Soil water balance modelling highlights limitations for pasture production in northern NSW

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ABSTRACT

Measurement and simulation model estimates of components of the long-term soil water balance (Rainfall=Evapotranspiration+Runoff+Deep Drainage) indicate that up to 90% of annual rainfall in northern New South Wales can be lost as actual evapotranspiration (ET_a, evaporation and transpiration). In pastures with low leaf area and low ground cover, around 40% of ET_a may occur as soil water evaporation. This has important implications for pasture production since water that is lost from the soil by evaporation is not available for plant growth. Producers need to consider how to retain this moisture in the soil for longer periods, so that more water is available for plant growth. Using a modelling approach has also highlighted some potential areas of concern that may occur in estimating the parameters of ET_a, allowing for canopy and litter evaporation and in calculating deep drainage.

KEY WORDS

Soil water balance, evaporation, transpiration, runoff, deep drainage, modelling.

INTRODUCTION

Northern NSW is in a predominantly summer rainfall zone with 60% of total annual rainfall occurring from November to March (1), mainly as high intensity storms. In pastures with low (<40%) ground cover, this results in high surface runoff of water (90-160 mm per year, 3). Also, in summer potential evapotranspiration (ET) rates are high (7-10 mm/day), reducing rainfall effectiveness, particularly where ground cover is low and a high proportion of water is evaporated from bare soil surfaces. As a result, although mean annual rainfall on the North-West Slopes of NSW is 650 mm, average stocking rates are only 3.3 dry sheep equivalents per ha and native grasslands dominated by more xerophytic genera such as *Aristida* and *Austrostipa* are the major pasture types (5).

As part of the Sustainable Grazing Systems (SGS) Program (8) three experimental sites were established on the North-West Slopes of NSW, with the primary focus of examining the relationship between grazing management, surface runoff, groundcover, water infiltration and ET (8). As part of the project some pre-experimental modelling simulations were undertaken as described by (12). For a wallaby grass, subterranean clover pasture at Tamworth mean annual rainfall (1971-93) was 708 mm; mean annual actual ET (ET_a), 659 mm and mean surface runoff (Ro) and deep drainage (DD) were estimated at 21 and 25 mm per year, respectively (12). These values indicated that the highest proportion of annual rainfall (93.1%) was in the ET_a term of the average annual water balance. If half of this rainfall was being lost as water evaporated from the soil, then around 330 mm per year or about 50% of the mean annual rainfall on the North-West Slopes of NSW was not available for plant growth.

Detailed studies (6, 7) have been initiated to better understand the partitioning of the water balance into its components of evaporation, transpiration, surface runoff and deep drainage. However, deep drainage (which is likely to account for about 3.5 % of the mean annual rainfall, 12) is not being directly measured, but can be estimated by modelling or by difference ($DD=Rainfall-Ro-ET_a-\Delta SWC$). The SGS Pasture Model has been developed to meet the specific needs of the program. It integrates pasture and animal production and utilisation with water and nutrient dynamics (4). The soil water component of the SGS Pasture Model is based on the procedures described by (2) and the version used in the simulation (5.2.3) uses modified Campbell functions in solving the Richard's equation.

Data from an experimental area that was stocked in September 1997 as part of the SGS National Experiment (8) were used to run the SGS Pasture Model (version 5.2.3). The soil was a red chromosol and the natural pasture a native perennial tussock grassland dominated by summer-growing redgrass (*Bothriochloa macra*), wiregrass (*Aristida ramosa*), and yearlong green wallaby grass (*Austrodanthonia* spp.). Pasture and litter herbage mass and ground cover were estimated by two observers using the methods described by (10). In each plot, each observer scored 10 quadrats in two permanently located transects and herbage mass scores were regressed against 30 calibration quadrats. Climate data (rainfall, temperature, solar radiation, relative humidity, and wind run) were logged at 30-minute intervals from an on-site meteorological station. Surface runoff data were collected from bounded runoff plots (6) and reference ET was calculated using the Penman-Monteith method described by (13). Within each of the treatment plots (each 0.5 ha) for which data were simulated there were four neutron moisture meter (NMM) access tubes (0-210 cm), in which soil water content was estimated every 4 weeks. The whole site contained a network of 49 access tubes, 25-50 m apart.

