Non-fallow and tillage options for control of dryland salinity in the Murray Mallee

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Abstract

We used a simulation analysis to evaluate fallow and non-fallow wheat crop sequences with different levels of tillage and stubble retention for dryland salinity control in the Murray Mallee. Simulations were conducted to explore likely responses of wheat cropping sequences on a sandy loam soil to a wide range of observed weather conditions (58 years). The analysis concentrated on grain yield, root-zone soil-water accumulation, runoff and deep drainage as affected by crop sequence and stubble and tillage management. Simulated drainage was episodic and agronomic management influenced total drainage. No strong relationships were evident between drainage and rainfall ($R^2 \leq 0.2$). Drainage was related to soil-water content at sowing. Fallowing reduced yield failure, but, in conjunction with stubble retention, increased episodic and total drainage. Stubble-retained zero-tilled fallows conserved more soil water and subsequently showed the highest level of drainage. Conventional tillage and stubble burning decreased drainage, but increased runoff and evaporation. Wheat-wheat and fallow-wheat rotations drained in ≈6% of years without stubble retention, but when stubble was retained drained in 10-70% of years, which represented an increase in drainage from ≈0.5 to 10-20 mm/year. Non-fallow annual cropping sequences failed to provide a dry soil profile at sowing, and hence prevent drainage, especially in wet years. Therefore, a wider range of strategies, such as growing agronomic perennials to dry subsoils prior to sowing, is likely to provide more effective control of deep drainage and dryland salinity.

Key Words

drainage, stubble retention, conservation tillage, zero tillage.

Introduction

Dryland salinity is a widespread and serious water quality and land degradation issue facing Australia. Rising groundwater and salty inflows to streams within the Murray-Darling Basin are of concern, especially the salt contribution mobilised from dryland catchments in the Basin. Increased recharge to groundwater is a consequence of massive changes in the water balance following the clearance of native vegetation for agriculture. In the Mallee, time lags for deep drainage to become recharge (reach the saline watertable) are long, and aquifer responses are only recently being observed over much of the region after 80-100 years of cropping. The Mallee environment of southeastern Australia has a semi-arid climate (annual rainfall 250-500 mm) with a variable rainfall regime. This makes timely water supply the major factor limiting reliable grain yields. Crop sequence may influence soil-water dynamics and hence the potential to optimise water use. Farmers have several management options to change the amount and pattern of crop water use and reduce year-to-year variability to achieve economic grain yields. Long fallowing is one such common cultural practice that directly impacts on soil-water availability to crops; however, it also increases the risk of deep drainage (1). This water could be better utilised for agronomic purposes. Modifications to fallow preparation, such as reduced tillage and stubble retention, can also increase the risk of drainage by minimising surface sealing, enhancing infiltration and reducing soil evaporation (2,3). On light textured Mallee soils, stubble retention might be expected to increase the risk of groundwater recharge, but as yet this has not been conclusively demonstrated (4,5).

The variable timing and intensity of rainfall results in drainage occurring on an event basis (episodic). As a result, analysis of the episodic nature of drainage using a crop model may help to develop strategies that reduce potential groundwater recharge. Simulation of management options for drainage reduction is permitted by the integration of soil, agronomic and climatic factors. Using such an approach for rainfed agricultural systems offers the advantages of being less resource expensive than field experiments with long-term water balance or chloride leaching measurements. In this paper, we used a wheat crop model to evaluate agronomic management options for dryland salinity control using 58 years of historical weather conditions from the Victorian Mallee. We concentrated on root-zone soil-water accumulation and associated runoff and deep drainage as affected by crop sequence, and stubble and tillage management on a sandy loam in these analyses.

Methods

Simulations were conducted to explore responses of wheat cropping sequences under a wide range of observed weather conditions. The multiple-year, daily time step O'Leary and Connor simulation model (6) was used since it was developed and validated in the Mallee, is able to simulate crop-tillage sequences and is capable of handling long-term historical variation in weather (7). We used data from Walpeup (35° 07'S, 141° 59'; elevation 85 m) which was representative of a major cropping area of northwest Victoria. The soil type was a pedal hypercalcic Calcarosol (Gc 2.22, sandy loam). Mean annual rainfall and pan (class A) evaporation at Walpeup is 338 mm and 2227 mm, respectively. The model was run continuously from 1st January 1939 to 31st December 1996, using daily meteorological observations encompassing the extreme weather variation experienced in this region.

