Application of climate data to predict pasture production

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Abstract
With increasing climate variability, a reliable method of estimating pasture growth has eluded farmers. Rain, temperature, evapotranspiration, radiation and soil moisture status are components which interact and affect pasture production. In 1992, soil moisture monitoring in Marlborough vineyards was extended to pasture. Using this medium, it was possible to predict when pastures would be under moisture stress and/or stop growing. Computer modelling, incorporating a herbage production formula based on a temperature, soil moisture, fertility and plant reproductive indices, calculates potential pasture growth. Since 1994, a soil moisture/pasture growth model developed by CALM has been used which gives an indication of current and future pasture production.
Keywords: soil moisture, pasture production, models, Southern Oscillation Index, Pacific Decadal Oscillation

Introduction

The purpose of this paper is to identify the interaction of climate variables and a computerised pasture production model to estimate short term pasture growth rates. With increasing climate variability, a reliable method of estimating pasture growth has eluded farmers. Rain, temperature, evapotranspiration, radiation and soil moisture status are components which interact and affect pasture production. CALM has developed a computer based model that works on daily rainfall, temperature, solar radiation and evaporation inputs to produce the expected dry matter pasture production for that day. It is responsive to the farming system, soil type and fertility and water holding capacity. Regularly farmers use the frequency and intensity of rainfall to determine potential pasture responses and their stock trading and management policies. The use of rainfall alone without reference to its effect on soil moisture leads to a poorer determination as to the intensity of the dry period and subsequent pasture production.

In 1992, soil moisture monitoring in Marlborough vineyards using time domain reflectometry (TDR), was extended to pasture. Using this method, it was possible to predict when pastures would be under moisture stress and/or stop growing. Computer modelling, incorporating a herbage production formula, based on temperature, soil moisture, fertility and plant reproductive indices, calculates potential pasture growth. Since 1994, a soil moisture/pasture growth model has been used which gives an indication of current and future pasture production. It is also useful in detecting the effects of climate change.

The Programme

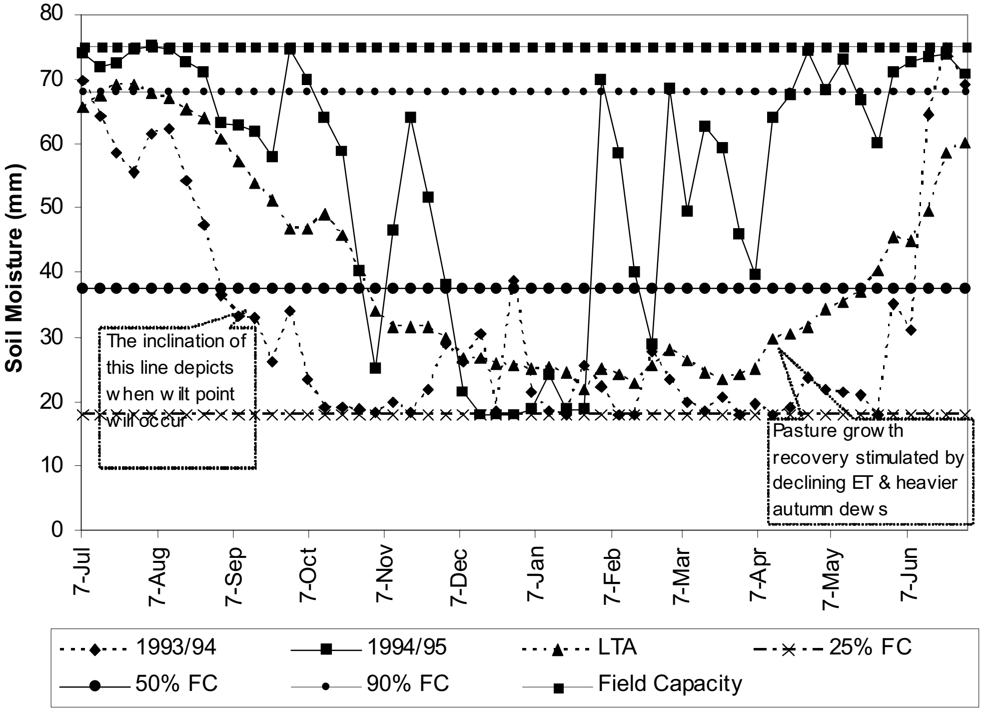
Two distinct programmes go into estimating pasture growth rates. The first is the estimation of plant available soil moisture. The second is a herbage production index.

