WATER UPTAKE BY HILL COUNTRY PASTURE – MORE THAN YOU THINK

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Abstract

Hill country pasture production on the east coast of the North Island is often constrained by moisture deficits during the summer and autumn months. To date, little has been published about the soil water balance of New Zealand hill country under pasture. It has been suggested that hill country soils have a small water storage capacity with moisture uptake limited to a depth of 150 mm, and that pasture growth is much more dependent on rainfall frequency than total annual rainfall, with less than 50% of the annual rainfall being used to replenish the root zone moisture pool.

In this study, a trial site was established (April 2006) at Pori Station (22 km SSE of Pahiatua). Runoff plots (2 x 1 m) and climate stations have been installed on; both a steep (30^o) and shallow (20^o) slope of a north facing aspect, a steep and shallow slope of a south facing aspect, and two east facing aspects (steep slopes). Soil cores were taken at approximately monthly intervals for gravimetric water contents and bulk density data was used to convert these to volumetric water contents. Climatic data was gathered using a combination of a manual rain gauge and a NIWA meteorological station approximately 5 km distant.

Our research suggests that significant water extraction occurs to a depth of at least 350 mm and that between 65 and 80% of the annual rainfall contributes to the available soil moisture pool. A simplified water balance model based on the work of Bircham and Gillingham (1986) is described and discussed. It is hoped that this model will provide further impetus for research into the soil water balance of New Zealand hill country pasture systems and assistance to those people who manage these systems.

Introduction

The soil water balance for flat pasture land in New Zealand has been extensively studied and is quite well understood. Woodward et al. (2001) provide an analysis of previous work, leading to a daily time-step, two soil-layer model which they validated using 11 historical datasets. In contrast, relatively few studies have been published on the water balance in hill country, despite it constituting over 75% of New Zealand’s pastoral land.

Bircham & Gillingham (1986) provide the only in-depth published study of the water balance of New Zealand hill country pasture soils. The experimental data they present consist of three years of weekly or bi-weekly, 0-75 mm depth soil water content measurements at two Waikato hill country sites, one with a Yellow-brown earth and the other a Yellow-brown loam. A pair of 20^o or 30^oN and S facing slopes was studied at each site.

The conceptual side of their paper presents a detailed model of the soil water balance for sloping land. The first year’s gravimetric water content data is used to evaluate some of the model parameters, and the remaining two years’ data is used to validate the model. The most innovative feature of their model is a “soil rewetting function”, which throttles infiltration when the surface soil is dry to take into account the soil water repellency often observed under dry conditions in hill country (Morton et al. 2005).

Bircham & Gillingham (1986) drew two major and not previously apparent conclusions about pasture on hill country from their study. First they concluded that pasture growth was much more dependent on rainfall frequency than total rainfall and second, that the actual evaporation (and so effective rainfall) was probably between 400 and 600 mm/year, or only about 50% of the reference crop evaporation which they estimated to be about 1050 mm/yr. This is despite the annual rainfall at the two sites for the years studied ranging from 1378 mm to 1935 mm.

Materials and Methods

The trial site (at 40°38’ S and 175°54’ E) is on a sheep and beef hill country farm which is 16 km E of Eketahuna and at an altitude of about 230 m. The soil on the slopes is primarily Atua silt loam (Mottled Orthic Recent Soil, Hewitt 1998) and the land use class is 7e1. Four locations were selected for the installation of duplicate side-by-side runoff plots, these plots being paired on 30° and 20° slopes on N and S facing aspects. Each plot is 2 m long along the slope and 1 m wide across the slope. The surface runoff from each plot is captured through a slot in a 55 mm diameter PVC pipe buried at the bottom of the plot, from where it flows into a 45 litre collection vessel set in a hole dug below the plot. A full description is given by Bretherton et al. (2010). Fig. 1 shows the location of the plots. Between 2 May 2006 and 30 October 2007, the collection vessels were emptied on about 30 occasions.

Between 2 May 2006 and 4 May 2007, a 25 mm diameter soil corer was used to collect samples for gravimetric water content determination at approximately monthly intervals. Bulk density data were used to convert the gravimetric water contents to volumetric water contents.

