The impact of a lucerne phase in a crop rotation on groundwater recharge in south-west Australia

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Abstract

The south-west of Australia is subject to a Mediterranean-style climate, with cool wet winters and hot dry summers. In the 300-500 mm rainfall zone, broad-scale clearing of native vegetation, and its replacement by annual crops and pastures, has resulted in increased groundwater recharge, and the development of large areas of dryland salinity. The deep-rooted perennial pasture plant, lucerne (*Medicago sativa* L.), has shown promise in reducing groundwater recharge. However, in a region where recharge in any one year can vary between 0 and 250 mm, lucerne's impact on average long-term recharge (currently 10-60 mm/year) is not known. In this paper, the impact of changing the length of the lucerne phase in rotation with a phase of annual crops was modelled over 81 years for the 300 and 500 mm rainfall zones, assuming that the buffer created by lucerne was completely filled before recharge commenced. In percentage terms, leakage was more readily controlled in the drier environment, on a duplex soil, where a rotation involving 50% lucerne (eg. 3 years of lucerne followed by 3 years of crop) reduced leakage by 95%. On an acid loamy sand in the wetter environment, the same rotation reduced leakage by 40%. Once appropriate leakage targets are established, the model described here can be used to design suitable rotations.

Key Words

LeBuM, phase rotation, simulation, water use

Introduction

In southern Australia, dryland salinity continues to spread, and without remedial action, is expected to affect 30% of the landscape by 2050 (1). It is caused by an interaction between climate, in which the majority of rainfall arrives at the time of year when potential evaporation is lowest, and the replacement of native vegetation with agricultural crops and pastures. The soil in the shallow root zone of crops and pastures is unable to store the normal winter excess of water, and so leakage to the groundwater is enhanced relative to the native system.

The incorporation of deep-rooted perennials such as lucerne into farming systems while the groundwater is still deep enough not to interfere with plant growth is one of the remedial actions suggested to try to restore the groundwater balance (2,3). In theory, lucerne acts by creating a zone of dry soil (referred to as a 'buffer') below the normal rooting depth of annual crops and pastures, partially reproducing the effect of the native vegetation. In a phase rotation, the buffer is firstly created during the lucerne phase, and then refilled during the cropping phase with water that would otherwise have contributed to groundwater recharge. The buffer is then re-created in the next lucerne phase, and so on.

However, leakage is very variable from year to year (4,5), and can range between 0 and 250 mm. The impact of this variability makes it difficult to assess the likely impact of a lucerne phase on long-term average leakage rates. Although the application of APSIM and similar models to phase rotations is currently under development, there is a need for a simple, user-friendly model to assist with the design of suitable rotations for recharge control. For this reason, we developed the Leakage/Buffer Model (LeBuM), which uses long-term modelled leakage amounts under annual crops or pastures to calculate the average leakage rate for a given phase rotation and buffer size. In this paper, LeBuM is described and then used to assess the impact of varying the length of the annual and perennial phases on long-term average leakage for two contrasting environments and two soil types in south-west Australia.

Methods

LeBuM

Input for the Leakage/Buffer Model (LeBuM) consists of a long-term series of annual leakage amounts (in mm) under traditional crops. In this paper we used 81 years of leakage data under wheat crops generated by the APSIM model (4). Parameters in LeBuM include the length of the crop phase (between 0 and 10 years, or variable length until the buffer is filled), the length of the perennial phase (between 0 and 5 years), the maximum buffer generated by the perennial phase (in mm), and the proportion of the buffer developed in the first, second and third years of the perennial phase. Buffer in this instance is defined as the *extra* water storage volume created by the perennial, in addition to the storage normally available after an annual crop.

Calculations in the model assume that the buffer created by the perennial phase is completely filled before leakage commences. This may take several years. For example, consider the case where the buffer size was specified as 100 mm at the completion of the lucerne phase, and annual leakage for the next three years under traditional crops (without the benefit of a buffer) was estimated by APSIM as 70 mm, 40 mm and 30 mm. In the first year of cropping, the 70 mm of leakage under continuous cropping would be completely absorbed by the buffer of 100 mm, which has now been reduced to a buffer of 100-70 = 30 mm. In the second year of cropping, when leakage in the absence of a buffer would have been 40 mm, the buffer can still absorb 30 mm, but the other 10 mm continues on as leakage. In the third year, when leakage without the buffer was estimated by APSIM as 30 mm, the buffer has now been completely filled, and so leakage is unchanged at 30 mm.

