

IMPROVING SUBSURFACE DRAINAGE DESIGN AND MANAGEMENT TO
REDUCE SALT LOADS FROM IRRIGATION AREAS IN
SOUTHEASTERN AUSTRALIA

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ABSTRACT

A field investigation on a new vineyard in the Murrumbidgee Irrigation Area showed that improved subsurface drainage systems reduce salt loads in drainage water whilst providing waterlogging and salinity control. By only draining the rootzone the drainage volume and salinity were greatly reduced.

Improved design and management options were tested against the current practice of deep pipe drains (1.8 m depth) widely spaced (20 m apart) allowed to drain continuously. This drain configuration was managed to prevent flow when the water table was deeper than 1.2 m from the soil surface, and not during irrigations. This resulted in a 50 % reduction in the drainage salt load. Shallow (0.7 m depth) closely spaced drains (3.65 m apart) were also tested and reduced the drainage salt load by 95 % when compared to the unmanaged deep drains.

This improved design and management will significantly reduce the amount of salt that requires disposal. This work, together with other field and modeling studies, has been used to develop a set of guidelines for subsurface drainage with the aim of improving drainage water quality.

INTRODUCTION

The irrigation areas in southeastern Australia have developed shallow water tables to the extent that about 80 % of many irrigation areas experience water

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tables within 2 m of the soil surface. These water tables create serious problems of waterlogging and land salinisation.

In the past waterlogging has been controlled by the installation of subsurface drainage (tile drainage) which lowers water tables. This has been successful in horticultural farms of the Murrumbidgee Irrigation Area (MIA), Shepparton Irrigation Region and the Riverland along the Murray river. However, the nature of subsurface drainage is such that large amounts of salt are exported in the drainage water. At the time of installation the downstream consequences of salt export were not considered.

Subsurface drainage schemes have been targeted as areas for salt export reduction, since the drainage water is normally an order of magnitude more saline than surface drainage waters. In the MIA, the Land and Water Management Plan (LWMP) (DLWC 1998) identifies subsurface drainage as a major salt exporter from the area. About 30 % of the salt load leaving the area is from subsurface drainage, although only 7 % of the area has subsurface drainage installed. The MIA L&WMP set a goal of a 25 % reduction in the salt load from existing subsurface drainage.

In the MIA, new horticultural developments are to a large extent on the heavier soils that were previously used for annual crops such as rice and vegetables. These soils are quite different from those previously associated with horticulture, which were more freely draining lighter textured soils. Thus, new drainage design and management are required to reduce salt loads and provide effective drainage in heavy clay soils.

RESEARCH AIMS AND OBJECTIVES

The research aims were to investigate and develop new subsurface drainage design and management techniques to reduce the salt load from subsurface drainage in horticultural developments in the Riverine Plain of southeastern Australia, and provide a set of

guidelines for water managers, installers and users of subsurface drainage. Specific objectives were:

- 1/ Develop and test improved subsurface drainage designs for clay soils that provide effective drainage of the rootzone whilst minimising salt mobilisation in the drainage water;
- 2/ Develop and test management practices for existing subsurface drainage systems to minimise salt export;
- 3/ Determine if deep drains with improved management are as effective as shallower drains in managing waterlogging and reducing salt mobilisation.

METHODOLOGY

Site Description

New subsurface drainage design and management strategies were tested in a replicated field trial on a newly established vineyard in the MIA, situated 30 km north east of Griffith, NSW, Australia. The vineyard was 2 years old, and was previously used for growing rice. The soil was a Griffith Clay Loam, Butler (1979). The top 0.3 m is a clay loam that becomes progressively heavier with depth down to about 0.9 m and then continues as a medium clay. The deep subsoil ranges from a light to heavy clay with soft and hard carbonate. Irrigation was applied down narrow furrows on both sides of the vines. Irrigations were about 8 hours in duration every 10 - 14 days. The irrigations were well managed with rapid advance times, about 4 hours to reach the bottom of the 400 m vine row, and only a small amount of run-off. The irrigation furrows were maintained in good condition.

Drainage Treatments

Drainage treatments installed in the experiment were:
1/ *Deep Drains* - Pipe Drains (100 mm slotted plastic pipe) at 1.8 m deep and 20 m apart, allowed to flow continuously. This represented current drainage design and management practices.

2/ *Managed Deep Drains* - Pipe drains configured as in treatment 1 above were managed to flow only when the water table was within 1.2 m of the surface, and not during irrigations.

3/ *Shallow Drains* - Shallow 'Mole' drains, 3.6 m apart and 0.7-0.8 m deep. A Mole drain is an unlined soil tunnel formed by soil compression.