A manual rain gauge was installed at the site, which was read whenever the site was visited.

We follow Jackson (1967) and express all results involving or implying unit area (e.g. evaporation, rainfall, runoff, drainage, and dry matter yield) on a horizontal projection basis.

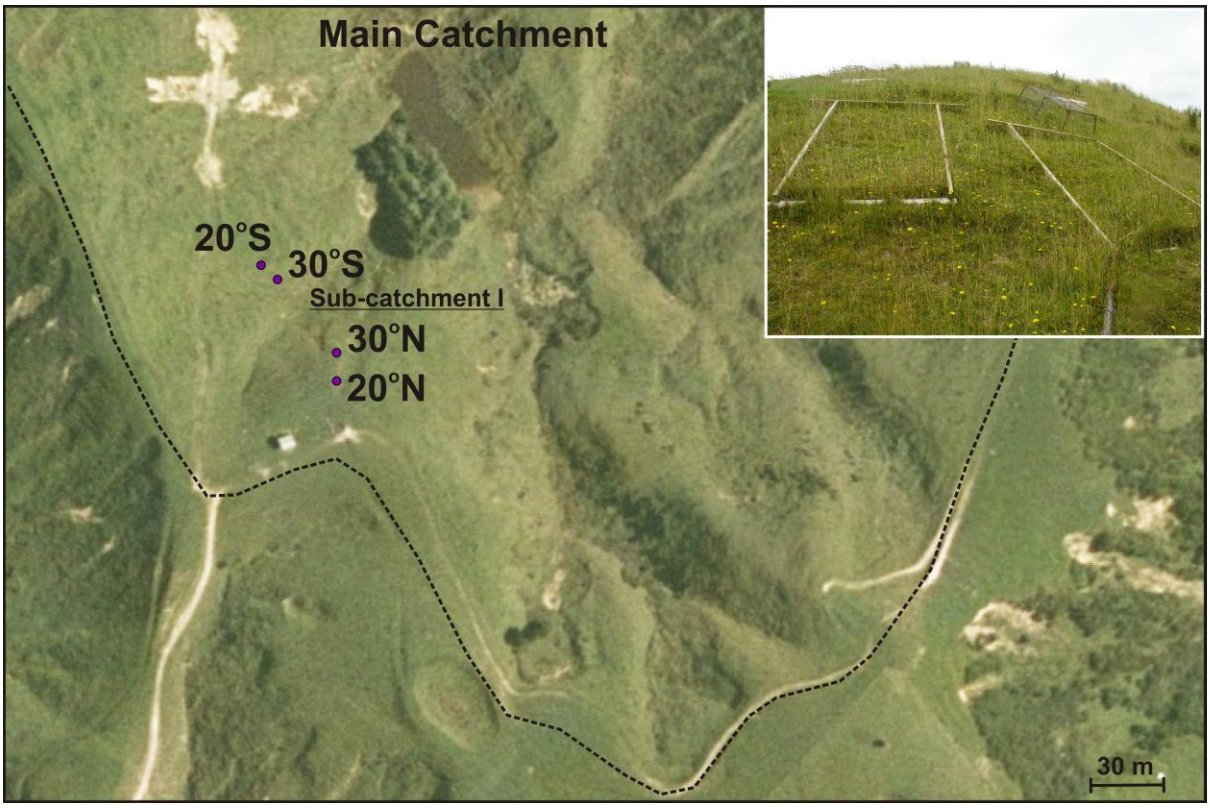

Fig.1 Aerial photograph (sourced from Terralink NZ Limited) showing the location of the N and S runoff plots. Each point represents a replicate pair of plots and the dotted line denotes the main catchment boundary. The top of the photograph is true North. Inset shows the 30°N (left) and 30°N (right) runoff plots.

Results and Discussion

The water storage difference between the driest and wettest soil water content profiles ranged from 69 mm for the 30°S location up to 87 mm at the 20°N location. Fig. 2 shows the data for these two locations. In all cases the data indicate water uptake by pasture roots at 300-350 mm depth, suggesting that there was also uptake from below 350 mm depth.