Because leakage is very variable from year to year, the actual leakage calculated by LeBuM can vary considerably depending on the stage of the rotation. For example, annual leakage of 100 mm as estimated by APSIM could be reduced to 0 mm if it occurred in a year immediately following the perennial phase, or may be retained as 100 mm if it occurred after the buffer had been filled. For this reason, LeBuM performs calculations on all possible rotation stages, and calculates the average leakage from each.

LeBuM makes no attempt to predict production levels, nor the actual buffer size generated by a perennial phase for a particular situation. It simply calculates the impact of a user-specified buffer size on the long-term average leakage value for a given rotation.

Model application

APSIM leakage outputs for the period 1912-1992 for Moora (462 mm annual rainfall) and Merredin (328 mm annual rainfall), on an acid loamy sand and a shallow duplex soil prone to waterlogging (4) were used as input for the LeBuM calculations. The average plant-available soil water for a wheat crop was 90 mm for the acid loamy sand and 81 mm for the shallow duplex soil. The influence of rotation length was determined by calculating the expected leakage from rotations with a lucerne phase length set at 3 years, and varying the cropping phase length from 0-10 years. Additional rotations included 2 years of lucerne followed by 10 years of crop; lucerne 0, crop 1; lucerne 4, crop 1; lucerne 5, crop 1; making a total of 15 different rotations. In all rotations, the buffer was assumed to be 50% developed after the first year of lucerne, 85% developed after the second year, and 100% developed after third and subsequent years, approximately following the buffer development previously observed (3). So, for a nominal buffer of 100 mm, leakage was reduced by a maximum of 50 mm (50% of 100 mm) in the second year of lucerne, 85 mm (85% of 100 mm) in the third year of lucerne or first year of crop, depending on the length of the lucerne phase, and 100 mm for subsequent lucerne years or the first year of the cropping phase.

Results

At Moora, leakage from both soil types decreased as the proportion of lucerne in the rotation increased (Figure 1). Increasing the buffer size created by lucerne had a relatively minor impact on leakage. At Merredin (Figure 2), with lower leakage values for all rotations, the same general trends emerged, except there was generally little benefit obtained by increasing the proportion of lucerne in the rotation above about 50%.

In percentage terms, the incorporation of a perennial phase was more effective at the drier site (Merredin). Leakage could be reduced by 95% on the shallow duplex soil at Merredin with a rotation of about 50% lucerne, but much higher lucerne intensities were necessary at Moora or on the acid loamy sand.

The variation in leakage from year to year resulted in large variation in the number of years that the buffer was expected to last (Table 1). At Merredin, a buffer of 70 mm could last for anywhere between 1 and 12 years, depending on the run of seasons, but at Moora, the same buffer was always filled within 5 years.

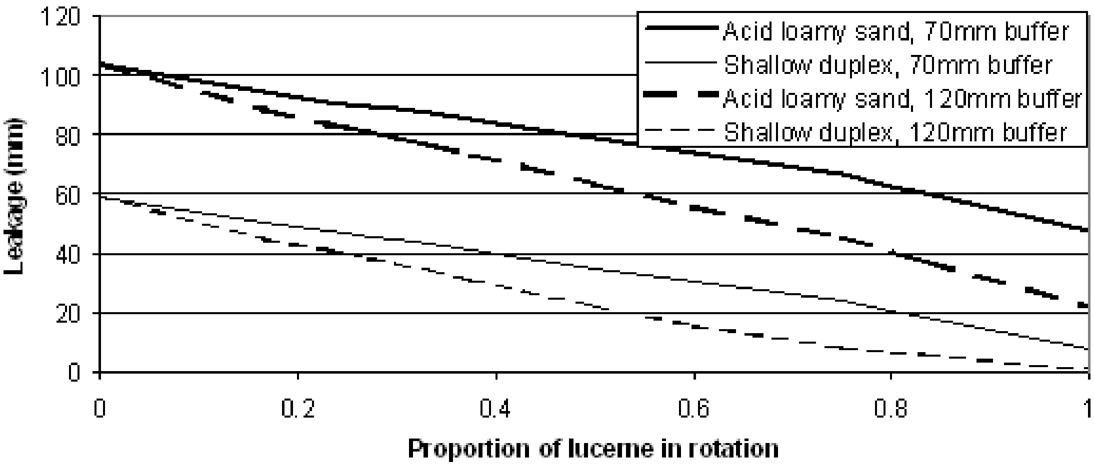

Figure 1. Influence of buffer size (70 or 120 mm) and proportion of lucerne in the rotation on leakage from an acid loamy sand or a shallow duplex soil at Moora.

