Simulation of deep drainage under a 13-year crop sequence in southern NSW

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Abstract

The APSIM simulation model was tested against comprehensive field data from a 13-year crop sequence study following a grass/legume pasture at Harden in southern NSW. Soil water balance was simulated using a multi-layer, cascading approach (SOILWAT2 module) and wheat, canola and legume crops were simulated using WHEAT, CANOLA and CHICKPEA modules, while fallow weeds were simulated using the WEED module. Average annual rainfall over the period was 625mm (range 340-823). Simulated soil water content closely matched the measured data (generally 1-2 times per year), providing confidence to consider the drainage component of the simulation. Average annual drainage + runoff was predicted to be 75mm, or 12% of annual rainfall. Annual drainage ranged from 0 – 207 mm, with an average of 51 mm/year. There was no relationship between annual rainfall and drainage (r^2=0.16). For example in 1992, 1993 and 1994 rainfall was 801, 823 and 424 mm and drainage was 0, 207 and 0 mm, respectively. In this study, significant drainage generally occurred in years where the profile was full in autumn, and subsequent growing season rainfall was above average. Most drainage occurred in the months July to September. Further, simulations indicate that if weeds had been completely controlled during the summer fallow, average drainage would have increased to 79 mm/year with a maximum of 251mm in 1993. This level of drainage may warrant changes to future management to reduce drainage, given salinity concerns in the Jugiong subcatchment.

Media summary

Deep drainage predicted by APSIM simulation of a 13-year crop sequence experiment at Harden, in southern Australia averaged 51 mm, or 8% of annual rainfall.

Key Words

APSIM, wheat, modelling, canola, weeds, rainfall

Introduction

In southern Australia, the mismatch in the timing of supply of water to and demand of water by annual crops and pastures results in considerable flows of water beyond the reach of the roots (Passioura and Ridley, 1998). Water escaping below the root zone represents both a potential yield loss and an environmental threat. Although direct measurements of drainage are rare, the exact number remains contentious. In south-eastern Australia in cropping systems where annual rainfall is around 600 mm, estimates of the annual average drainage plus runoff range from 37 to 100 mm, depending on crop management (Angus et al 2001, Keating et al 2002).

Kirkegaard et al (2001) discussed the possibility that farming systems designed to reduce runoff may increase drainage. This is supported by data from a long-term field experiment at Harden, in the Jugiong Creek subcatchment of southern NSW, which indicated drainage on stubble retained, direct drill plots was three times that observed on the conventionally burnt and cultivated plots (Kirkegaard et al 2001). At this site the drainage risk is likely to be higher than for the nearby region modelled by Angus et al (2001), due to higher rainfall and more porous soils with a lower water holding capacity. The Jugiong Creek subcatchment has the highest incidence of dryland salinity outbreaks in the Murrumbidgee catchment, with 6,915 ha of salinity, or 3.2% of the catchment (Howarth, 2001). These salinity outbreaks have drawn attention to the drainage losses from farming systems in this catchment. APSIM (Agricultural Productions Systems Simulator; Keating et al. 2003) has been previously shown to accurately simulate soil water content over a continuous 12-year crop sequence at this site (Lilley et al 2003). In this paper, we have further improved soil water content simulations by including fallow weed growth where it occurred in the experiment, and we present predictions of the drainage component of the soil water balance for the conventional tillage treatment.

Methods

Data from a 13-year tillage experiment conducted near Harden, NSW (Kirkegaard et al 1994, Kirkegaard et al 2001) was used in this simulation study. The soil was a red earth with total carbon in the surface of 1.3% and C:N ratio of 10. Paddock history was 5 years of perennial grass/lucerne/subterranean clover pasture prior to the commencement of the experiment in 1989 with an oat crop followed by wheat, lupin, wheat, canola, wheat, lupin, wheat, pea, wheat, canola, wheat, canola and finally wheat in 2002. Growing season rainfall ranged from 179 to 539 mm (April to mid-November). The burn/cultivate treatment of the study was selected for simulation as the incidence of soil-borne disease was negligible and crops yielded close to water-limited potential in most years. Stubble was burnt in late April of each year and plots were cultivated once with a scarifier prior to sowing. Fertiliser N was applied in 1993, 1994, 1996, 1998, 1999, 2000, 2001 and 2002 at rates of 97, 23, 22, 114, 130, 110, 72, and 148 kgN/ha, respectively. Measurements of profile soil water (gravimetric) and mineral nitrogen (NO_3 and NH_4; NO_3 dominated) to 160 cm depth were taken at sowing and maturity of crops in most years.

