Soil water balance – what can pastures do for farming systems?

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Abstract. Farming systems that are based on annual crop or pasture species are inherently leakier for water and nutrients than systems based on perennial species. Perennial pastures are an important component of any farming system and need to be incorporated into the system in a way that minimises economic penalty, yet maximises control of deep drainage and accumulation of soil nitrogen. To obtain high water use by pasture, manage pasture herbage mass (1500-3000 kg DM/ha), litter mass (1000 kg DM/ha) and ground cover (>70%) to minimise losses of water through surface runoff and evaporation and so maximise production. To return to cropping, remove the pasture before it declines and weeds invade and early enough to accumulate adequate stored soil water and nitrogen for the following crop.

Introduction

Farming systems in the mixed-farming zone that grow annual crops or pastures are undergoing a quiet transformation to increase sustainability and so ensure long-term production and profitability outcomes. Sustainability of these farming systems is under threat from loss of soil structure, declining soil fertility, wind and water erosion, and excessive losses of water and nutrients *via* deep drainage and surface runoff. Development of sustainable farming systems requires a thorough understanding of how the farming system impacts upon the water balance (Thurow 1991). One key threat is that farming systems that grow annual crops or pastures are inherently leaky due to their inability to maintain green leaf area throughout the year (Cocks 2003). Therefore, a key component of increasing the sustainability of these systems is to reduce the losses of water and nutrient by including a productive perennial pasture phase that can contribute to soil health and fertility, soil water balance and overall enterprise profitability. However, farmers may experience significant economic penalty during the time that cropping paddocks are sown down to a pasture phase. The goal in managing the pasture phase should be to maximise the production of dry matter and use of excess soil water so that the paddock can be returned to cropping as soon as possible. The aims of this paper are to explore the soil water balance of both cropping systems and pastures and see how management can improve their performance, and how this interacts with the water balance of the whole farming system.

Soil water balance

The water balance is a mathematical expression of the water cycle, which surround us and our activities each day. Rainfall is received and this water moves through the landscape along various pathways as shown in Figure 1.

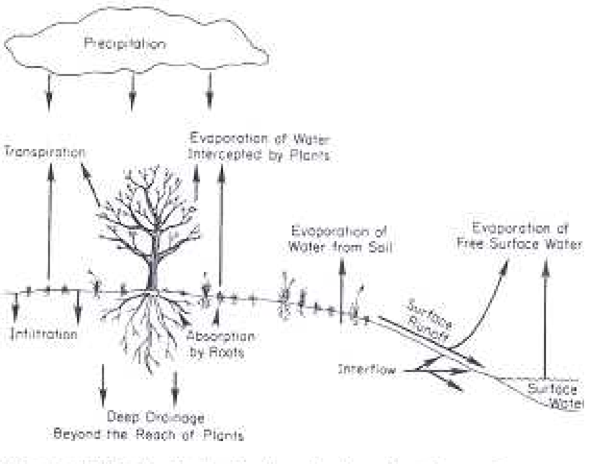

Figure 1. The hydrological cycle showing the major processes and pathways of water movement through a system (after Thurow 1991).

The water balance can be defined using the following equation;

$$P = R_o + ET + D_d + \Delta S$$

where P is precipitation, R_o is surface runoff, ET is evapotranspiration, D_d is deep drainage, and ΔS is

Table 1. Estimated long-term mean values for the water balance (mm) of crops and pastures on the Liverpool Plains (after Abbs and Littleboy 1998)

Crop or pasture	Rainfall	Runoff	Deep drainage	Transpiration	Evaporation[1]
Wheat - sorghum	616	11	48	174	384
Pasture	616	3	1	276	338
Response crop	616	7	22	213	375
Lucerne and response crop	616	4	8	244	360

[1] evaporation includes components of canopy interception and evaporation from litter and bare soil.

change in stored soil water. Evapotranspiration includes evaporation from canopy interception, litter mass, bare soil surfaces, and transpiration by plants.