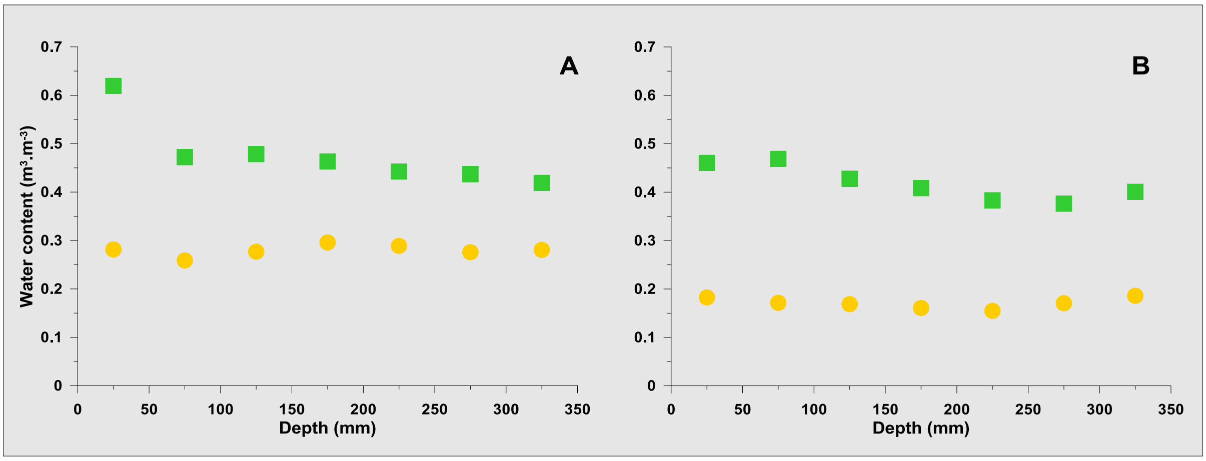

Fig. 2 Driest (●) and wettest (🟩) water content profiles measured at (a) 30°S and (b) 20°N locations.

The available water (*W*) stored in the top 350 mm on the various sampling dates at the four locations is shown in Fig. 3. To calculate these values it has been assumed that 55 mm of the stored water is unavailable, as this was the minimum amount of water present in the driest (N facing) plots. The volumetric water contents measured in the top 50 mm on the same dates at the four locations are shown in Fig. 4.

