmeier 1973 & Ghaemi and Willardson 1992). Resalinisation from capillary rise can occur from considerable depths (Talsma 1963) hence if shallow drainage systems are used there is the potential for salinisation from capillary upflow. Considering this a multi-level drainage system is proposed to control soil salinisation while still having the benefits associated with reduced salinity drainage water and effective waterlogging control.

2 OBJECTIVES

The aim of this experiment was to compare a Single-Level (SL) and Multi-Level (ML) drainage system in a field situation. The objectives were to:

1. Compare drainage volumes and salinity, and hence salt loads
2. Compare the effectiveness of salt leaching in relation to root zone removal of salts
3. Determine the effectiveness of water table and waterlogging control

3 METHODS AND MATERIALS

3.1 Site Description

The experimental site was situated in the Murrumbidgee Irrigation Area of New South Wales, Australia. The site had not been previously irrigated for several decades, whilst surrounding areas had been continuously irrigated. This led to severe salinisation of the area. Figure 3 shows the average soil salinity at the site before drainage installation.

It can be seen that the site was saline, well above the recommended salinity levels for grapes for no yield loss of 1.5 dS/m (Rhoades and Loveday, 1990). It was also apparent that the salt content of the deeper soil layers was higher than the surface layers (0-0.5m).

The soil at the study site was an Alfisol, known as a Red – Brown Earth of the Australian Great Soil Groups (Stace et al., 1968). The surface soil is shallow and passes quickly through a clay loam to a light clay. A grey subsoil develops below a depth of 0.75m and continues to a depth of 7m becoming heavier with depth. Soft and hard carbonates are found at depths below 0.5m.

3.2 Experimental Design

Two treatments were installed at the site. These being a **M**ulti-**L**evel (**ML**) subsurface drainage treatment and a **S**ingle-**L**evel (**SL**) subsurface drainage treatment. The deep drains on the multi-level drainage system were at the same spacing as the SL treatment. This allowed a direct comparison to be made between the systems, with any effects on the salt load of the system being directly attributed to the presence of the shallow drainage system. The ML treatment was placed in the highest salinity area of the field. This was done to provide a thorough assessment of the ML treatment in highly saline conditions.

Drain spacings of the deeper drains were calculated from the methodologies developed by Talsma and Haskew (1959), which led to a design spacing of 20m. Shallow drains were spaced at 3.3m to align with the center of each vine row. Deep drains were laid at a 0.2% gradient and the shallower drains at a 0.1% gradient. A plan view of the drainage system and treatment layout is shown in Figure 4. Surrounding fields were already drained at the same depth and spacing as the deep drains providing a continuous array of parallel drains. A cross-section of each of the drainage treatments is shown in Figure 5.