Management of crops and pastures can have a significant effect on the amount of water and the time that it resides in the soil profile. For example, fallowing on heavy cracking clay soils (vertosols) can retain up to 250 mm of stored soil water for many months prior to sowing of a crop. However, intense rainfall on soil with low ground cover will generate runoff and so have a very short duration in the farming system. The water balance quantifies the fate of all rainfall on an annual basis, whether it went into interception, surface runoff, evaporation, transpiration, deep drainage or a change in stored soil water content (Fig. 1). The water balance can be viewed as an assessment of how the farming system performs over different time frames (daily, monthly, annual, and decadal), and how effectively the system is utilising water, a most important and fundamental input.

Deep drainage under farming systems

Development of agriculture in south-eastern Australia has led to a substantial amount of native perennial woody vegetation being cleared and replaced with annual crops or pastures. Essentially, annual crops and pastures use less of the annual rainfall because of their shorter growing seasons and shallower root systems compared with the native vegetation, resulting in larger amounts of deep drainage (Johnston *et al.* 1999). Excessive deep drainage leading to ground water recharge is accepted as the cause of water table rise and land and river salinisation (Walker *et al.* 1999) that threatens the productivity and sustainability of a significant proportion of areas used for agricultural production.

For the Liverpool Plains area, for example, previous studies have estimated that perennial pastures had less deep drainage compared with any of the simulated crop rotations (Abbs and Littleboy 1998, Table 1). Pastures lost 1 mm to deep drainage each year on average, while crop rotations lost up to 48 mm. In more recent studies on cracking clay soils, mean deep drainage under long fallow and continuous wheat rotations was estimated at 66 and 75 mm/year, respectively compared with 0 mm/year under perennial pastures for the period 1995-1998 (Ringrose-Voase *et al.* 2003). Similarly, chloride mass balance estimated that the deep drainage rate on cracking clay soils under cropping rotations was 5-30 mm/year compared with 1-2 mm/year for lucerne or perennial grass pastures (Young and McLeod 2003). Cropping systems on lighter soils (non-vertosols) have deep drainage rates that are much higher (Table 2).

Soil water balance of pastures

Grazing management can affect the amount of water retained or lost by a pasture and so has an important role in defining a sustainable farming system. Simulation studies of the long term water balance for natural pastures on the North-West Slopes (Simpson *et al.* 1998; Lodge *et al.* 2002) estimated that annual rainfall was accounted for by evapotranspiration (89-95%), runoff (2.5-3.0%), and deep drainage (2.3-8.4%) components. Grazing management has the potential to manipulate these components by changing the physical structure and species composition of pastures.

Considering the large area of grazed pastures on the North-West Slopes of NSW, the potential for land salinisation is high (Beale *et al.* 2000), but is offset by a summer rainfall distribution occurring in periods of high evaporative demand. Therefore, the risk of deep drainage is smaller than southern regions with winter dominant rainfall (Simpson *et al.* 1998). However, due to the large but infrequent rainfall events that occur in summer, deep drainage is episodic in northern NSW. Further, deep drainage may recharge aquifers that supply irrigation and town water supplies elsewhere (e.g. Weltz and Blackburn 1995).

In the Liverpool Plains area, pastures based on

Table 2. Estimated mean deep drainage (mm/year) for crop and pasture rotations for black and red soils on the Liverpool Plains using Gunnedah climate data for periods 1886-1993 (after Abbs and Littleboy 1998) and 1958-1998 (after Ringrose-Voase *et al.* 2003)