4/ *No Drainage* - No subsurface drainage.

These treatments were chosen to:

1. Assess shallow closely spaced drains in providing effective drainage of the root zone, whilst minimising salt mobilisation, after work by Muirhead et al. (1995) and Deveral and Fio (1991).
2. Test the practice of managing existing drains to flow only when watertable levels are critical and not during irrigations, after work by Ayers (1996).
3. Determine if deep drains with improved management are as effective as shallower drains in reducing salt mobilisation, whilst managing waterlogging and rootzone salinity.

Experimental layout

The experiment was laid out in two blocks of equal area with complete randomisation in each block. Each treatment was 70 m long of varying width. Each individual drainage replicate had it's own sealed collector drain running to the pump sump where measurements of drainage quantity and quality were made, see Fig. 1.

Experimental Measurements

The experimental measurements aimed to quantify the drainage volume and salinity from each treatment and compare this with the effect of each treatment on water tables and soil salinity. Crop measurements were also made to ascertain the overall effect of the drainage treatments on vine growth and yield.

Irrigation applied to the vineyard was measured at the Dethridge wheel, which was calibrated using a Doppler

ultrasonic flowmeter. Irrigation water salinity was sampled several times during each irrigation. Rainfall was measured at the sump and run-off was estimated at 10% of water applied.

Drainage discharge from individual treatments was measured manually at the pump sump. Measurements were taken at around half hourly intervals at times of peak flows after irrigation and at subsequently larger intervals as the flow rates declined. Drainage samples for electrical conductivity and chloride were taken in conjunction with the flow rate measurements.

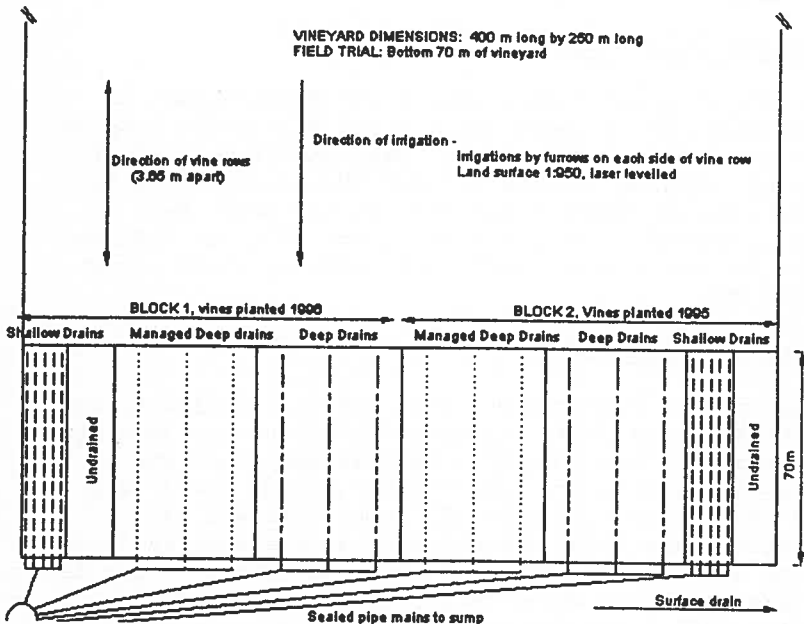


Fig. 1. Field Experiment Layout

Watertables and piezometric levels in each drainage treatment were measured using 1 m test wells and 3 m piezometers. These were situated in the vine row between drains in the shallow drainage treatments, and above and between the drains in the deep drainage treatments. These were logged at half hourly intervals.

Soil salinity was measured after each irrigation season by soil sampling to 2 m and EM38 survey and leaf chloride and yield measurements were undertaken at the end of the experiment. A detailed description of the site, treatments and measurements can be found in Christen and Skehan (1999).

Climatic Conditions

The MIA climate is described as 'Mediterranean' or semi-arid. The summers are hot and dry, while winters are mild with frosty nights. Mean annual rainfall is 418 mm, ranging between 140 and 700 mm. Rainfall is fairly evenly distributed through the year. Mean annual potential evapotranspiration (ET_o) is 1800 mm. Only for the winter months does mean rainfall almost match ET_o.

Seasonal Conditions

Experimental measurements were taken from January 1997 until February 1998, encompassing almost two growing seasons that are typically between September and February. During the experimental period there were few periods of high rainfall. Most rainfall was in small amounts which was absorbed at the soil surface. There was only one rainfall event of 30 mm, on the 12th of January 1998, which caused the drains to flow. During 1997 there was only 336 mm of rain in total compared to the annual average at Griffith of 418 mm. The probability of exceedance of 336 mm of rainfall at Griffith is 70 %, when analysing the entire 121 year rainfall record.