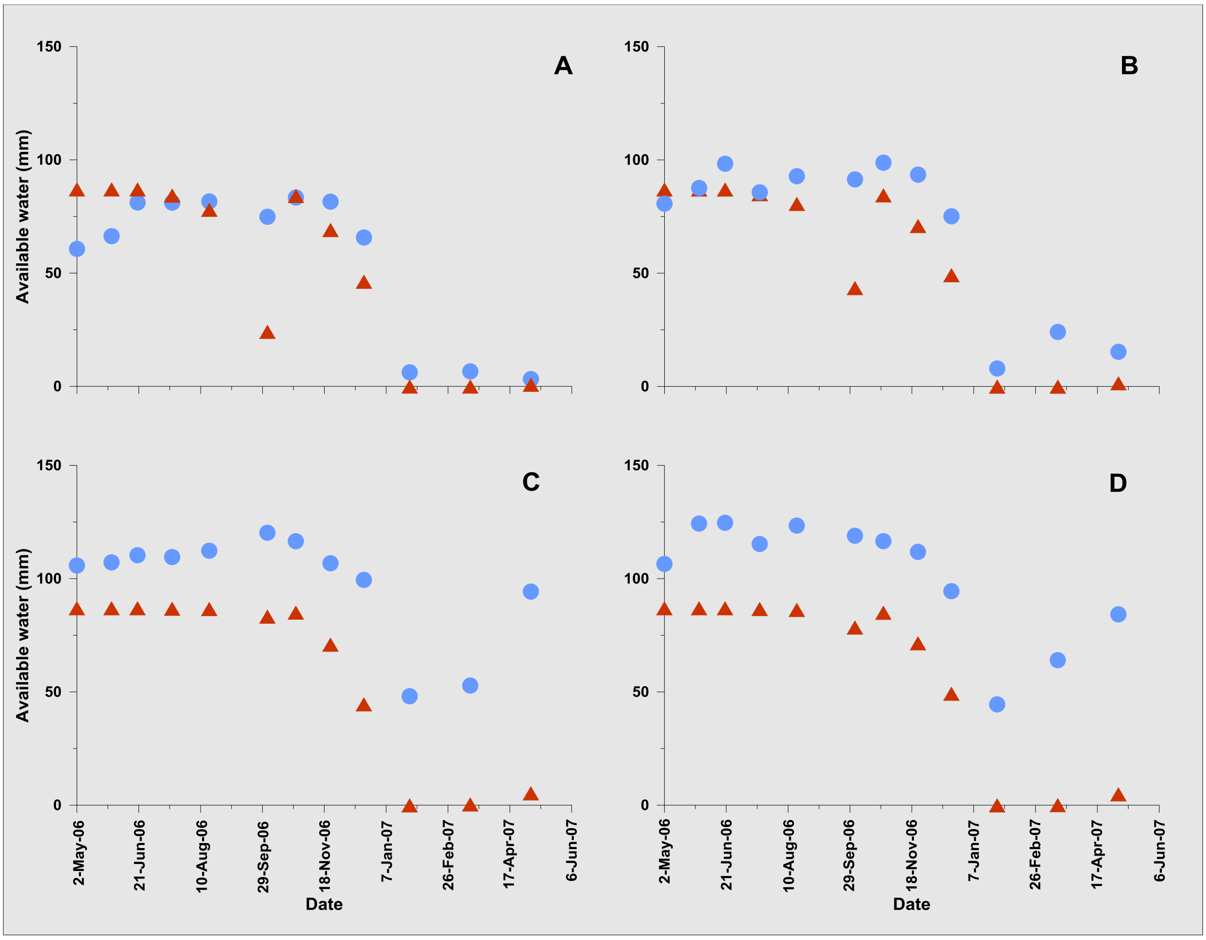

Fig. 3 Modelled (▲) and measured (●) available water in the top 350 mm of soil at locations (A) 30^{o}N, (B) 20^{o}N, (C) 30^{o}S, and (D) 20^{o}S on various sampling dates.