APSIM release 2.1 was utilised to simulate the crop sequence and details of model configuration and parameterisation are given by Lilley et al (2003). Plant available water content of soil profile to a depth of 1.6m was 169 mm. The SOILWAT2 module was employed to simulate soil water. Drainage was calculated as water drainage below 1.6m, the maximum rooting depth for wheat observed during the experiment. Simulations began on 1/2/89, before sowing of the oat crop. The model was specified to run continuously from 1989 to 2002, however, soil mineral N and soil water profiles were reset as follows: 1) soil water and mineral N profiles were reset to values measured at sowing of the 1990 wheat crop (the first measurement taken at the site); and 2) soil mineral N profiles were reset at sowing in each year that profile data were available. Annual resetting of soil mineral N profiles was necessary as continuous simulation without resetting depletes soil mineral N content well below observed values (Lilley et al 2003).

Crops were simulated using WHEAT (cv. Janz), CANOLA and CHICKPEA (cv. Amethyst) (to represent narrow-leaf lupin and the pea crop which was cut for hay). Weeds were simulated by assuming germination occurred if there was no crop growing and rainfall on two consecutive days exceeded 25 mm. This followed a rule by Fischer et al. (1990). The WEED module was set to grow a late winter grass at a density of 15 plants m^{-2}. Weed death was simulated on dates corresponding to the actual spraying, burning or cultivation operations in the field experiment. A comparison simulation was set up assuming that weed control was complete for the entire 13-year period. This is referred to as the ‘weed-free’ simulation, while the simulation matching actual weed management of the experiment is referred to as the ‘data-based’ simulation. The model simulations of above-ground biomass and yield compared well with the observed data (Lilley et al 2003).

Results

Simulated soil water content for the whole profile agreed closely with measured data during the 13-year period of the experiment (Figure 1). Simulation of weed growth during the summer period improved the simulation of soil water content considerably compared to the previously published comparison (Lilley et al 2003). Average runoff plus drainage over the period was predicted to range from 1 to 286 mm, with an annual mean of 75mm. This average value is within the range suggested by Keating et al (2002) and as expected is greater than the value Angus et al (2001) suggested for well managed crops at Wagga Wagga, a lower rainfall site with soils of greater water holding capacity.

In the ‘weed-free’ simulation, soil water content was significantly higher over the summer / autumn of 1992, 1994, 1996, 1997, and 1998, leading to increased drainage in those years of 28, 82, 117, 0 and 30 mm, respectively (Fig. 2). In other years the difference in drainage was small (<15mm), apart from 1993 where the profile was wet over most of the summer in both the 'data-based' and 'weed-free' simulations and less drainage was predicted in the 'data-based' simulation due to the presence of summer weeds.

Despite a lack of correlation between drainage and rainfall (r^2=0.16), drainage occurred in all but two of the eight years where rainfall was above average, and in only two of the five years where rainfall was below average (Fig 2). For the 'weed-free' simulation drainage occurred in all but one of the above average rainfall years. The exception, 1999 was a high-rainfall year (723 mm) in which the profile only just filled by sowing of the canola crop. Subsequent monthly rainfall was below average (52 mm), except in October and December when monthly totals were 205 and 135 mm, respectively. The crop depleted the profile and utilised the lower than average rainfall up until October when timely large falls resulted in a large crop (11 t/ha total biomass; Lilley et al. 2001) which completely dried the profile at maturity. This dry soil profile provided a buffer against the large falls recorded in December.

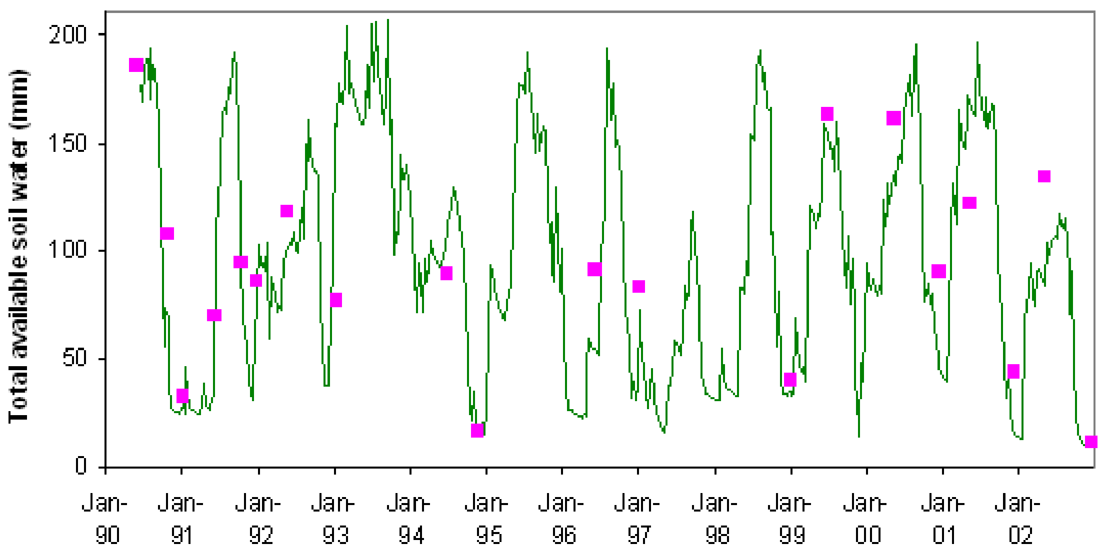

Figure 1. Simulated (line) and actual (squares) available soil water content for 13 years of a crop sequence experiment (1990 to 2002).