RESULTS

Drain Flow

The different drainage treatments resulted in markedly different drainage volumes and salinities, and hence salt loads. The differences in flow resulted from the drain position in the soil profile and the management of the drains. The Deep Drains flowed continuously for the irrigation seasons, a small saline flow being sustained between irrigations and a large flow during and just after irrigation, Fig. 2.

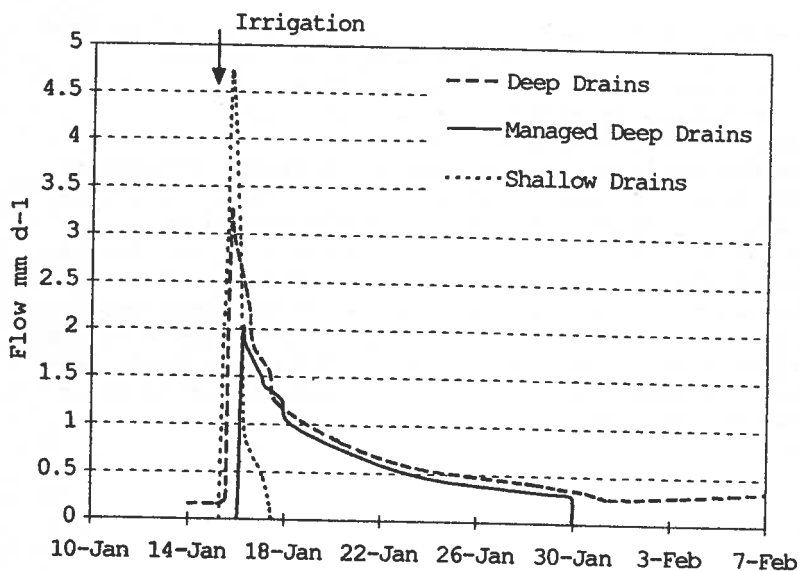


Fig 2. Treatment Hydrographs During and After an Irrigation

The Deep Drains continued to flow long after the Shallow Drains had ceased because they were draining a larger soil volume, down to 1.6-1.8 m, and they were influenced by regional groundwater pressures, Deverel and Fio (1991) also reported this effect. Regional groundwater effects were demonstrated by a 0.5 m rise in piezometric levels at the beginning of the

irrigation season before any irrigations had been applied at the site.

The Managed Deep Drains were influenced less by these regional effects as they were prevented from flowing when the watertable reached 1.2m deep. The Shallow Drains had the shortest flow durations with the highest peak flows. This is due to only draining a shallow soil depth and the regional potentiometric level being below these drains.

Drain Water Salinity

Irrigation water salinity during the trial varied from 0.1-0.2 dS m⁻¹. There were significant treatment differences in the overall drain water salinity and in the variation in salinity over time, Fig. 3. Initially, the Deep Drains maintained a fairly constant salinity both during and between irrigations apart from a slight reduction in salinity at the time of the irrigation. This was probably caused by irrigation water flowing preferentially to the drains through the more permeable trench above the drain. In comparison, the managed drains had lower drain water salinities, with the lowest salinity drainage from the shallow drains. Muirhead et al. (1995) also found that discharge from shallow drains had much lower salinity than that from deep drains.

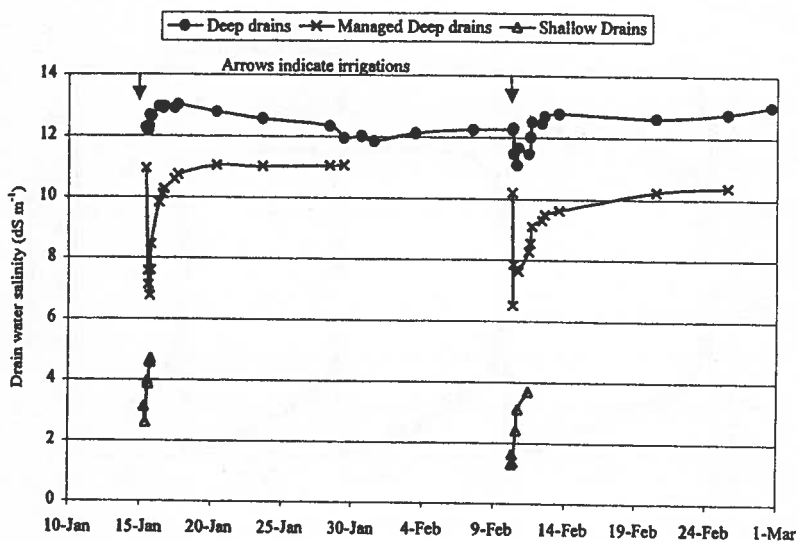


Fig. 3. Drain Water Salinity over the Period of the 3rd and 4th Irrigations

Watertable Depth and Drain Water Salinity

The watertable response under the Deep drains, Fig. 4, shows that a deep pipe drainage system, without major groundwater inflow from surrounding areas, only needs to be run for 2 to 7 days after an irrigation to lower the watertable below the root zone. After which turning off the pump can discontinue further drainage.