Soil moisture

The soil moisture model is a determinant that indicates when pastures are likely to come under growth stress in the spring and recover to full seasonal capacity with the arrival of adequate late summer or autumn rains. The CALM soil moisture model is based on soil type, fertility and its water holding capacity. The amount of soil moisture that is available will determine the nutrient uptake by the plant. NIWA operates a simple water balance model, based on daily soil moisture at the start plus rainfall minus evaporation = soil moisture at the finish. Both the CALM and NIWA soil moisture models work on the general premise that for full pasture growth to be moisture-satisfied, the soil's water holding status must be within the range of 50% to full capacity. Plant growth also comes under increasing water restriction once the plant available soil moisture falls below 50%. One of the prime differences between the NIWA water balance model and the CALM model is in the calculation of evapotranspiration (ET). The former tends to use Penman or Priestley Taylor calculated ET whereas the CALM model uses Priestley Taylor ET which has been modified by days since rain and an appropriate crop factor. As a soil dries, the same amount of water is not going to be available for nutrient uptake, transpiration or evaporation on day 10 as on day 1. Likewise, as the majority of soil moisture loss comes from plant transpiration, the plant's crop factor will determine the rate at which the water will be emitted by the plant. This will normally be at variance with daily calculated Penman, or Priestley Taylor ET.

Soil moisture is the key and the most variable index that is used to quantify the herbage production rate calculations. Apart from this, it is also a key indicator of when herbage production is likely to come under moisture

Figure 1 Marlborough's best and worst annual soil moisture profile since 1990.



stress. For this paper, 75 mm is the plant available water (PAW) of a clay soil down to 30 cm, which is typically maximum pasture root depth. In the model, the 75 mm is referred to as the plant available water field capacity. Pasture growth caused by moisture stress progressively slows down once the plant available water falls below 50% and plant death occurs at incipient wilt point at 25% of plant available water field capacity. Below 50% plant available water, not only is growth retarded but there is also a substantial decline in existing pasture quality.

The monitoring of soil moisture data has resulted in a key graph which allows an immediate assessment of the current moisture position, the rate of moisture loss and an estimation of when the important benchmarks 50% and 25% soil moisture, will be reached (Fig. 1). In Figure 1, a deliberate minimum value of 18 mm has been set to equate to 25% field capacity. Soil moisture will continue to fall beyond this point, but it will be too low for extraction by the plant.

In Marlborough since 1990, the worst and the best two seasons for soil moisture are shown in Figure 1. In the 1993/94 season, wilt point was encountered on 5 October. Another 127 "wilt days" were experienced in that season. In 1994/95, wilt point was encountered on 4 November. It then poured with rain and wilt point was not encountered again until 7 December. In the 1994/95, only 44 wilt days were recorded.

An important feature of the graph in Figure 1 is the slope of the soil moisture line as it departs from near field capacity. In 1993/94, the last recorded date at field capacity was the 28 June. Through a lack of rainfall and enhanced evaporation rates, 50% soil moisture was reached by 27 August and wilt point by 5 October. That is a period of 59 days to fall from field capacity to 50% and another 39 days to fall from 50% soil water to wilt point. In contrast, coming out of the winter in 1994/95, the last recorded full field capacity point was registered on 15 August. By the 23 September, the field capacity had been restored and it stayed around that level until 30 September. The key 50% soil moisture was reached on 25 October, 25 days later. By 4 November, 6 days later, wilt point had been reached. Thus comparing the two seasons, in 1993/94 it took 100 days to go from field capacity to wilt point. In 1994/95, although a more productive season, it took only 31 days to go from saturation to wilt point once the soil moisture started falling.

Marlborough's soil moisture is driven markedly by rain, which in turn is influenced by the status of two climate patterns, the Southern Oscillation Index (SOI) and to a lesser extent the Pacific Decadal Oscillation (PDO). Rain distribution in New Zealand is very much influenced by local sea surface temperature. The situation in sea surface temperature surrounding New Zealand is in effect the opposite of what is happening in the monitored PDO area. When the PDO area is measured as "cold", the effect around New Zealand is for the sea surface temperature to be marginally warmer. Likewise a "Warm" PDO index relates in New Zealand to "Neutral" to "Cool" sea temperature conditions. No attempt in this paper has been made to translate the PDO index into local sea surface values. The raw data and what it stands for are used.

