Using long term model simulations of soil water content of grazed pastures to predict the onset of drought on the North-West Slopes of New South Wales

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Droughts are an important feature of Australian agriculture that have widespread social, environmental and economic consequences. For grazing industries, drought may have large negative on-farm impacts on green forage availability, ground cover, perennial and sown species persistence, stocking rate, animal health, animal production and costs associated with transport, agistment, and supplementary feeding and so loss of income. Off-farm, droughts can impact on commodity prices, product demand, business and community viability and issues of landscape degradation and air and water quality associated with overgrazing.

O'Meagher *et al.* (1998) noted 2 important areas for future drought research: the development of reliable early warning systems and understanding the impact of climate variability on ecological systems. For grazed pastures, Donnelly *et al.* (1998) used measures of rainfall, pasture production and supplementary feeding requirements to define drought and reported that the availability of green herbage and particularly the weight of supplement fed were more relevant criteria than rainfall for assessing the production and financial management impacts of drought on grazing systems. Similarly, for rangelands Stafford Smith and McKeon (1998) used a simulation model to test the use of different measures of a drought event (rainfall, soil moisture, pasture growth, liveweight gain and an economic productivity index) and concluded that total soil moisture appeared to be the best single measure.

Rainfall may be an imprecise measure of the onset and occurrence of drought since its effectiveness is related to patterns of occurrence (intensity and duration), timing in relation to temperature and evapotranspiration losses, differences in soils, plants and topography, and water loss from soil surface runoff. Measures of soil water content (SWC) integrate the effects of rainfall, temperature, soil type, plant water use and the availability of water for plant growth. These in turn impact on forage availability, often the main criterion used by producers to identify periods of drought. Intuitively then SWC, which acts as a "bridge" between rainfall and plant growth, may be a useful indicator of the likely onset of drought, allowing for better forward planning and timely management decisions by producers.

This paper reports the use of a pasture simulation model to firstly estimate total SWC (0-210 cm) for a grazed native pasture in northern New South Wales and secondly to examine the use of this approach as an early warning system to predict the onset of drought.

Materials and methods

Data were collected from a field site near Barraba on the North-West Slopes of NSW that had a redgrass (*Bothriochloa macra*) dominant native pasture on a Red Chromosol soil and was set stocked at 4 sheep/ha from spring 1997 to spring 2001, with no fertiliser inputs (Lodge *et al.* 2003). From early 1998 to spring 2001 calibrated estimates of total SWC (mm) were obtained from 3 neutron moisture meter access tubes to 210 cm in 3 replicated plots (0.5 ha), at approximately 4-week intervals (43 sampling times). Daily climate data (rainfall, maximum and minimum temperature, relative humidity, solar radiation) for Barraba the nearest town were extracted from a Silo data drill (Jeffery *et al.* 2001) for the 47-year period from 1957 to 2004 and used to calculate daily potential evapotranspiration rates (Priestley and Taylor

1972). These data were then applied to the SGS Pasture Model (version 1.5.2, Johnson *et al.* 2003) parameterised from site data for 1998 (initial herbage mass, species composition, volumetric SWC for a soil depth of 0-210 cm, hydraulic conductivity, and initial animal liveweight; Lodge *et al.* 2003). After a 5-year initialisation period the model was then run for this stocking rate and a nil fertiliser regime for the 47 years of daily climate data, to obtain daily estimates of total SWC (mm). Correlations between actual and predicted total SWC were examined for 3 model runs; (i)1998 data (1-year only, n = 12), (ii) 1998-2001 data (n = 43) i.e. running the model for 4 years, and (iii) 1998-2001 total SWC data (n = 43) after running the model for 47 years (1957-2004).

Daily predictions of total SWC (mm) were then examined for the period 1957-2004 and in particular for the known drought years of 1965, 1980, 1994 and 2002 (Clewett *et al.* 2003). For each of these years there was little or no plant growth and SWC (0-210 cm) was generally <410 mm. Also, at a SWC of 410 mm plant available water was <0, (Lodge *et al.* 2003) and so this value was chosen as a conservative threshold for indicating drought for this soil type. Each year was then categorised, based on the number of days that daily total SWC was <410 mm. Years were grouped (Table 1) into those in which the proportion (%) of days with <410 mm total SWC were >70%, 70-50, 50-30, 30-20, 20-10 and <10% of the year (i.e. the higher the proportion the drier the year).