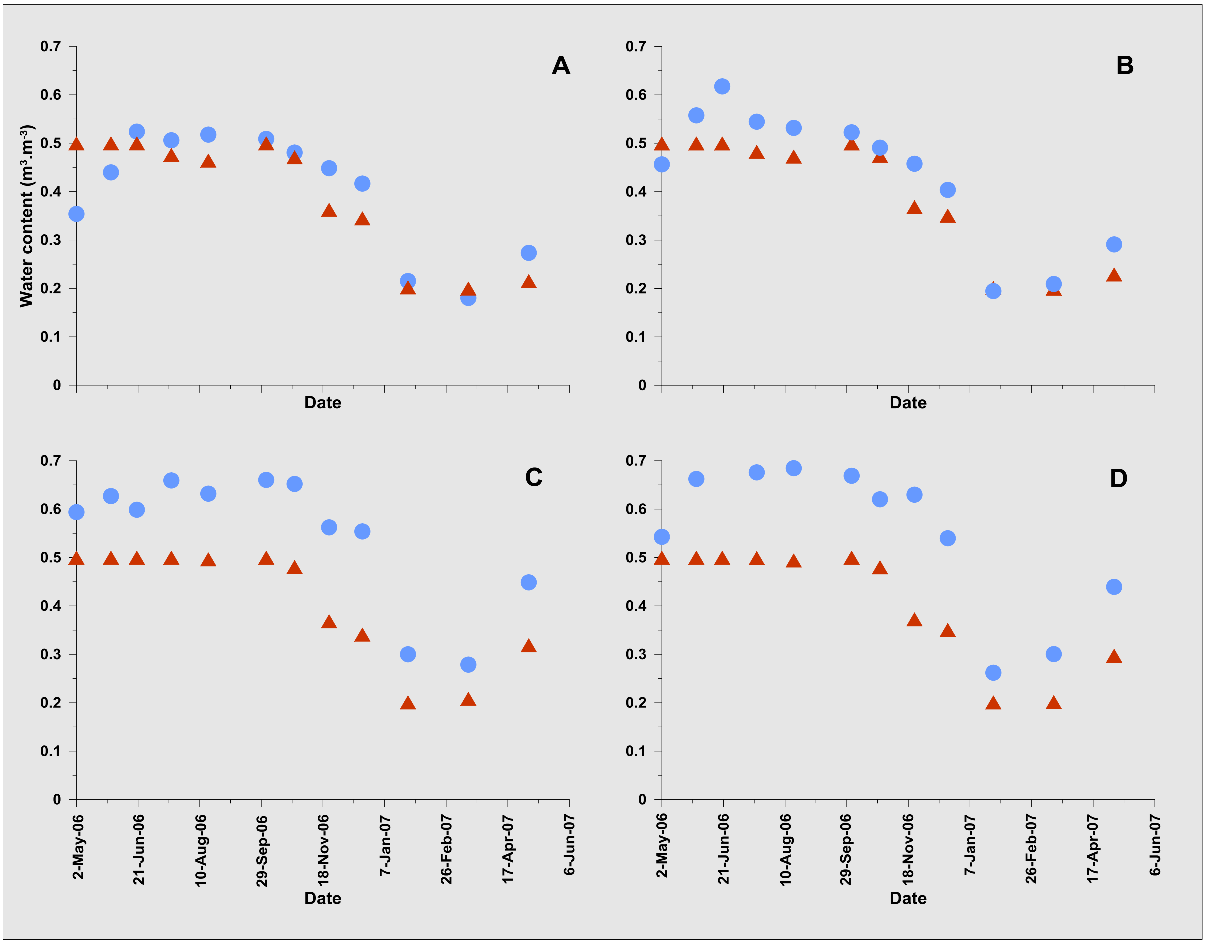

Fig. 4 Modelled (▲) and measured (●) available water in the top 50 mm of soil at locations (A) 30°N, (B) 20°N, (C) 30°S, and (D) 20°S on various sampling dates.

The runoff data are presented in Fig. 5. There is a problem with some of the data, as the 45 litre storage containers could only hold just over 22 mm of runoff and at times they were filled to overflowing at the time of sampling. Thus all the runoff values of 22 mm are lower bounds of the runoff for the period rather than actual values. The plots producing the most runoff (24% and 23% of the 1761 mm of rainfall) were the 30°S ones, but the actual runoff would have been considerably greater than that, due to overflow occurring on 11 occasions.