The Southern Oscillation Index (SOI) is measured in specific equatorial zones 0.5º either side of the equator. An El Niño in the equatorial area usually means warmer sea waters around New Zealand and more westerly summer air flows turning to more southerly winter winds. It is also associated with cooler water south of Tasmania and the South Australian Bight. This generates more rain on the west of New Zealand and less rain on the east. A La Niña is the opposite with neutral to cooler waters off New Zealand but warmer water south of Tasmania and the South Australian Bight. It normally means more wind flows from the north to easterly quarter. The rain pattern change brings more easterly rain to the country and less to the west. It is understood that the two oscillation patterns do not directly influence each other. The Australian Bureau of Meteorology scaling system for the Southern Oscillation Index is used (www.bom.gov.au/glossary/soi.shtml). This index is divided into +/- units of six to identify the intensity of the El Niño or La Niña. The Index for the Pan Pacific Oscillation (jisao.washington.edu/pdo/) is based on the criteria used by the University of Washington.

Assessing herbage production rate

Herbage Production Rate is based on the equation as described by McKenzie *et al.* (1999):

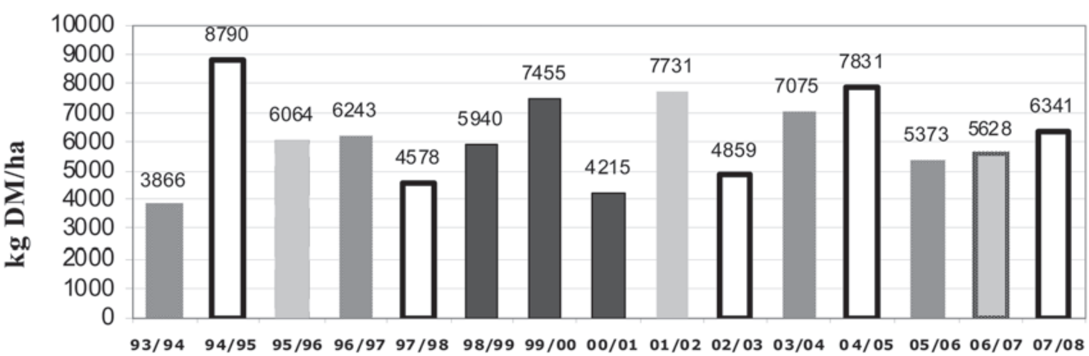
Herbage production rate = Maximum Rate x Temperature Index x Moisture Index x Soil Fertility Index x Plant Reproductive Index.

McKenzie *et al*. (1999) suggest, "we could set the maximum herbage accumulation rate to 90 kg dry matter per day." However this would be typical of dairy pasture growing at maximum values. Reducing the maximum rate down to between 65 or 70 kg dry matter per day would equate with the annual dry matter yield expected under sheep conditions in Marlborough. The degree of control of the maximum rate on the final dry matter output of the equation is best compared with the annualised stocking rate and estimated pasture production of any property under review.

McKenzie *et al*. (1999) suggest that "the moisture response is the most difficult to model and usually involves a moving soil moisture balance generated from rainfall and evaporation". For this reason, the CALM model is at present directed at soil types with a known or estimated water holding capacity. From the climate data recorded by the Marlborough Research Centre (MRC), Figure 2 sets out the suspected influence of these two oscillations on the value of 15 years of dry matter the MRC could be expected to have produced. The trend occurring at the Marlborough Research Centre would be similar to that occurring throughout the dry land area of Marlborough. The data are separated into the Southern Oscillation values as well as those of the Pacific Decadal Oscillation.

Taking the annual pasture production data (Fig. 2) and combining them according to the annual SOI and PDO reading gives the pasture output set out in Table 1. Within the Table, the results are ranked in comparison with the production of a "neutral" season. Neutral being defined as a period where there is no identifiable Southern Oscillation Index or Pacific Decadal Oscillation influence. In Table 1 the "neutral" season varies from 5373 to 7731 kg DM/ha. It is based on a clay soil type with a PAW of 75 mm and an Olsen P of 12. The most advantageous

Figure 2 The annual influence of the SOI and PDO on Marlborough's pasture production 1993/94 to 2007/08.