		Black soil		Red soil	
Crop or pasture	Rainfall (mm)	Drainage (mm)	Rooting depth (cm)	Drainage (mm)	Rooting depth (cm)
			Abbs and Littleboy (1998)		
LF wheat-sorghum	616	71	120	81	120
Wheat	616	55	120	56	120
Sorghum	616	49	120	52	120
Pasture	616	4	300	15	300
			Ringrose-Voase et al. (2003)		
LF wheat-sorghum	631	50	210	85	90
Wheat	631	63	210	88	90
Sorghum	631	18	190	62	90
Opportunity crop	631	16	190/210	61	90
Pasture (improved)	631	1	150	5	150

perennial species have higher evapotranspiration and less deep drainage on an annual basis compared with cropping systems based on annual species (e.g. Table 2). The main reason is that perennial pastures have more green leaf for longer periods compared with annual species. To effectively increase water use and reduce deep drainage, choose the deepest-rooted perennial species that is at least as profitable as the system that it replaces. This may include a perennial pasture species such as lucerne (*Medicago sativa*) or trees, or combinations of these. Depending on soil type, location, and climate, the optimal configuration of cropping, pastures and possibly trees needs to be determined (Stirzacker *et al.* 2002).

Lucerne being a deep-rooted perennial species is ideal for high water-use and deep drainage control in many landscapes. Where there are no subsoil constraints, lucerne will actively mine stored soil water from the profile to depths of up to 6.0 m in sandy soils (Dolling *et al.* 2003). This can provide buffering for deep drainage, water table rise and saline discharge (Bee and Laslett 2002). The water use of lucerne has been reported for a variety of situations and climatic conditions (e.g. Crawford and MacFarlane 1995; Lolicato 2000; Ridley *et al.* 2001). In areas with lower annual rainfall (i.e. 300-600 mm/year), the ability of lucerne to prevent drainage is more tree-like and is likely to be an economic alternative (Bathgate and Pannell 2002). However, limitations to the growth of lucerne across the landscape include its low tolerance to acidic and saline soils (Humphries and Auricht 2002; Murphy and Leys 2004). Grazed lucerne may also develop low ground cover, which increases the risk of surface runoff and erosion (Young *et al.* 2003). For vertosols in northern areas, Bambatsi panic (*Panicum coloratum* var. *makarikariense*) together with a winter growing species may be a suitable alternative for using summer rainfall and prevent profile filling (Ringrose-Voase *et al.* 2003).

Lucerne has been widely reported as a suitable plant to dewater soil profiles in south-eastern Australia (e.g. Angus *et al.* 2001). The principle of this approach is that lucerne retrieves excess stored soil water that as deep drainage would otherwise be lost from the production cycle (e.g. Bee and Laslett 2002). Others have discussed the use of lucerne that is grown in phases to limit deep drainage in cropping systems in southern Australia (e.g. Crawford and MacFarlane 1995; Dolling *et al.* 2003) and for northern NSW (e.g. Young *et al.* 2003). However, the duration of the cropping period before a return to a lucerne phase is rotation and location specific and is highly dependent upon large rainfall events. To best determine the timing of a return requires monitoring of stored soil water (e.g. Murphy and Lodge 2004).

Water use by pastures

Management of the amount of stored soil water within the root zone provides an opportunity to mitigate deep drainage losses. Across southern Australia, considerable effort has been expended to compare the drying ability of different crop and pasture sequences for the purpose of managing dryland salinity, and to further understand the dynamics of herbage mass production.