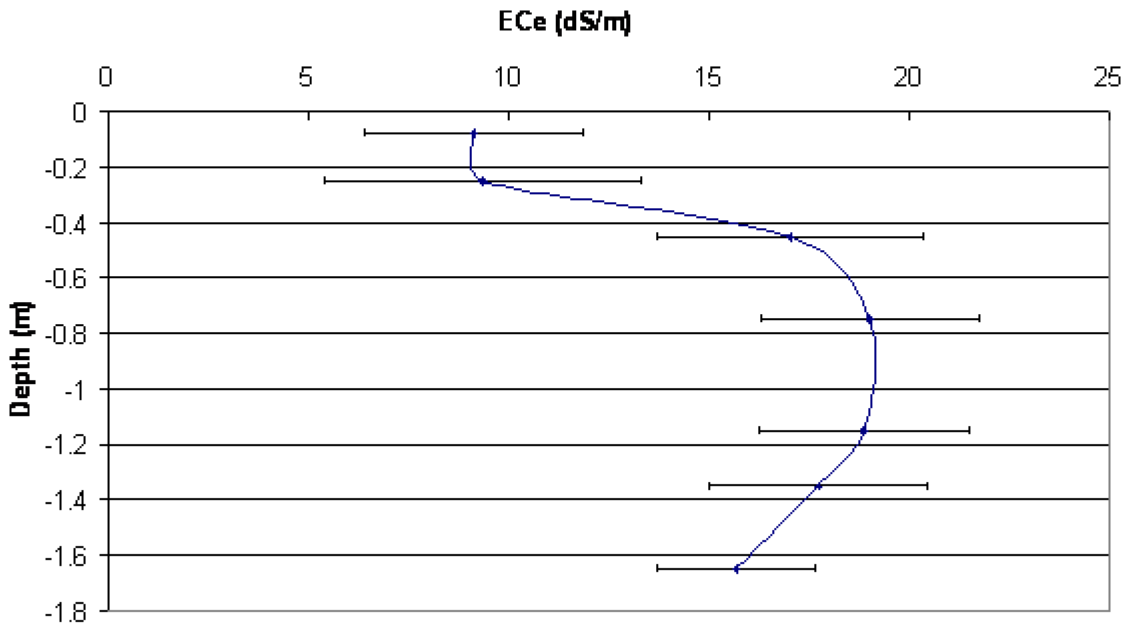


Figure 3 Average soil salinity at the experimental site, based on 22 cores. Horizontial bars show standard deviation

Drainage water and salt loads were monitored continuously from sumps 2 and 4 using tipping buckets and TPS electrical conductivity sensors (TPS Pty Ltd) interfaced to GPSE dataloggers (Harris Pty Ltd). A total of 42 testwells and piezometers installed at various depths were used to monitor groundwater movement in the treatments. Positioning of the instrumentation is shown in Figure 4.

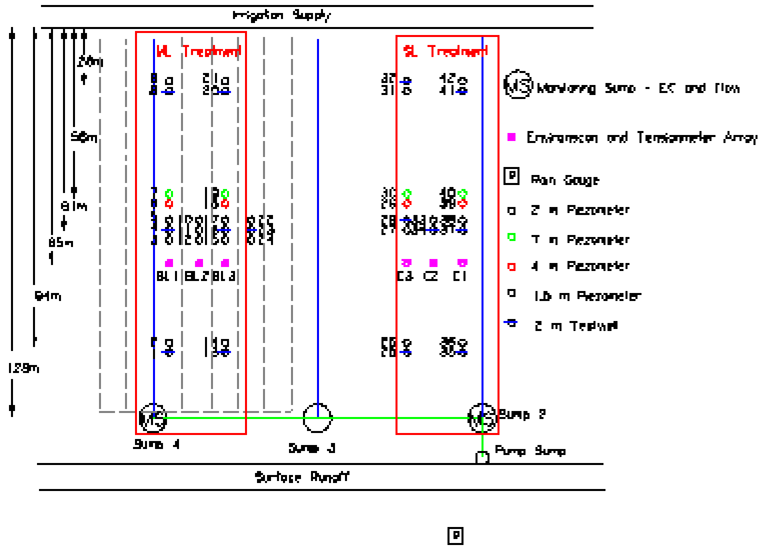
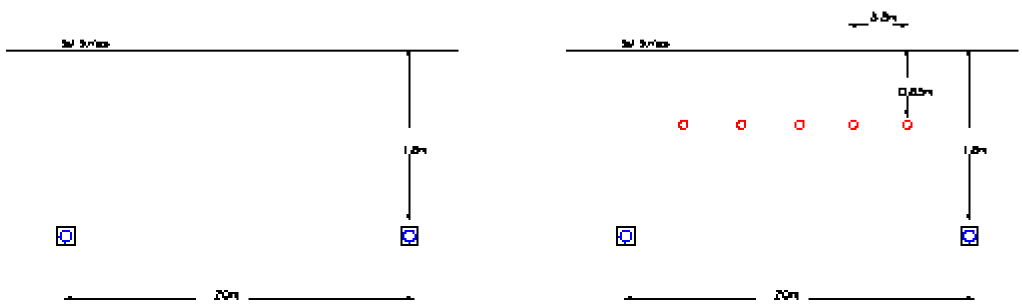


Figure 4 Plan view of experimental site showing drainage layout and monitoring equipment



a **b**

Figure 5 Drainage treatments investigated at the site. a. Single-Level drainage system, b. Multi-Level Drainage System

4 RESULTS

4.1 Drain Flows and Salinity

The salt and water balance data for the treatments during the 2001/2002 irrigation season are shown in Table 1.