Data were modelled for two contrasting treatments; continuous grazing at 6 sheep/ha, which resulted in low ground cover and herbage mass and rotational grazing (4 weeks grazing; 12 weeks rest) at 4 sheep /ha (high ground cover and herbage mass). Estimates of the components of the soil water balance derived from the SGS Pasture Model were used solely to illustrate that these two markedly different pasture situations resulted in large differences in the partitioning of the components of the soil water balance. The model generally gave good agreement with observations of soil water content, pasture herbage mass (green and dead) and animal growth, but these data have not been presented since the main aim of the paper was to examine the differences in soil water dynamics for the two contrasting pastures.

RESULTS

Five months after the grazing treatments started there were substantial differences in the pasture and litter herbage mass and the ground cover of the two treatments (Table 1), with the rotationally grazed plots having the highest levels of each. These differences were maintained over the simulation period (Table 1). Total rainfall for the simulation period (1 March 1998 to 1 March 1999) was 735.4 mm. This period included winter 1998, which was one of the wettest winters (275.2 mm) on record. Total potential (reference) ET for the 12-month period was 1347.5 mm.

Table 1. Pasture herbage mass (kg DM/ha), litter herbage mass (kg DM/ha), ground cover (%) values at 1 March 1998 and 1 March 1999 for the high ground cover-herbage mass (High GC-HM) and a low ground cover-herbage mass (Low GC-HM) plots at the experimental site, "Springmount", Upper Manilla.

	High GC-HM		Low GC-HM	
	1/3/1998	1/3/1999	1/3/1998	1/3/1999
Herbage mass (kg DM/ha)				
Pasture	3400	7500	1500	2180
Litter	800	1000	260	40
Ground cover (%)	87	88	53	50

In the high ground cover-herbage mass (High GC-HM) plot, the transpiration component of ET_a was predicted to be about 210 mm and evaporation from the soil, litter and canopy to be about 390 mm, giving a total ET_a of around 600 mm for the 12-month period (Table 2). In contrast, the low ground cover-herbage mass (Low GC-HM) plot was predicted to have a total ET_a of around 545 mm (170 mm T; 375 mm E, Table 2). Inclusion of canopy and litter estimates for evaporation in the SGS Pasture Model enabled water taken up and released by these pasture components to be considered as separate from soil water infiltration and evaporation. Where the canopy and litter contain high proportions of dead, dry material, considerable amounts of water can be accounted for by these processes and differences in the structure of the two pastures were reflected by the predicted differences in these components (Table 2). As expected the High GC-HM was predicted to lose less water from soil evaporation (76 mm), but more

water by transpiration (211 mm) compared with the Low GC-HM pasture (225 and 169 mm, respectively, Table 2). Hence, lower ground cover and exposure of the bare soil surface was predicted to allow 18% more of the total rainfall to evaporate from the soil than in the High GC-HM pasture.

Deep drainage was predicted to be low (less than 5 mm, or less than 1% of rainfall) in both pastures, despite the wet winter in 1998. Supporting evidence for a low amount of deep drainage was also observed in the measured profile soil water content, where the top 80 cm often had high moisture content, but the bottom (1-2 m) was relatively dry. This suggested low transmission rates of water through the profile with water from high rainfall events taking weeks or months, rather than days, to move to the lower part of the profile.

Table 2. SGS Pasture Model output of the soil water balance for a simulation from 1 March 1998 to 1 March 1999 for a high ground cover-herbage mass (High GC-HM) and a low ground cover-herbage mass plot (Low GC-HM) at the experimental site. Values in brackets are the proportion (%) of total rainfall.

	High GC-HM		Low GC-HM	
Initial soil water content (mm)	411.2		381.9	
Final soil water content (mm)	535.7		485.5	
Total rainfall (mm)	735.4		735.4	
Transpiration (mm)	210.6	(28.6)	169.3	(23.0)
Evaporation (mm)				
Canopy	166.2	(22.6)	60.3	(8.2)
Litter	147.4	(20.0)	89.7	(12.2)
Soil	75.6	(10.4)	224.5	(30.5)
Drainage (mm)	2.0	(0.3)	4.4	(0.6)
Surface runoff (mm)	9.1	(1.5)	83.5	(11.4)

Runoff under High GC-HM conditions was predicted to be around 1.5% of total rainfall, compared to 11.5% for the Low GC-HM pasture (Table 2). Measured runoff for the simulation period was 2.1 mm (one runoff event) in the High GC-HM plot and 76.1 mm for the Low GC-HM pasture. In the latter pasture, runoff occurred in 17 events, but three high rainfall events accounted for more than 75% of the runoff. These three events were associated with major fluxes of water into the soil profile, indicating the episodic nature of the dynamics that are being modelled.