When the water table was shallow, during and just after an irrigation, the drainage water salinity was low, as the water table receded the drainage water salinity became more saline, Fig. 4. This is because drainage water salinity is a function of the depth of dominant water flow paths, Jury (1975) and in these soils the groundwater salinity is around 12 dSm⁻¹ and soil salinity increases with depth.

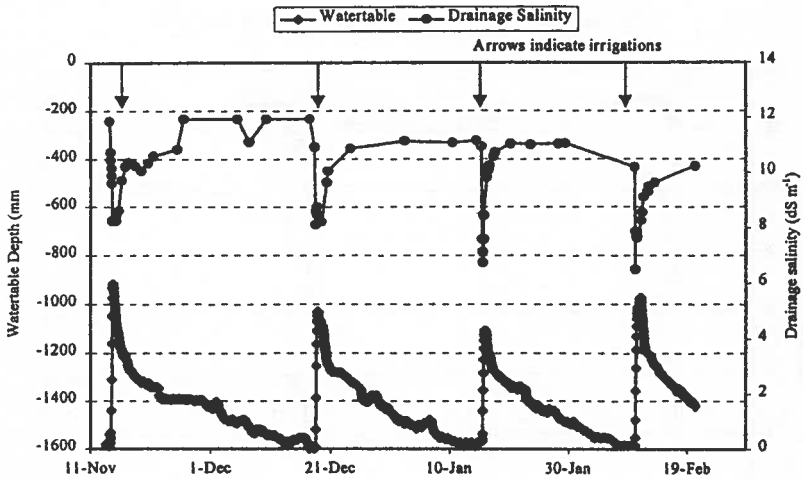


Fig. 4. Drainage Water Salinity and Water Table Depth for Deep Drains

Drainage Salt Load

The Managed Deep Drains removed 10-14 times the salt applied in the first three irrigations monitored (This additional salt is from that stored in the profile). This then declined to 0.3-4 times the salt applied. Overall the Managed Deep Drains removed 6 times more salt than applied, about half that of the Deep Drains, Table 1.

This was also the case for the rainfall event, where the Deep Drains removed 401 kg ha^{-1} compared to 223 kg ha^{-1} for the Managed Deep Drains.

Table 1. Salt Applied in Irrigation Water and Removed by Drains over Two Seasons (10 events)

	Salt applied (kg ha ⁻¹)	Salt removed (kg ha ⁻¹)		
		Deep Drains	Managed Deep Drains	Shallow Drains
Total	508	5867	2978	319
Ratio*		11	6	0.6

* Ratio of salt removed to salt applied

The least salt removed was by the Shallow Drains, only about 0.6 of the salt applied in the irrigation water. This indicates that salt is accumulating in the profile with the Shallow Drains. This accumulation of salt is not necessarily a risk to the crop as the salt was not found to be accumulating in the root zone. Also the total amount of salt accumulated is relatively small, 189 kg ha⁻¹, which could be removed subsequently by irrigation or rainfall.

During the course of this trial there was only one significant rainfall event in a very dry period so the more normal effects of leaching by winter rainfall did not occur. Of the three drainage treatments the Shallow Drains were the closest to having a salt balance between salt applied and salt removed.

Watertable Control

The Deep Drains limited watertables less than 1 m deep to 8% of the time over the irrigation season, Table 2. The management changes used to control water flow from deep drains had little effect on the period watertables were above 1m. The Shallow Drains gave the best control of shallow watertables, but the watertable did build up beneath this treatment and was controlled at mole depth, which is consistent with results of Muirhead et al. (1995).

Table 2. Duration of Water Tables above 1 m

Treatment	Duration (% of season)
Deep Drains	8
Managed Deep Drains	10
Shallow drains	3
Undrained	42

Soil Salinity

There was a variation in the initial soil salinity's of the treatment plots, the Deep Drain plots having the highest salinity. After two seasons the salinity in the top 0.6 m had dropped in the Deep Drain treatment but had remained static for the other treatments, Fig. 5.