Results and discussion

Predicted and actual total SWC were always significantly correlated (P<0.05, r>0.82) indicating that the short (1-year), medium (4-year) and long term (47-year) model estimates of total SWC derived from daily climate data were in agreement with actual values.

Clearly, the SGS Pasture Model reliably predicted the occurrence of drought for the soil type and grazing system modelled (Table 1 and Fig. 1*a*). Predicted total SWC was estimated to be <410 mm for >70% of the time in 1957, 1965, 1980, 1994 and 2002 with the years 1965, 1980, 1994 and 2002 corresponding to known drought years (Clewett *et al.* 2003). In association with these drought years, predicted SWC was also estimated to be <410 mm for 50-70% of the time in 1966 and 30-50% of the time in 1967, 1981, 1982, 1993, 2001 and 2004 (Table 1).

In marked contrast, SWC was predicted to be <410 mm for <10% of the year in 1964, 1978, 1983, 1997 and 2000 (Table 1) and in these years mean total SWC was around 500 mm (Fig 1*b*). Total SWC was predicted to be >410 mm for all days of the year in only 1 year (1983). An actual maximum total SWC of 583 mm was recorded in August 1998 (predicted SWC 597 mm, 47-year model run) after the second wettest winter on record for Barraba (328 *v.* 354 mm in 1920). However, despite above average spring rainfall in 1998, predicted SWC had declined to about 410 mm (actual SWC 427 mm) by early January 1999. Similarly, despite January monthly rainfall totals of >200 mm in 1964, 1968, 1971, 1978, 1984, 1996 and 2004 and a total rainfall of 523 mm in January and February 1971, total SWC was often <410 mm by the end of March of each year, and always by mid-May.

Therefore, in this environment, rainfall in summer is less effective than that in winter and so the latter is

Table 1. Years in which the proportion (%) of days had an estimated total SWC <410 mm

Proportion (%)					
>70	70-50	50-30	30-20	20-10	<10
1957	1959, 1960	1958	1971	1968, 1969	1963, 1964
1965	1962	1961	1979	1974, 1975	1978
1980	1966	1967	1985	1977	1983
1994	1970	1973	1987	1984	1989
2002	1972	1981, 1982	1992	1988	1991
	1976	1986		1990	1997
		1993		1995, 1996	1999, 2000
		2001, 2004		1998, 2003	

Figure 1. Predicted daily total SWC (mm) for (*a*) years in which it was <410 mm for >70% of the time, and, (*b*) years that it was <410 mm for <10% of the time.