The analysis concentrated on grain yield, crop residue at maturity, root-zone soil-water accumulation and associated runoff and deep drainage as affected by crop sequence and stubble and tillage management. Sixteen treatments were compared per year for the 58 year historical climatic data set, viz.: 3 crop sequences (WW, wheat-wheat; FW, fallow-wheat; FF, fallow-fallow), 3 tillage (CT, conventional tillage; MT, minimum tillage; ZT, zero tillage) and 2 stubble (SR, stubble retained; SB, stubble burnt) management options. Tillage management under the WW sequence was either CT or ZT, as a MT treatment is not practical due to the short-fallow period.

The model was initialised according to typically observed soil-water conditions over summer (65% of full profile). The limitation to crop production from a lack of nitrogen in favourable growing seasons was minimised by setting an adequate initial profile of soil N. Soil physical and chemical properties, and the climatic, fallow and crop parameters necessary to initialise the crop model have been reported elsewhere (8). The initial stubble level was set at 2 t/ha on 1st January 1939, a typical amount for the district. Tillage of CT long fallows occurred on DOY (day of year) 255, 360 and 15, regardless of rainfall. The CT short fallow was tilled on DOY 15 and 46. All scenarios (except ZT) received a pre-sowing tillage on DOY 75. The MT treatment received tillage on DOY 255 and DOY 75. Date of sowing was based upon rainfall and time (restricted to between early May (DOY 130) and the end of September (DOY 273)). The SB cropping sequences had residues burnt prior to sowing (DOY 60). Total profile-soil-water content (mm) at sowing, grain yield (kg/ha), crop residue at maturity (kg/ha), runoff (mm) and deep drainage (mm) beyond the crop root-zone (150 cm) were simulated daily and summarised annually.

Results

Growing season conditions

Between 1939 and 1996, extremes in rainfall resulted in several years of drought with consequent crop failure, and some very wet years. The lowest growing season (Apr-Nov) rainfall occurred in 1982 (77 mm) and the highest in 1973 (498 mm). Periods of distinct weather patterns are evident in the progressive cumulative deviation from the long-term mean rainfall, where pronounced and prolonged periods of below- or above-average rainfall occurred. Simulations commenced from 1939, when daily records commenced, which coincided with a relatively dry period that persisted from the 1940's to the 1960's.

Fallow management impacts soil-water conservation at sowing

Simulations of wheat sequences revealed that a greater soil-water content in the root-zone (0-150 cm) resulted from fallowing (FW, median range: 412-450 mm) compared with continuous cropping (WW, median range: 384-425 mm). This reflected crop frequency and associated water use. Stubble burning (SB) reduced water storage under both fallow (median ≈34 mm) and continuous cropping (median = 10 mm) sequences. Under continuous cropping (WW) with stubble, tillage over the short-fallow period (CTSR *v*. ZTSR) reduced soil water at sowing by 18 mm. Without stubble, the impact of tillage was 10 mm less (WW: CTSB *v*. ZTSB). Without any crop (FF), high soil-water content was, as expected, simulated at sowing. Tillage on the FF sequence had no impact on soil water. In the FW-with-stubble sequence, reduced tillage during fallow slightly (≤ 8 mm) increased water storage (ZT > MT > CT). Tillage made no contribution to water conservation without stubble under FW sequences. However, in a continuous-cropping sequence (WW), removal of tillage

(CT *v*. ZT) during the short-fallow period increased sowing soil water by 18 and 8 mm with and without stubble, respectively.

Table 1. Simulated grain yield, run off and deep drainage under wheat cropping sequences at Walpeup for the period 1939 to 1996.

Sequence	Tillage treatment	Stubble treatmen t	Average annual yield (t/ha.year)	Average annual run-off (mm/year)	Total drainage (mm)	Average annual drainage (mm/year)	Proportion of years in which drainage occurs (%)
Wheat-wheat	Conventional	Burnt	1.51	14	23	0.4	5
Fallow-wheat	Conventional	Burnt	0.93	26	35	0.6	7
Fallow-fallow	Conventional	Burnt	0	54	71	1.2	28
Fallow-wheat	Minimum	Burnt	0.93	26	35	0.6	7
Fallow-fallow	Minimum	Burnt	0	54	71	1.2	28
Wheat-wheat	Zero	Burnt	1.37	18	52	0.9	5
Fallow-wheat	Zero	Burnt	0.93	26	35	0.6	7
Fallow-fallow	Zero	Burnt	0	54	71	1.2	28
Wheat-wheat	Conventional	Retained	2.06	24	283	4.9	40
Fallow-wheat	Conventional	Retained	1.41	47	745	12.8	43
Fallow-fallow	Conventional	Retained	0	56	115	2.0	43
Fallow-wheat	Minimum	Retained	1.46	52	980	16.9	47
Fallow-fallow	Minimum	Retained	0	56	115	2.0	43
Wheat-wheat	Zero	Retained	2.34	49	885	15.3	67
Fallow-wheat	Zero	Retained	1.51	60	1362	23.5	47
Fallow-fallow	Zero	Retained	0	56	115	2.0	43

Grain yield and crop residue respond to fallow and stubble retention

Sowing occurred in every crop year (between DOY 130-198). Crops that yielded ≥ 0.2 t grain/ha.year were grown more frequently under stubble-retained cropping sequences. Crop failure occurred only once with retained stubble over the 58 year period (1940, FW: CTSR) compared with numerous failures without stubble in years of low rainfall (e.g. 1940, 1944, 1954 and 1982).