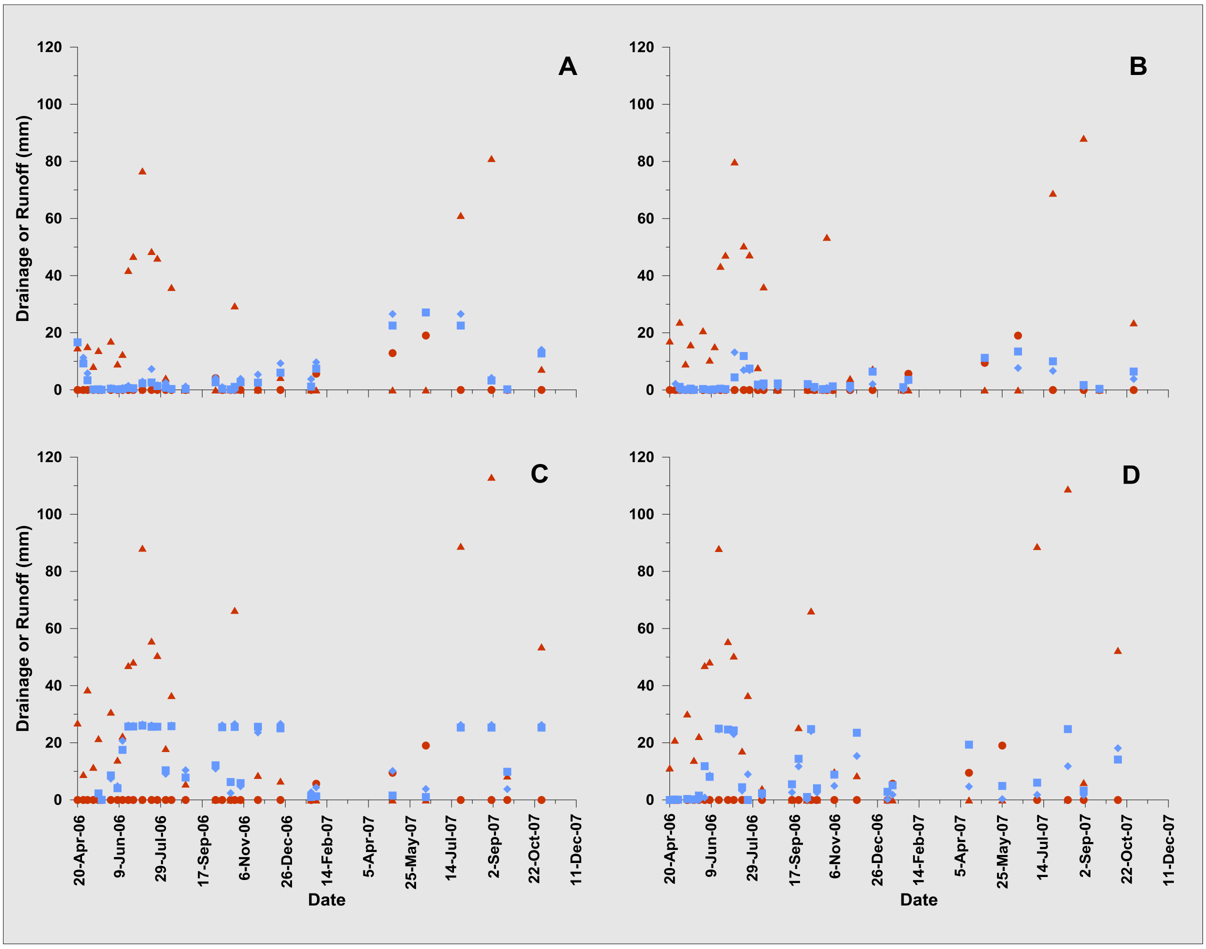

Fig. 5 Modelled drainage (▲), repellency-induced surface runoff (●) and measured surface runoff (■ for left- and ◆ for right-paired plots) at locations (A) 30°N, (B) 20°N, (C) 30°S, and (D) 20°S on various sampling dates.

A Modified Model

Bircham & Gillingham's (1986) model treats the root zone as four separate layers, each of which is 37.5 mm thick, and then uses the simulated water content of the top 37.5 mm of soil to decide whether or not repellency throttles infiltration. Infiltrating water cascades through all four layers before any excess drains out the bottom.

To obtain a simpler model, while preserving the feature of throttled infiltration when the topsoil is dry, we calculate two water balances in parallel to obtain more realistic evaporation estimates during rewetting as advocated by Scotter et al. (1979b) and Woodward et al. (2001). The main (first) water balance is similar to that employed by Coulter (1973). It assumes an available water holding capacity (W_a) for the root zone and when this is exceeded, surplus water is lost immediately as drainage (D), part of which may be surface runoff. Evaporation (E) proceeds at the reference crop rate (E_o) if available water is present, and drops to zero once it is used up. The available water in the root zone at the start of the next day (W_{n+1}) is found in the usual way as:

$$W_{n+1} = W_n + I - D - E \qquad (1)$$

where I is the daily infiltration from rainfall on day n. The second water balance is specifically associated with the top 50 mm of soil and is calculated in parallel in much the same way, but a smaller available water holding capacity ($W_{s,a}$) is assumed, and the evaporation from the topsoil (E_s) is estimated as some fraction of E.

The amount of water uptake from the top 50 mm of soil depends on the root distribution and the dryness of the topsoil relative to the rest of the root zone. Trial and error suggested that E_s (the uptake from the top 50 mm) is reasonably well described by the equation:

$$E_s = E_o W_s / (2 W_{s,a}) \qquad (2)$$

where W_s is the computed available water in the top 50 mm of soil on the day of interest. Thus at field capacity, half the uptake is from the top 50 mm, with the fractional uptake decreasing in proportion to the available water remaining as the top 50 mm dries out.