For the high rainfall zone of southern Australia, various studies have shown that annual pastures use less water (25-40%) than perennial pastures (Scott and Sudmeyer 1993; Ridley *et al.* 1997; Simpson *et al.* 1998; Dolling 2001; Heng *et al.* 2001; Ridley *et al.* 2001). Studies of stored soil water dynamics for pastures in northern NSW are somewhat rarer. However, a range of studies has recently been completed and reported in the literature (e.g. McLeod 2002; Murphy 2002; Lodge *et al.* 2003). For the Northern Tablelands of NSW, a well managed phalaris (*Phalaris aquatica*) -white clover (*Trifolium repens*) mixed pasture used twice the amount of water of either a degraded phalaris or annual pasture in autumn. The phalaris-white clover pasture extracted 16% of this water from the subsoil (55-130 cm depth), while the other pastures used water only from the top 50 cm. As a result, deep drainage under the phalaris-white clover pasture was only half of that under the other pastures (McLeod 2002). For the North-West Slopes, redgrass-wallaby grass pastures oversown with subterranean clover maintained significantly drier soil profiles than the same pasture without subterranean clover and although the amounts were <5.7 mm each year for the 30-170 cm depth (Lodge *et al.* 2003), this may also reduce deep drainage. However, grazing method (continuous *vs.* rotational) had little affect on the total amount of stored soil water for the same pasture type during the monitoring period (Murphy 2002), but rotational grazing produced a significantly wetter surface soil (0-30 cm, 2.9 mm each year, Lodge *et al.* 2003).

Simulation studies have indicated that grazing management may have a minimal impact on water use of perennial grass based pastures and so deep drainage, compared with the effect of different rooting depths of alternative plant species (Simpson *et al.* 1998). The SGS Pasture Model (Johnson *et al.* 2003) was used to estimate deep drainage under grazed natural pastures on the North-West Slopes and showed that drainage events were highly episodic and occurred mainly in years with above average rainfall (Lodge *et al.* 2002). For example, 3 years with above average rainfall (1996-1998) accounted for over 20% of the estimated deep drainage for the period 1971-2001. Individual years showed estimated deep drainage values of up to 272 mm, but the mean was just 56 mm/year (Lodge *et al.* 2002).

What practical guidelines can producers use to maximise pasture water use?

While rainfall and soil conditions may vary between farms, there are general indicators that can be applied to pasture management so that water use by pastures can be maximised. Each of these indicators has direct impact on components of the water balance and the interactions between them and so should not be viewed in isolation: herbage mass (kg DM/ha), litter mass (kg DM/ha), and ground cover (%).

Results from grazing studies conducted in the SGS National Experiment indicated that although surface runoff is largely influenced by storm size and intensity, the amounts of surface runoff and soil erosion can be controlled by maintaining high levels of ground cover (>70%) and a minimum litter mass of 1000 kg DM/ha (Lang 1979; Murphy 2002; Murphy *et al.* 2004*a*). Bare soil evaporation can be a major loss of water from pastures and this can be reduced by maintaining high levels of litter. Studies of evaporation indicated that for a wet soil surface a litter mass of 3000 kg DM/ha reduced evaporation by 1 mm/day thereby maintaining a higher soil water store for pastures to use for a longer period following rainfall (Murphy *et al.* 2004*b*). Canopy interception can be a significant part of the water balance for pastures depending on herbage mass of the pasture and amount, intensity and frequency of rainfall (Dunkerley and Booth 1999). For redgrass-wallaby grass pastures in northern NSW, the SGS Pasture Model estimated that interception may be between 2-20% (or 14-131 mm) of annual rainfall depending on their herbage mass (Murphy 2002). Maintaining pasture herbage mass between 1500-3000 kg DM/ha will reduce losses through canopy interception while maintaining adequate amounts of ground cover and litter mass for runoff and evaporation control. These herbage mass conditions are also similar to those recommended by PROGRAZE™ for maximum feed quality and intake by sheep and cattle (Bell 2003). Sowing species that grow year round or a mix of summer and winter active species would provide the best opportunity to maximise water use of pastures in northern NSW.

Techniques to measure stored soil water

Monitoring stored soil water can provide a useful insight into pasture growth and help forecast down turns in growth rates (Murphy and Lodge 2004). Estimates of stored soil water conditions can be obtained using a variety of techniques ranging from physical sampling (soil cores), tensiometers (soil water potential), electrical resistance sensors (soil water potential), time domain reflectometry (TDR), and neutron scattering techniques (NMM). Commercial equipment commonly used to measure soil water includes EnviroSCAN®, Diviner 2000®, Tain SoilMoisture Loggers®, HydroSense®, EcH$_2$O® and others. Sensors can be connected to automatic dataloggers and personal computers to assess stored soil water conditions continuously to aid management decisions as demonstrated by Murphy and Lodge (2004). A more practical method to indicate the amount of stored soil water is the frequent use of a push-probe, particularly for vertosols. Another simple technique and reasonably practicable is to determine the gravimetric water content of soil samples obtained with a post hole digger (e.g. see the Mallee Sustainable Farming website, www.msfp.org.au).