93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08
Weak El Niño	El Niño	Weak La Niña	SOI Neutral	El Niño	La Niña	Weak La Niña	Weak La Niña	SOI Neutral	Weak El Niño	SOI Neutral	Weak El Niño	SOI Neutral	Weak El Niño	Weak La Niña
PDO cool	PDO Neutral	PDO Cool	PDO Cool	PDO Warm	PDO Warm	PDO Cool	PDO Neutral	PDO Warm	PDO Neutral	PDO Neutral	PDO Cool	PDO Warm	PDO neutral	PDO Neutral

Table 1 Annual pasture output under the Southern Oscillation Index and the Pacific Decadal Oscillation.

SOI Status	PDO Status	No. of Records	Average annual dry matter (kg/ha)	Percent of neutral
El Niño	Warm	4	6541	107.5
El Niño	Cool	1	5628	92.9
Neutral Warm	Warm	5	6057	100
La Niña	Warm	2	6203	102.4
La Niña	Cool	3	5870	95.8

Table 2 The influence of the Southern Oscillation Index and the Pacific Decadal Oscillation Marlborough's spring and autumn stratified growth rates.

SOI Status	PDO Status	No.	Spring DM (kg/ha)	% of Neutral*	Autumn DM (kg/ha)	% of Neutral	Total DM (kg/ha)	% of Neutral
El Niño	Warm	4	2007	107	1643	145	3650	121
El Niño	Cool	1	2027	108	1224	108	3251	108
Neutral	Warm	5	1878	100	1129	100	3007	100
La Niña	Warm	2	2190	117	1597	141	3787	126
La Niña	Cool	3	2387	127	952	84	3338	111

*Neutral being defined as periods where there is no significant El Niño/La Niña or PDO influence.

Table 3 The range of variation in spring and autumn pasture production as influenced by the PDO and SOI 1993/94 to 2007/08.

Season	PDO Annual Status	SOI Spring	Spring DM (kg/ha)	SOI Autumn	Autumn DM (kg/ha)	Total DM (kg/ha)
1993/94	Warm	El Niño	1571	El Niño	1309	2880
1994/95	Neutral	El Niño	1356	Weak El Niño	2398	3754
1995/96	Warm	Neutral	1278	Weak La Niña	2392	3670
1996/97	Neutral	Weak La Niña	1297	El Niño	2475	3772
1997/98	Warm	El Niño	1713	El Niño	2123	3836
1998/99	Neutral	La Niña	1356	La Niña	2664	4020
1999/00	Cool	Weak La Niña	1729	La Niña	2055	3784
2000/01	Neutral	Weak La Niña	1270	Neutral	2475	3745
2001/02	Cool	Weak El Niño	1726	Weak El Niño	2358	4084
2002/03	Warm	El Niño	1651	Weak El Niño	1725	3376
2003/04	Neutral	Neutral	1471	Neutral	2416	3887
2004/05	Neutral	Weak El Niño	1870	Weak El Niño	2288	4158
2005/06	Neutral	Neutral	1438	Weak La Niña	1611	3049
2006/07	Neutral	El Niño	1604	Neutral	1941	3545
2007/08	Cool	Weak La Niña	1539	Weak La Niña	2465	4004
Average			1525		2179	3074

annual production is obtained under a warm PDO associated with a warm El Niño. The least productive is a cool PDO associated with either an El Niño or La Niña.

In Marlborough, the most significant influence of the SOI is on pasture production in the spring and autumn (Table 2). This difference is largely the result of the variation in the rainfall pattern and evaporation rates in these periods. While the PDO is likely to be the same from spring through to autumn, the SOI can change dramatically during this period. The SOI is effectively monitored on its 90 day average value. Historically an El Niño has been seen as the culprit of low pasture production. In fact Table 2 identifies that in spring a cool PDO and a La Niña produces the most grass and a warm PDO and neutral SOI the least. In the autumn the situation alters with a warm PDO and an El Niño producing the most pasture and a cool PDO and La Niña the least.