We use Revfeim's (1982) equations to correct the incoming radiation for slope and aspect, and use the FAO56 version of the Penman-Monteith equation to estimate E_o (Allen et al. 1998) from the nearest NIWA site with solar radiation data at East Taratahi, about 30 km S of the site.

To derive daily rainfall estimates, data from Eastry Station (about 5 km away) were used in conjunction with the cumulative data from the site. Trial and error led us to assume that when the water content in the top 50 mm of soil is less than 0.25 $m^3.m^{-3}$, and thus the available water there (W_s) is less than 2.5 mm, the daily infiltration is limited to a set maximum (I_r) of 5 mm. Otherwise, all the rainfall infiltrates and $I = P$ where P is the precipitation. Daily repellency-induced surface runoff (R) is thus found as $P - I_r$.

A more complete description of the modified model is given by Bretherton et al. (2010).

Model Outputs and Discussion

The observed water uptake patterns in Fig. 2 are at variance with the key assumption made by Bircham & Gillingham (1986) that the effective root zone is only 150 mm deep, implying available water storage capacities of just 40 mm and 46 mm for their two soils. At our site, both the effective rooting depth and available water storage capacity are at least twice the values assumed by Bircham & Gillingham who recognised that their assumption of a 150 mm deep rooting zone may not have been valid.Fig. 3 shows the measured and modelled values for the available water in the root zone. As expected for the N aspect locations, the maximum and minimum values are in quite good agreement, as the model parameters were chosen so this would be so. The values for the S locations are nearly all higher than the model values by between 20 and 40 mm. The observed and modelled time trends of W are closely synchronised, with three exceptions. The first was that in most cases the first three data points show the soil was still rewetting, whereas the model indicates the soil had reached field capacity. The second is for the N facing locations on 3/10/2006, when the modelled values were much lower than the measured values. The third exception was that the two S facing locations 'wet up' towards the end of the observation period while the model predicted that W would remain small. Despite these discrepancies, the simple water balance with its embedded E_o values seems accurate enough to be useful. The modelled and measured values in Fig. 4 for the water content in the top 50 mm are in quite close agreement, with the exception of the S locations where, again, the measured values tend to be higher than the modelled values, particularly when the soil was around field capacity. A fuller discussion of the model outputs is given by Bretherton et al. (2010).

The relative size of the components of the water balance generated with the modified model for our site (see Table 1) are markedly different to those generated by Bircham & Gillingham (1986) for their sites using their model. These actual evaporation values are higher than the values estimated by Bircham and Gillingham's model for their sites, despite the rainfall at their site being about twice the rainfall at our site.

Table 1 Summary of model outputs for all aspect and slope combinations for the year 31 October 2006 to 30 October 2007 when total rainfall was 840 mm.

Aspect and slope	Modelled reference evaporation (mm)	Modelled actual evaporation (mm)	Modelled drainage + runoff (mm)
N 30^o	1154	671	191
N 20^o	1054	635	226
S 30^o	843	545	313
S 20^o	850	550	309

Conclusions

While hill country soils are usually shallower than lowland soils (Molloy 1988), the data presented here suggest that Bircham and Gillingham's (1986) assumption of a typical rooting depth of 150 mm is much too shallow. We observed significant water extraction down to at least 350 mm depth. Because the rooting depth assumption is central to their model, this throws into question their major conclusions that the availability of moisture to pasture in hill country soils was "*highly dependent on rewetting frequency rather than the total rainfall and (that) probably less than 50% of the total annual rainfall was involved in replenishing soil moisture at plant-available depths*." The modified model presented here suggests that between 65 and 80% of the 840 mm of rainfall over a 12 month period was evaporated by the pasture at our site.

Acknowledgements

Our thanks go to Clem and Joy Smith for allowing access to and development of the research site on their farm. We are also very grateful for the technical assistance provided by Ian Furkert, Bob Toes, Ross Wallace, and Anja Moebis.

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