DISCUSSION

While we acknowledge that these model simulations require further validation and have limited interpretation, they clearly show that different herbage mass, ground cover and litter levels in pasture gave marked differences in the partitioning of the soil water balance. In particular, low ground cover and litter were likely to lead to high loss of water by evaporation from bare soil surfaces. To reduce this water loss and allow more water to be retained in the profile, producers should manage native pastures on the North-West Slopes of NSW to maintain ground cover at higher than 70% and litter herbage mass at 1500-2500 kg DM/ha. Maintaining high ground cover would also reduce water loss by surface runoff (3, 6).

Sub-surface lateral flow was not considered an issue at this site and so was not included in the model simulation, but there is provision for it to be implemented in the SGS Pasture Model. Although the soils at the SGS site were duplex the textural change from A to B horizons was not abrupt (clay loam to light clay). Sub-surface lateral flow or preferential flow did not appear to be occurring since there was no bleaching or marked differences among the soil water contents at the A-B horizon boundary for the 49 NMM tubes.

The inclusion of litter and canopy and their role in both absorbing rainfall and evaporating water has been a key development in the SGS Pasture Model. This has allowed for a more realistic estimate of the amount of rainfall that is actually available for water infiltration or surface runoff as well as a more appropriate partitioning of evaporation into its components of soil, canopy and litter.

Clearly, on the North-West Slopes of NSW ET is the largest term of the soil water balance equation, compared with runoff and deep drainage. In the SGS Pasture Model potential ET is calculated as reference ET (9, 13) using a standard albedo value of 0.23. In a study of net radiation, albedo and evaporation and transpiration components for a range of plant density, litter and bare soil conditions in this environment, Murphy and Lodge (7) found that albedo values varied from 0.13 (wet, bare soil) to 0.24 (dry, 3000 kg DM/ha litter). Since ET actual is derived from the ET reference value the inclusion of locally modified crop coefficients in the Penman-Monteith equation, as suggested by Meyer (9), may better reflect these differences and provide a more accurate estimate of this term. The two pastures in the simulation study were different in terms of herbage mass, proportion of green leaf, height, canopy structure, litter and ground cover and so would not be expected to have similar net radiation and albedo values.

In the soil water balance, deep drainage is often estimated by difference after measuring rainfall, runoff, lateral flow (if appropriate), change in soil water content and estimating ET actual. Given the above concerns about estimating ET actual and its relatively large size, any inaccuracies in calculating this term may be inadvertently attributed to the deep drainage term. Since the interpretation of deep drainage is critical to understanding the issues of soil salinity and acidity and water movement in the landscape some caution may be required when using values from model outputs.

Good agreement between modelled and observed soil water content data through time does not necessarily imply that the model is “correct”, since errors in the fluxes into and out of the soil water may balance out (e.g. overestimating both ET and drainage). We have therefore used the SGS Pasture Model as a research tool to increase our understanding of the processes and their interactions, rather than solely as a predictive tool.

The importance of understanding and correctly estimating the individual components of the water balance in attempting to assess transpiration and deep drainage cannot be over-emphasised. Infiltration is a relatively slow process (as shown by hydraulic conductivity values, 11) and so deep drainage typically lags behind rainfall. Accurate estimates of ET, rainfall interception by the pasture canopy and litter, as well as data for soil water characteristics are essential for modelling and understanding soil water dynamics. Errors in these values may result in errors in estimates of plant available water or water lost as deep drainage.

CONCLUSIONS

Simulations from the SGS Pasture Model reflected differences in the herbage mass, ground cover and litter levels of two contrasting native pastures on the North-West Slopes of NSW. Producers need to reduce bare soil evaporation by increasing ground cover and litter. Use of the SGS Pasture Model highlighted some limitations in the calculation of ET reference and actual values and estimates of deep drainage and some caution may be required when interpreting these values.

ACKNOWLEDGEMENTS

SGS is an initiative of Meat and Livestock Australia, the Land and Water Resources Research and Development Corporation, the Murray-Darling Basin Commission and collaborating agencies.

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