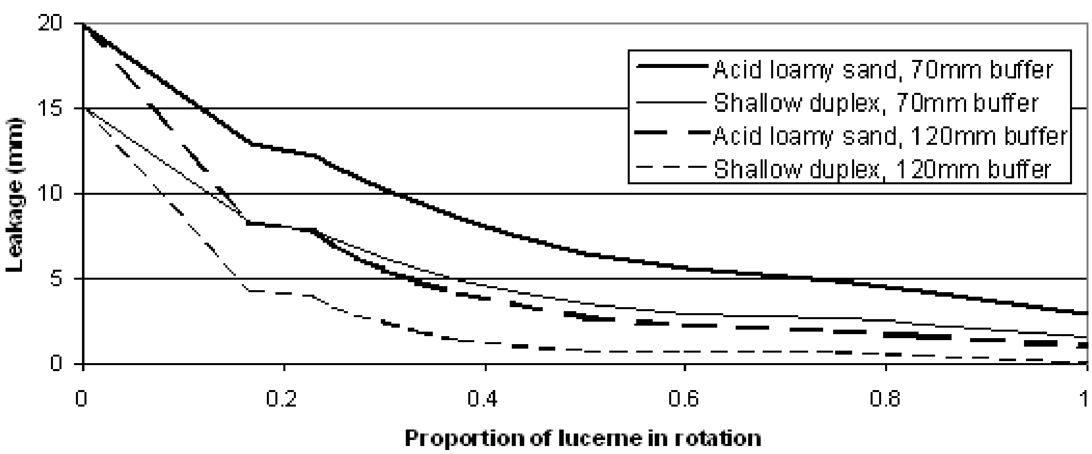

Figure 2. Influence of buffer size (70 or 120 mm) and proportion of lucerne in the rotation on leakage from an acid loamy sand or a shallow duplex soil at Merredin.

Table 1. Minimum, maximum and average number of years to fill a buffer of 70 mm or 120 mm on a duplex or acid loamy sand at Merredin or Moora.

Buffer size (mm)	Moora	Merredin

		Acid loamy sand	Waterlogging duplex	Acid loamy sand	Waterlogging duplex
70	Min	1	1	1	1
	Max	5	5	12	12
	Mean	**1.5**	**1.7**	**4.8**	**5.6**
120	Min	1	1	1	3
	Max	5	6	15	16
	Mean	**1.9**	**2.7**	**7.8**	**8.5**

Discussion

The buffer sizes used here (70 mm and 120 mm) reflect the range of buffers measured under southern Australian conditions. A buffer of 70 mm at Katanning (similar rainfall to Moora) has previously been reported (3), and a buffer in excess of 100 mm was measured at Merredin (D. Tennant, personal communication). A review of lucerne water use (6) found buffers ranging between 0 and 550 mm, with most in the range of 50-150 mm.

The major difference between soil types was that leakage from the acid loamy sand was always greater than leakage from the shallow duplex, possibly due to the slower hydraulic conductivity of the duplex soil (4). However, their response to the inclusion of a perennial phase into the rotation was similar. For this reason, larger responses (in percentage terms) were observed for the duplex soil. However, only in the lower-leakage environment (Merredin), on the lower-leakage duplex soil, was leakage reduced to the levels usually recommended by hydrologists to restore the groundwater balance (7). In this environment, a phase rotation involving about 50% lucerne was sufficient to reduce the average annual leakage by 95%.

The average number of years required to refill the buffer created by the perennial phase allows the design of a tentative phase rotation system. In general, a buffer created by a perennial phase lasted longer in the drier environment (5-8 years) than in the wetter environment (2-3 years), and soil type had only a minor impact. However, the variability identified by LeBuM in the number of years to refill the buffer, due to the natural year-to-year climate variability, suggests that flexibility in phase lengths will be an important aspect of successful phase rotations.

It is also important to note that the calculations used here assume that the buffer created by the perennial phase is completely filled before leakage commences. In other words, we have assumed that there is no preferential flow through the buffer, which may not be correct in some circumstances. For example, water balance calculations at Katanning indicated that leakage occurred while the buffer still had about 10 mm of storage space available (3).

Conclusion

The simple modelling approach used here to estimate long-term leakage rates under a phase rotation can be used to assess regions and soil types where a phase rotation is likely to have a beneficial impact on groundwater levels. Although models such as APSIM may in the near future perform a more rigorous assessment, the simple LeBuM approach may be a more user-friendly decision support tool in the design of suitable phase rotations. Input from hydrologists will be required to set appropriate recharge targets to restore the groundwater balance for the various regions and soil types. Once recharge targets are known with more confidence, phase rotations and required buffer sizes can be modelled to determine whether the recharge targets are achievable. Further research and model development is necessary to include the effects of preferential flow paths through the buffer on long-term leakage rates.

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