Table 1 Irrigation and drainage volumes and salt applied and removed in the ML and SL treatments

Treatment			**Total**
ML	Irrigation (mm)		541
	Drainage (mm)	Total	139
	Leaching Fraction	Total	0.26
	Drainage (mm)	Shallow Drains	36
	Drainage (mm)	Deep Drain	103
	Salt Applied (kg/ha)		433
	Salt Removed (kg/ha)	Total	21868
	Salt Removed (kg/ha)	Shallow Drain	1367
	Salt Removed (kg/ha)	Deep Drains	20500
	Average EC (dS/m)	Shallow Drains	4.7
	Average EC (dS/m)	Deep Drain	31.7

SL	Irrigation (mm)	551
	Drainage (mm)	120
	Leaching Fraction	0.22
	Salt Applied (kg/ha)	493
	Salt Removed (kg/ha)	22541
	Average EC	29.5

The ML treatment drained 15% more water than the SL treatment, due to the shallow drains. The shallow drains contributed 26% of the total discharge from the ML treatment and the deep drains in the ML treatment drained 15% less than the deep drains in the SL treatment. This indicates that the shallow drains are effective in removing water from the soil profile and reducing the hydraulic load on the deeper drains.

The average salinity of the shallow drains was 4.7 dS/m. This is significantly lower than in the deep drains that averaged 31.7 dS/m and 29.5 dS/m for the ML and SL treatments respectively. This reflects the increasing soil salinity with depth. These results show that by having shallow drains the aggregate salinity of the drainage water can be reduced. Also, the drainage volumes show that by having shallow drains the flows from the deeper drains can be reduced.

In comparing the total salt removed by each of the treatments it can be seen that the ML and SL treatments were comparable at 21868 kg/ha and 22541 kg/ha respectively. However the ML treatment was more saline than the SL treatment (Figure 8). In the ML treatment the shallow drain salt load was 6% of the total, reflecting the lower drainage volumes and salinities than the deep drains. An important issue is where in the soil profile salt removal is occurring, i.e. in or below the root zone. This is discussed in a later section.

In this trial the deep drain spacing in the ML treatment was identical to the SL treatment. Due to the increased drainage rates provided by the addition of shallow drains a sensible design step would be to increase the spacing of the deep drains. With an increased spacing the volumes of drainage from the deep drains in the ML treatment would be reduced and hence salt loads.

Considering these results it can be seen that the multi-level drainage system has the potential to reduce drainage water salt loads over single-level drainage systems.

4.2 Waterlogging And Water Tables

Water tables measured at mid-spacing of the deep drains in the ML and SL treatments with continuous data recorders are shown in Figure 6. It can be seen from the hydrographs that the two treatments only differed greatly during periods of high recharge. This occurred during the first irrigation of the 2000/2001-irrigation season and after the 3rd and 4th irrigations and rain event, which occurred in the 2001/2002 irrigation season