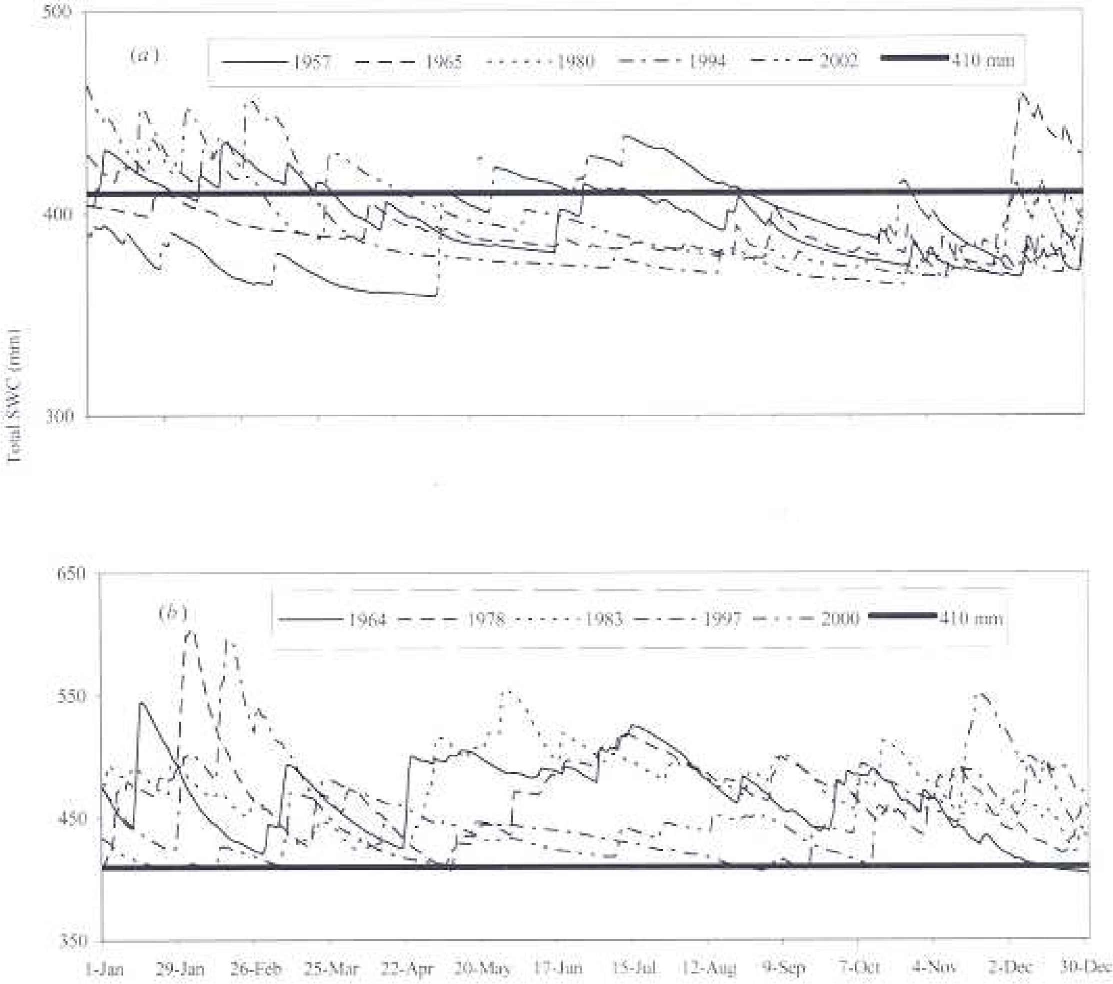

Table 2. Actual monthly rainfall (mm) for Barraba in 1964, 1965, 1979, 1980, 1994 and 2002-2004 and the mean monthly rainfall and long term average annual rainfall (123 years)

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
1964	248	27	128	86	58	16	78	38	91	116	39	17	942
1965	28	6	4	32	16	11	11	20	40	43	21	120	352
1979	46	21	79	17	99	56	10	19	51	48	108	9	563
1980	56	15	16	6	92	15	37	11	2	49	9	86	394
1994	52	72	69	6	16	21	10	26	4	24	56	64	420
2002	43	49	80	2	8	27	4	15	24	23	22	29	326
2003	11	96	46	127	3	41	42	50	2	97	43	106	664
2004	246	79	27	18	12	13	35	34	69	62	64	211	870
Mean	89	76	55	40	43	46	45	40	44	64	73	78	692

more likely to lead to the ending of drought. Hence the droughts of 1965 and 1994 were predicted to end in winter 1967 and 1995, respectively. The 2002-2003 drought was characterised by being preceded and followed by relatively dry years. With low effectiveness of summer rainfall and below average rainfall at Barraba up to March 2005, average to above average rainfall will be required in winter 2005 to maintain SWC >410 mm.

Based on a total SWC of 410 mm the 1994 and 2002 droughts commenced in March (Fig 1*a*) of those years, despite above average rainfall in that month (Table 2). Similarly, the 1965 and 1980 droughts started at the end of November 1964 and 1979, respectively (Fig 1*b*), although in these years rainfall was above average (Table 2).

Clearly, these preliminary studies indicate that the SGS Pasture Model and threshold values for total SWC may be an extremely useful early warning tool for predicting the onset of drought. Further work is required to validate the use of this approach for other soils, pastures and environments and to explore the effects of different climate variability and global warming scenarios on expected drought frequency and duration.

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