Getting ready for the next crop

The length of a pasture phase depends on the reasons why it was used. For example, if the main reason was to dry the soil profile to maximum extent, then it may last for 2-10 years (Bee and Laslett 2002). Alternatively, the pasture phase may be used to regenerate soil structure, provide a disease break, or increase soil nitrogen (N) and soil organic carbon levels, which may be achieved in a shorter time frame of 2-4 years. Once the decision has been made to return to cropping the timing relies upon having the greatest opportunity to accumulate adequate amounts of soil water and soil N for the following crop. For lucerne based pastures, studies have suggested that removal should take place before the stand thins excessively, which will help avoid weed invasion and any possible deep drainage and leaching of soil N before the crop can be established (e.g. Young *et al.* 2003). To achieve this for a red soil type in central NSW a September removal has been suggested (Butler 2002). Also, September as opposed to December removal resulted in higher grain yield and protein content. Studies of fallows on the Liverpool Plains for vertosols suggested that no more than 12 months was required to accumulate adequate stored soil water for sowing a crop (Ringrose-Voase *et al.* 2003). For vertosols, removal of lucerne 9-12 months before sowing wheat may allow soil water reserves to replenish and soil N benefits may occur for up to 5 crops following the pasture (Crocker and Collett 2003).

Once the decision has been made to remove the pasture, the technique should also consider the risk of erosion from a fallow with low ground cover. Fallow from legume pastures can have very low ground cover due to the rapid breakdown of their stubbles. The preferred method of terminating lucerne where a high risk of surface runoff or erosion exists is chemical removal without tillage. Herbicide should be applied when the lucerne plants are actively translocating photosynthate to the crown and taproots (Davies and Peoples 2003), 2-3 weeks after defoliation. Actively growing plants are more likely to translocate the herbicide to all parts of the plant compared with those that are stressed due to a lack of soil water or cold conditions. Careful and accurate application of herbicide (according to the manufacturer's guidelines and statutory requirements) when plants are actively growing is most likely to terminate the lucerne at a time that offers greatest benefits of soil water and N accumulation (Davies and Peoples 2003).

Conclusions

Perennial pastures are an important component of any farming system and need to be incorporated into the system in such a way that minimises economic penalty, yet maximises control of deep drainage and accumulation of soil N. Perennial pastures can offer great opportunities to increase soil structure and soil health, reduce excess stored soil water and deep drainage losses. To obtain high water use by pasture, it is important to manage the total herbage mass, litter mass and ground cover so that losses through surface runoff, evaporation and deep drainage are minimised, thereby also increasing the productivity of the pasture. If the paddock will be returned to annual cropping following the pasture phase, then it is important to plan the removal of the pasture so that the greatest opportunity is provided to accumulate adequate amounts of soil water and soil N prior to sowing the first return crop.

Take home messages:

- Farming systems that are based on annual crop or pasture species are inherently leakier for water and nutrients than systems based on perennial species.

- A phase of perennial pasture can redress the risk of deep drainage.
- A pasture phase is likely to be most productive when maximum stored soil water is available.
- Use grazing to manage pasture herbage mass (1500-3000 kg DM/ha), litter mass (1000 kg DM/ha) and ground cover (>70%) to minimise losses of water through surface runoff and evaporation and so maximise production.
- To return to cropping, remove the pasture before it declines and weeds invade and early enough to accumulate adequate stored soil water and soil N for the following crop.

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