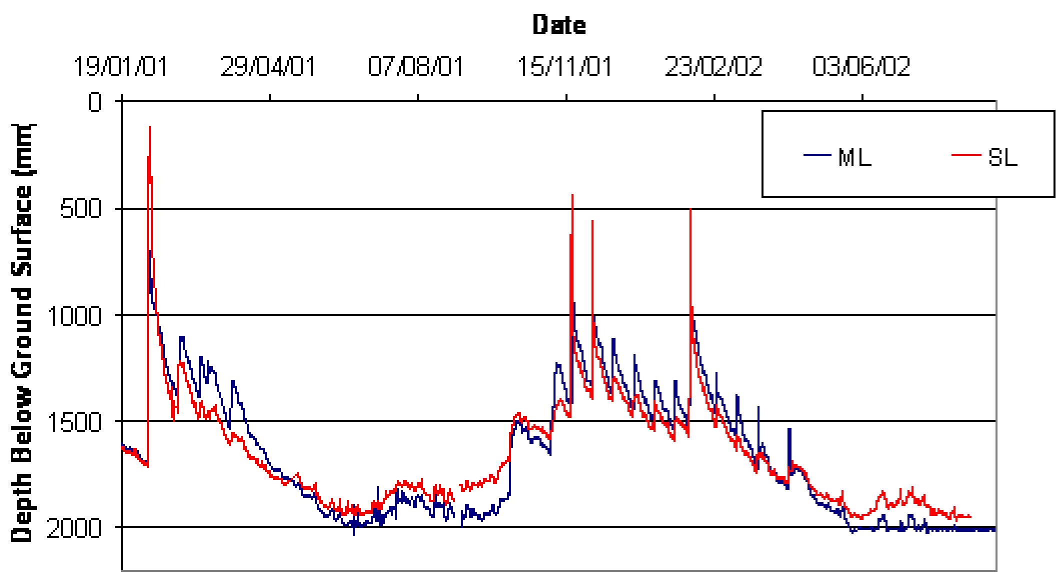


Figure 6 Water table depths under the ML and SL treatments over the experimental period

It is evident that during these high recharge events the ML treatment was more effective in controlling the water table below rootzone depth. During the high recharge periods the water table in the SL treatment reached levels within the rootzone that could be considered detrimental to the plants. At other periods the water table regime in the ML and SL treatments were similar, although water table depths were slightly higher in the ML treatment than the SL treatment. This may have been due to the slightly lower hydraulic conductivity of the ML treatment.

Table 2 shows the number of hours the water table remained above given depths during both irrigation seasons as measured in the seven testwells located in each treatment. It can be clearly seen that the ML treatment is significantly more effective in keeping the water table below the rootzone.

Table 2 Total time water table levels above specified depths (hours)

	Treatment	
Depth	**ML**	**SL**
< 500 mm	84	526
< 750 mm	248	764
< 1000 mm	784	1330

Based on the water table data the ML treatment can be seen to be more effective in preventing waterlogging than the SL treatment. Water table levels after high recharge events are rapidly reduced due to the presence of the shallow drains, which are extremely effective in preventing waterlogging of the rootzone.

4.3 SOIL SALINITY

Soil salinity changes were monitored over the experimental period using EM38 ground conductivity surveying and soil coring. Six cores were taken in each treatment during each sampling event at cross-sectional positions on the drain and at mid-drain spacing of the deep drains. This cross-section sampling was undertaken at ¼, ½ and ¾ lengths down the field in each treatment. The ESAP software package (Lesch, Rhoades and Corwin, 2000) was used to construct calibrated soil salinity maps. These are shown as 9 layers for before drainage and after two irrigation seasons, Figure 8.

It can be seen that there was significant reductions in soil salinity in both treatments. The higher initial soil salinity levels in the ML treatment have been reduced to levels similar to the SL treatment. The shallow soil layers (<0.5m) have been more effectively leached in the ML treatment. The effect of the deep drains in both treatments can clearly be seen in the 1.05, 1.35 and 1.65m depths where salt leaching close to the drain has been much greater than at mid drain spacing.

To investigate the zone of salt removal the percentage reduction in soil salinity for each soil layer was calculated, Figure 7.

