Variable soil water accumulation under fallow management: Explanation using a pulse paradigm

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Abstract

Despite the general understanding that fallow management can play an important role in whole system water-use efficiency, the magnitude of the observed effects on soil water accumulation has been variable, especially in short fallow (Dec– Apr) systems. We present the results of a field experiment of fallow management effects and extend these using simulation analyses to capture the impacts of climatic variability. The results allow identification of rainfall patterns that influence the effects of residue management and weed control. To move beyond whole-of-fallow, retrospective explanations of fallow management effects, we explain the results using a pulse paradigm adopted from the field of arid land ecology. Rainfall variability is viewed in terms of different possible sequences of rainfall events, which create pulses of soil water. By considering pulse frequency, duration and depth we explain the observed and simulated fallow management effects and provide an approach towards assessment of soil water accumulation within the fallow period.

Key Words

water-use efficiency, residue management, stubble, weed control, dryland agriculture, climatic variability

Introduction

The use of a fallow period to conserve rainfall as stored soil water is an established component of dryland agricultural systems in semi-arid regions. It is also common in systems that grow winter crops in climates with summer dominant rainfall. Much research has been carried out in relation to these systems using fallow management options like crop residue management and weed control through tillage or chemical fallowing. Recent years of drought in south-eastern Australia have drawn attention to stored moisture in systems that traditionally received sufficient rainfall for crop growth during the growing season (May – November). Despite the general understanding that fallow management can play an important role in whole system water-use efficiency, the magnitude of the observed effects on soil water accumulation has been variable, especially in these short fallow (December – April) systems.

Although evaporative demand, soil water storage capacity, rainfall amount and frequency have been identified as key factors in the water balance; there is no simple, conceptual framework that predicts the combinations of conditions and management options when fallow management benefits can be expected. Recently developed empirical models by Monzon *et al.* (2006) and Fernandez *et al.* (2008) require further testing for a wider range of conditions and are limited to whole-of-fallow, retrospective explanations of fallow management effects on soil water accumulation. Farm managers, however, need to predict during the fallow period what the likely outcomes are of fallow management decisions considering rainfall conditions at the time. This requires that we view rainfall variability in terms of different possible sequences of rainfall events.

Exactly that approach is reflected in the 'pulse-reserve' paradigm used in the field of arid land ecology to describe the response of primary productivity to rainfall variability (Noy-Meir 1973, Schwinning and Sala 2004). A single rainfall event or a sequence of events is considered to cause a pulse of available soil water, which in turn triggers a range of ecological responses depending on their response thresholds (Schwinning and Sala 2004). In these models the depth and duration of the soil water pulse are determined by rainfall event size and frequency, soil characteristics, antecedent soil water, and evapotranspiration rates. The similarity of processes and factors determining the soil water pulse sizes (depth and duration) and those linked to the effectiveness of residue management and weed control suggest that this paradigm, and especially the pulse part of it, may provide a useful conceptual framework to explain and predict fallow management effects on soil water accumulation. In this paper we explore this approach by using it to synthesise the findings of a field experiment with different summer fallow management treatments and of matching simulations that use historical climate data.

Methods

The effects of different summer fallow management practices on soil water storage were studied using a replicated field experiment with five treatments: (1) wheat stubble harvested for straw with strict weed control, (2) stubble left standing after harvest with or (3) without weed control, and (4) stubble flattened (as with Coolamon harrow) with or (5) without weed control. The experiment was located on a Red Kandosol at Charles Sturt University, Wagga Wagga, NSW. It was complemented by simulations using the APSIM model (Keating *et al.* 2003) for the same soil and similar management controls, using historical weather data (1960-2006) to explore the effects of climatic variability. APSIMv5.2 was used and includes the SurfaceOM module that allows standing stubble to be simulated (http://www.apsim.info/Wiki/SurfaceOM.ashx). The climate at the site is temperate with a mean annual rainfall of 547 mm for the period 1960-2006 (Australian Bureau of Meteorology station 73127). Mean monthly rainfall ranges from 34 (February) to 55 mm (September), but the mean number of days of rain in a month ranges from just 5 in summer (January – March) to 19 in winter (July). Mean daily potential evapotranspiration (estimated by APSIM) ranges from 6.3 mm/day in summer (January) down to 1.1 mm/day in winter (June – July).

Results

During 2003-04 and 2004-05 there were no treatment effects as both summers were very dry (January-April rain 38 mm and 85 mm, respectively). In 2005-06 weed control was more important to water conservation (on average 22 mm saved) than flattening of stubble (no effect) and harvesting of straw caused an average loss of 10 mm soil water (Table 1). The simulated effects of fallow management controls for 2005-06 were similar to measured values.

Table 1. Observed treatment effects in the 2005-06 field experiment and simulated fallow management controls.