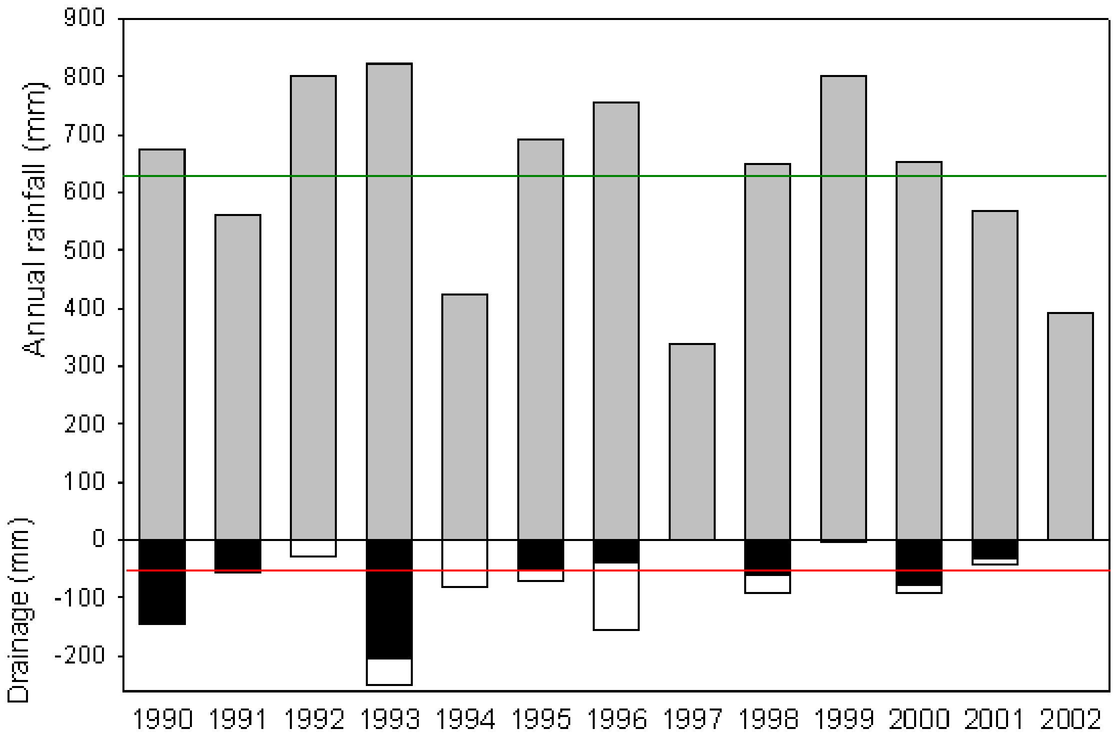

Figure 2. Annual rainfall (grey bars) for each of 13 years of the crop sequence experiment at Harden and simulated annual drainage below 1.6m depth ('data-based' - black bars; 'weed-free' – black+open bars) for the burn-cultivate treatment of the experiment. Horizontal lines indicate mean annual rainfall (625 mm) and drainage (51 mm) for the 13-year period of the experiment.

The episodic nature of drainage is demonstrated by the high rainfall years of 1992 and 1993 (801 and 823 mm, respectively). No drainage was predicted in 1992 as the profile was relatively dry in January and a large wheat crop (18.8 t/ha total biomass; Lilley et al 2003) was grown on timely rainfall for that year with a simulated crop water use of 298mm. However, the large drainage total simulated in 1993 (207 mm) followed a wet summer in 1992/93, large rainfall in July 1993 (190 mm) and a canola crop (9.3 t/ha total biomass; Lilley et al 2003), which used substantially less water (242 mm simulated crop water use) than the previous wheat crop. In this case the growth of the canola crop was below potential, most likely due to N deficiency.

Conclusion

Average annual runoff plus drainage (75 mm) and drainage (51 mm) over the 13-year period fit well with estimates from long-term simulations of Keating et al 2002, Angus et al 2002 and Verburg et al 2004. This simulation study is a rare example of drainage predicted from a continuous model simulation based on comprehensive data observations from a long-term crop sequence experiment.

Drainage was largely associated with above average rainfall and conditions leading to a full profile in autumn such as high summer rainfall, effective summer weed control, and poor soil water extraction by a current or previous crop. This level of drainage may warrant changes to future management to reduce drainage, given salinity concerns in the Jugiong subcatchment. Continuous cropping using conservation practice (Kirkegaard et al 2001) and careful weed management (Verburg et al 2004) may lead to high drainage risk. Use of longer season crops such as dual purpose winter wheats may assist in reducing the drainage risk to some extent. It is likely that grazed perennial pastures currently in the system will form an important part of drainage control.

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