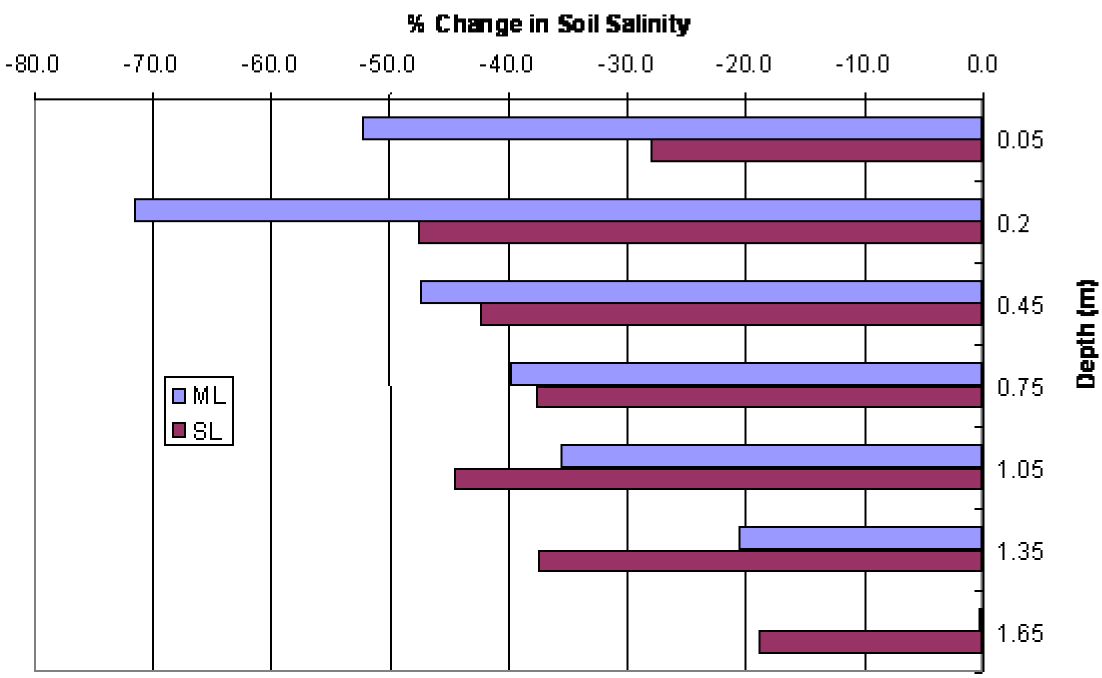
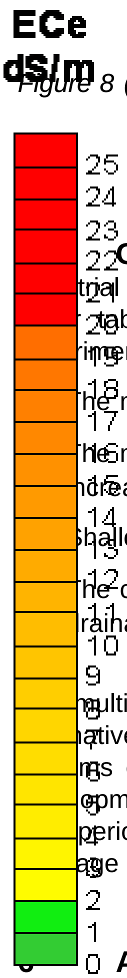


Figure 7 Percentage change in soil salinity ($EC_{1:5}$) over two irrigation seasons

It can be seen that the ML treatment has been more effective in removing salts from the upper soil layers (<0.5m) compared to the SL treatment. This is useful as this is the main root zone which requires leaching to be as rapid and uniform as possible. Between 0.5 and 1.0m the two treatments performed similarly, however below 1.0m the SL treatment removed more salt. This is not a great advantage to the crop as this is well below the main root zone. For the Semillon vines grown during the experiment it appeared root depth was no deeper than 0.4m based on soil moisture monitoring. For mature vines the rooting depth would be greater. Cox (1995) in studying root distributions in well water furrow irrigated vineyards with mature vines in the region found maximum rooting depths of 0.6-0.8m. Therefore, leaching of salts is only essential to a 0.8m depth to maintain vine health. Leaching below these depths is essentially non-beneficial to the plant, also resulting in higher salinity water requiring disposal.



(a)

(b)

Figure 8 (a) Soil salinity before drain installation, (b) After the 2001/2002 irrigation season

5 CONCLUSIONS

This trial examined a multi-level drainage system and a single-level drainage system in relation to the drainage flows, salt loads, water table regimes and soil salinity. Based on the experimental results the following conclusions can be drawn from the experiment:

- The multi-level drainage system provided excellent waterlogging protection
- The multi-level drainage system provided greater leaching of the main root zone than the single level system, but without increasing drainage salt loads
- Shallow drains were found to have significantly lower drainage salinities than deeper drains
- The combination of deep and shallow drains in a multi-level drainage system provides significant benefits in relation to drainage water disposal problems over single-level systems

A multi-level subsurface drainage system offers potential benefits over traditional single-level drainage systems and may offer an alternative which begins to potentially satisfy the agronomic, economic and environmental constraints of subsurface drainage systems of the present day. Further investigation of the multi-level subsurface drainage system is currently ongoing along with development of a coupled unsaturated-saturated water and solute transport model to further investigate the system over longer time periods and with different modes of operation (i.e. selective use of the shallow and deep drains with active management of the drainage system).

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