	Treatment	Available soil water (mm)*			
T1	Stubble harvested for straw, with weed control	34[a]			Simulated maintenance stubble cover
T2	Stubble left standing, no weed control	22[b]	Simulated weed control (T3-T2) † + 19 mm		(T3-T1) +6mm
T3	Stubble left standing, with weed control	45[c]		Predicted flattening stubble (T5-T3) 2 mm	
T4	Stubble flattened, no weed control	23[b]			

T5	Stubble flattened, with weed control	44[c]

*Available soil water measured on 12/4 to 1 m depth

†(T3-T2) refers to the difference in soil water between treatments T3 and T2

Simulations using 47 years of historical climate data (1960-2006), confirmed that strict summer fallow weed control was the most effective way to increase soil water storage with a higher average effect than flattening of stubble, and a more frequent occurrence of larger effects of > 20 mm/yr (Table 2). Maintaining stubble cover as opposed to harvesting straw increased soil water storage, with the magnitude of the effect rapidly increasing the longer residue reduction (e.g. burn) was delayed.

Table 2.Simulated effect of summer fallow management controls and their effect on soil water storage at sowing*

	Average effect	Proportion of years in which effect was		
	(1960-2006)	< 5 mm	> 20 mm	> 30 mm
Weed control† (T3-T2)	+11 mm	47%	26%	11%
Flattening stubble (T5-T3)	+ 4mm	77%	0%	0%
Maintaining stubble cover – until 15/4 (T3-T1)	+ 10 mm	49%	17%	4%
Maintaining stubble cover – until 30/4 (T3-T1)	+ 13 mm	36%	19%	11%
Maintaining stubble cover – until sowing (T3-T1)	+ 20 mm	4%	45%	23%

*Treatments refer to those in Table 1. Sowing was conditional upon rainfall within a window from 1/5 until 15/6.

†A density of 15 weed plants/m^2 was assumed, with a maximum rooting depth of 60 cm, and weeds killed by 15/4.

An analysis of the impact of rainfall amount and distribution on the simulated fallow management impacts showed the following:

i) Residue management had a bigger impact on water conservation in years with rainfall distributed over several events rather than in large single events which would be followed by prolonged dry periods.

ii) Residue management impacts increased dramatically in autumn and early winter (cf. Table 2).

iii) In years with very high summer rainfall (> 300 mm) residue effects were minimised due to full wetting up of the profile.

iv) In these very wet years, weed control also made less difference, except when profile wetting occurred early (by January or early February).

v) Summers dominated by smaller rainfall events or those with late germinating rain (after February) benefited less from weed control.

vi) In very dry summers, residue and weed management impacts on soil water storage were negligible, especially if prolonged dry periods occurred.

vii) However, the total amount of rainfall between harvest and sowing on its own was not a good predictor of the benefits of weed control because of possible carry-over of late rainfall from the previous cropping season.

Discussion – explanation using a pulse paradigm

Residue management effects for a single rainfall wetting event (pulse) only function to delay the loss of the infiltrated water to evaporation and the delayed system (the one with residue) will 'catch up' if it is not followed by a second pulse (Fig. 1a). This means that residue management effects are determined by the soil water pulse duration relative to the pulse frequency. If pulses overlap, water can move further down in the soil in the delayed system and effects can become more 'permanent' if pushed beyond the evaporation zone of the soil profile (Fig. 1b).

The pulse frequency is derived from the rainfall frequency, which has often been considered a factor influencing fallow management effects (Monzon *et al.* 2006, Broberg 2002). Pulse duration is determined by the amount of rainfall that infiltrates and how quickly this water evaporates (controlled by soil type, residue cover, and evaporative demand; Gregory *et al.* 2000). For residue management to create a difference in the amount of accumulated soil water, the balance between pulse frequency and pulse duration must be such that successive soil water pulses are overlapping or are caused to overlap by the presence of residue cover. In summer evaporative demand is very high and the water within the evaporative zone is quickly lost, before another pulse arrives. This explains findings i) and vi) above. In winter evaporative demand is low, so that pulse duration is much longer. Combined with more frequent rainfall events, this explains why we then do see the largest residue management effects (finding ii) above). Note that a single, large but isolated soil water pulse that reaches past the evaporation zone does not in itself create a storage difference in response to residue management, as in that case the amount of water stored at depth is the same for both treatments (finding i) above). When a series of rainfall events cause a soil water pulse that wets up the whole profile, any residue cover effects are reset (finding iii) above).