The Undrained treatment also experienced little change in salinity indicating that the drainage conditions were adequate to prevent salt accumulation. These results are only for a relatively short period and as such may not reflect the longer term effects of the treatments.

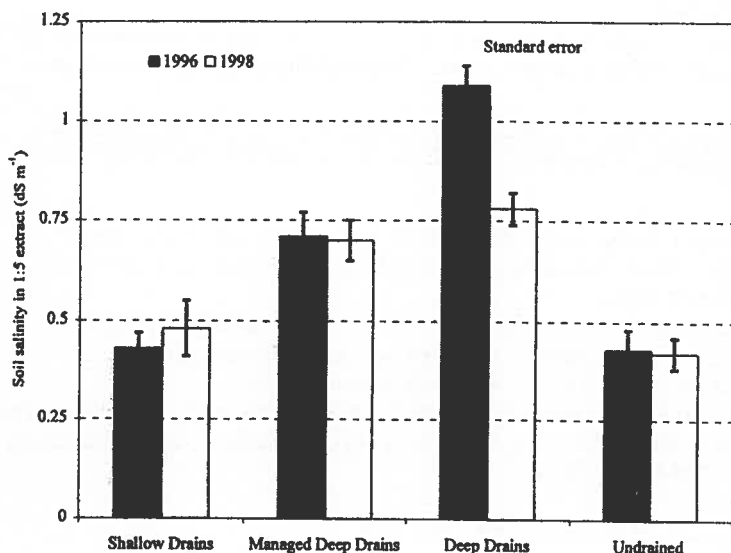


Fig. 5. Average Soil Salinity to 0.6 m (1996 sampling is before treatments were installed)

Vine Yield and Leaf Chloride

Leaf analysis found that the leaf chlorides in all treatments were similar, 0.57 - 0.69%, and well below the 1% toxic level. Vine yields taken at the end of the second season were found to be fairly uniform and quite high, 6.1-6.7kg/vine.

CONCLUSIONS

Changing drainage design from deep widely spaced drains to shallow closely spaced drains.

- Shallow drains removed less water than deep drains, thus potentially making more water available for plant use.
- Shallow drains have low drainage water salinity and remove smaller drainage volumes, thus reducing salt

load, up to 95 % reduction compared to deep drains in this trial.

- Shallow closely spaced drains control watertables in the root zone better than deep widely spaced drains.

Managing deep drains by preventing discharge during irrigation and whenever the water table was below 1.2 m

- Managed deep drains removed less water than deep drains, thus potentially making more water available for plant use.
- Managing drains reduces drain flow compared to unmanaged drainage, resulting in a reduction in drainage salt load, 50 % in this trial.
- Deep drains, even when managed, were not as effective as shallower drains managing waterlogging and reducing salt mobilisation.

Impact of the drainage systems

An important outcome from this analysis is that the drainage treatments had only small effects on the root zone salinity over the experimental period and no measurable effect on vine health, but still drained water and salt from the area. Therefore, over the period monitored the water drained, salt removed, costs incurred, and downstream impacts of drainage water resulted in little direct productivity benefit to the farm.

A subsurface drainage system provides long term benefit to a farm in controlling waterlogging and salinity. However, there are periods when drainage is not critically required as occurred during this experiment. This can be due to changing land use, changing external hydrological impacts or dry climatic conditions. During these periods it is even more important that the drainage system incurs the least downstream impacts and least costs to the farmer.

This experiment showed that drainage systems for irrigated areas on clay soils in south eastern Australia can be designed and managed better than the currently accepted practices, so that detrimental

downstream environmental effects due to excessive salt export are reduced, without affecting the productivity of the farm.

GUIDELINES FOR SUBSURFACE DRAINAGE DESIGN AND MANAGEMENT TO IMPROVE DRAIN WATER QUALITY

Using this work and results from other field trials and modeling not reported here guidelines for the Riverine plains, Australia have been developed.

New Drainage Systems

New drainage systems should consider the potential for salt mobilisation:

- Avoid sites where large volumes of drainage may occur from regional groundwater.
- Install drains as shallow as possible.
- Design drainage systems into management units aligned with irrigation units.
- Install drainage control structures to manipulate water tables
- Main drains and sumps that are installed at depth should be sealed to prevent entry of saline water.

Existing Drainage Systems

- Should have control structures installed so that drainage can be managed.
- Should be divided into management units with control structures aligned with irrigation units.

Management of Drainage Systems

- Drainage systems should be prevented from discharging during irrigation events.
- Drainage systems should be controlled to maintain water tables safely below the root zone, not left to drain uncontrolled where water tables may fall much deeper than required.

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