Grain yield responses reflected the soil-water conditions. The median yield increase due to stubble retention was 0.5-0.6 and 0.5-1.0 t/ha.year under fallowing and continuous cropping respectively (Table 1). Reduced tillage (CT *v*. MT *v*. ZT) during long fallow with stubble, increased simulated grain yield (≈ 0.1 t/ha.year). Yield differences due to tillage during the short fallow (WW sequence) were simulated with and without stubble. Tillage reduced grain yield by 0.3 t/ha.year with and 0.1 t/ha.year without stubble retention. Stubble management (stubble burning *v*. retention) greatly influenced current year crop residues compared with tillage management (CT *v*. MT *v*. ZT). The median increase in crop residue due to stubble retention was 0.8-1.0 and 1.0-1.3 t/ha.year under fallowing and continuous cropping, respectively.

Greater drainage more frequently under stubble retention

The drainage response to variations in rainfall showed that drainage was episodic and cropping sequences that retained stubble had high drainage (Table 1). Drainage was negligible in cropping sequences without stubble; hence, in these cropping sequences tillage had no impact. With stubble retention, however, continuous cropping (WW) reduced drainage compared with fallow cropping (FW). Conversely, reduction in fallow tillage operations increased the risk of drainage (CT<MT<ZT) irrespective of crop sequence. Irrespective of crop sequence (FW or WW), zero tillage with stubble retention (ZTSR) drained more water (15.3-23.5 mm/year) than conventional cropping (CTSB) sequences (0.4-0.6 mm/year) (Table 1). Examination of the total annual drainage under each crop sequence reveals episodic events from 1939-1996. Drainage was also episodic under the non-cropped sequence (FF). Smaller drainage events were simulated compared with the other crop sequences (FW or WW) due to large runoff events (Table 1) from wet soil profiles, especially when stubble was retained.

For the period 1982 to 1990, simulated drainage for FW (CT with stubble) was 14 mm/year greater than for WW. For the same period, field measurements at Walpeup have shown 11-56 mm/year greater drainage by fallowing every third/second year compared with a non-fallow rotation of pasture-wheat (1).

Drainage and rainfall relationships
Drainage and rainfall relationships were investigated, but discussion is restricted to the crop system with the largest total drainage (FW with stubble). In this case, drainage occurred over a wide spectrum of climatic conditions, including years in which 47 to 351 mm of growing-season rainfall were received. The relationship between growing-season rainfall and drainage was weak ($R^2 \leq 0.2$). Likewise, no distinguishable relationship between simulated drainage and previous growing-season rainfall (73-365 mm) could be deduced. Similarly, no relationships were evident under any crop scenarios for deep drainage *v.* antecedent rainfall (growing plus non-growing season or annual), nor *v.* previous deep drainage.

Drainage relates to soil-water content at sowing
Drainage under each cropping system was related to the root-zone soil-water content at sowing. Under stubble retention, most drainage occurred when profile (150 cm) water contents at sowing exceeded 420 mm. No such relationship between drainage and soil-water contents occurred at anthesis or harvest. Shallower and/or lighter textured soils would be expected to have greater drainage.

Conclusion
This study shows greater soil-water conservation under fallowing compared with continuous cropping. Simulated grain yield reflected soil-water conditions. Drainage was episodic and affected by agronomic management. Stubble retained, zero-tilled long fallows clearly result in greater soil-water storage and drainage risk for dryland salinity. Slightly less drainage occurred under continuous cropping with stubble retention. Burning stubbles reduced drainage by re-directing soil water to increased evaporation and runoff. Soil-water content at sowing was the best indicator of the deep drainage risk.

Farmers can manipulate cropping sequences in semi-arid environments to minimise drainage (potential groundwater recharge). Both field and simulation studies confirm that fallowing increases drainage and this is exacerbated by stubble retention and zero tillage in the Victorian Mallee. Further, non-fallow annual cropping sequences failed to provide a dry soil profile at sowing for the prevention of drainage, especially in wet years. We believe investigations into strategies that use agronomic perennials to dewater subsoils prior to sowing will assist dryland salinity control in the Murray Mallee.

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