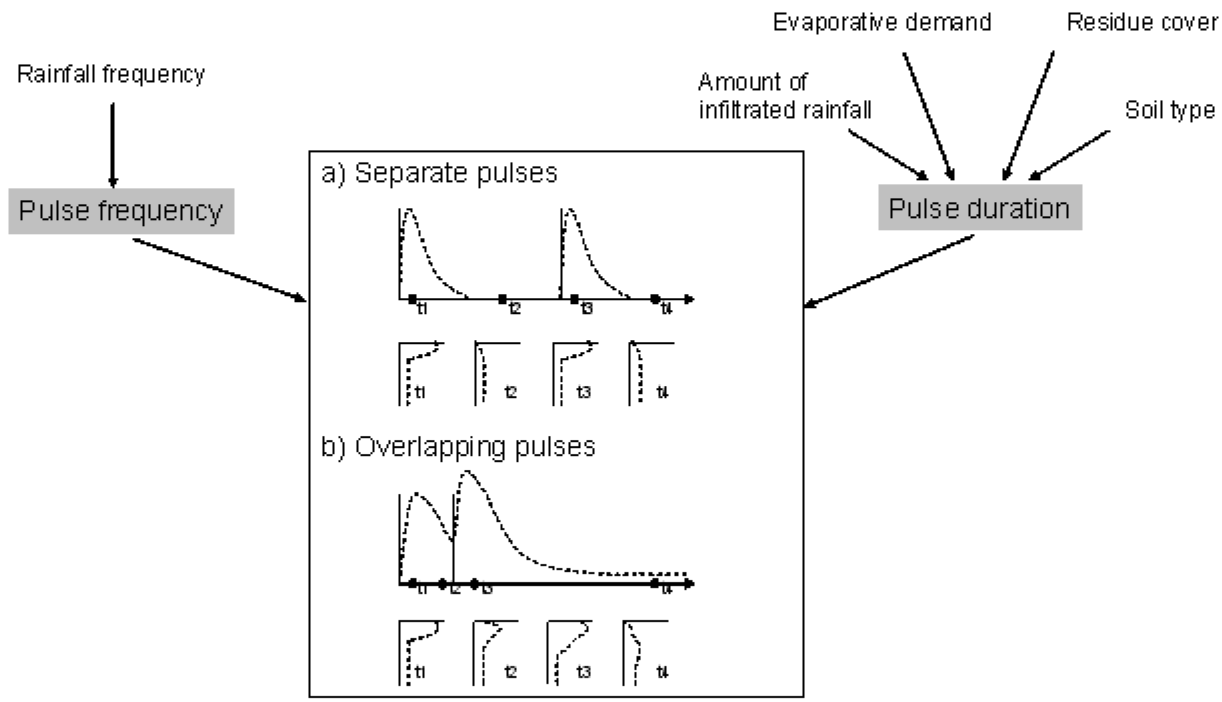

Figure 1. Pulse paradigm as applied to the impacts of residue management (adapted from Noy-Meir, 1973).

Whether we see an effect of weed control depends on the pulse size, but also pulse depth. The event needs to be large enough to germinate weed seeds, but if water stays within the evaporation zone, and pulse is not soon followed up by another that pushes it deeper, then weeds will either not survive or not make a difference as the water would get evaporated anyway (findings v) and vi) above). We can, therefore, only expect an effect of weed control if soil was wet below the evaporation zone from a single large event or multiple smaller events where the balance between frequency and duration caused overlap of soil water pulses. Once soil below evaporation zone has wet up control of any flush of weeds that could grow its roots into that zone will have an impact. Note that unlike with residue effects, the wetting may come from a single event. This could be during the summer fallow, but an event late during the preceding growing season would have a similar impact, as was captured in finding vii) above.

Towards assessment of soil water accumulation within the fallow period

Viewing rainfall variability as causing pulses of soil water with different magnitude and duration is a useful way to explain the summer fallow residue management and weed control effects. It could also be a useful conceptual framework for farmers and advisers to think about likely outcomes of management decisions in view of the conditions created by evaporative demand, residue cover, soil type and recent (sequences of) rainfall events. To use the pulse paradigm as an approach for assessment of soil water accumulation within the fallow period will require the development of simple calculations with site-specific parameters that can support the concepts of pulse depth and duration. These could then be used to underpin a set of simple rules of thumb. Having an assessment of the likelihood that a pulse has moved beyond the evaporation zone or an evaluation whether or not pulses tend to overlap and lead to accumulation of soil water, can inform management during the fallow period.

Conclusion

A pulse paradigm adopted from the field of arid land ecology was successfully applied to explain summer fallow management findings from a field experiment and from matching simulations using historical climate data. With this approach rainfall variability is viewed in terms of different possible sequences of rainfall events that create pulses of soil water. The effects of summer fallow residue management and weed control are explained by considering soil water pulse frequency, duration and depth. This approach provides a useful conceptual framework to interpret observed fallow management effects. It could also be developed into a method to assess soil water accumulation within the fallow period to consider the likely outcomes of fallow management decisions.

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