Table 3 gives an overview of how the status of the SOI and PDO has affected seasonal production over the years. In Figure 1, the 1993/94 spring was a warm PDO with a strong El Niño influence. The autumn was still a warm PDO with an even stronger El Niño presence. In contrast, 1994/95 had a warm PDO and a strong El Niño spring and the autumn was a cool PDO with a weak El Niño autumn. In very few situations does a good spring mean that there will be a favourable autumn.

Of the PDO and SOI spring and autumn mix and

Table 4 Total spring and autumn pasture production according to the mix of the Pacific Decadal Oscillation/ Southern Oscillation Index 1993/94 to 2007/08.

PDO Status	SOI Status	Spring			Autumn			Total
		No. of periods	Average DM (kg/ha)	% of Ave	No. of periods	Average DM (kg/ha)	% of Ave	Spring + Autumn (kg/ha)
Warm	Weak El Niño				1	1725	79.1	-
Warm	El Niño	3	1645	107.8	2	1716	78.7	3361
Warm	Neutral	1	1278	83.8				-
Warm	Weak La Niña				1	2392	109.7	-
Neutral	Weak El Niño	1	1870	122.6	2	2343	107.4	4213
Neutral	El Niño	2	1480	97.0	1	2475	113.5	3955
Neutral	Neutral	2	1455	95.4	3	2277	104.4	3732
Neutral	La Niña	1	1365	89.5	1	2664	122.2	4029
Neutral	Weak La Niña	2	1284	84.1	1	1611	73.8	2895
Cool	Weak El Niño	1	1729	113.3	1	2358	108.1	4087
Cool	La Niña				1	2055	92.3	-
Cool	Weak La Niña	2	1684	110.4	1	2465	130.7	4149
Average			1525	100		2180	100	3802

Table 5 Spring and autumn pasture production as influenced by the Southern Oscillation Index 1993/94 to 2007/08.

SOI Status	Spring			Autumn		
	Number of periods	Average DM (kg/ha)	% of Ave	Number of periods	Average DM (kg/ha)	% of Ave
El Niño	7	1642	107.6	7	2096	96.1
Neutral	3	1396	91.5	3	2277	107.4
La Niña	5	1348	83.4	5	2237	102.6
Average		1525	100		2180	100

Table 6 Spring and autumn pasture production as influenced by the Pacific Decadal Oscillation 1993/94 to 2007/08.

PDO Status	Spring			Autumn		
	Number	Average DM (kg/ha)	% of Ave	Number	Average DM (kg/ha)	% of Ave
Warm	4	1553	101.8	4	1887	86.5
Neutral	8	1664	109.1	8	2017	92.5
Cool	3	1887	123.7	3	2292	105.1
Average		1525	100		2180	100

matches in Table 4, the best annual scenario is a neutral PDO phase in association with a weak El Niño. The worst situation is a neutral or warm PDO phase allied with an El Niño. If the PDO is ignored (Table 5) and only the SOI phases accumulated together under an El Niño, Neutral, or La Niña status then an El Niño spring followed by a neutral autumn is the best SOI event. Table 6 is based on production during the PDO period, independent of the SOI status. Separating the PDO into warm, neutral, or cool without regard to the status of the SOI indicates that the autumn and spring pasture production is less variable than when solely influenced by the SOI (Table 5). The percentage is based on the respective total average spring or autumn production. A cool PDO spring/autumn mix is the most productive.

Validation

It is acknowledged that there are insufficient annual data sets to make a worthwhile statistical comparison as to the effects and interaction of the PDO and the SOI on Marlborough's annual, spring and autumn pasture production. The use of actual NIWA climate station or virtual climate data sets over at least a 30 year period should provide a better insight into the PDO and SOI influence on the region's pasture production. NIWA's 30 year virtual climate data has been used on a summer dry Marlborough and summer moist Nelson property. The influences on pasture production of the Southern Oscillation Index and the Pacific Decadal Oscillation were clearly identified. The CALM pasture production model appears to be both robust and flexible enough to produce daily, weekly, monthly and annual pasture growth rates. Tested against AgResearch's Pasture Plan

(Clarke-Hill & Fraser 2007) model for its two Marlborough properties, the Correl correlation coefficients for the 4 years of pasture cuts ranged from 0.47 to 0.95. Currently climatologists are relatively accurate in at least a 6 month prediction of the SOI. PDO trends are longer in duration and while changes can be estimated, the level of prediction is not so accurate. However, the 3 to 6 month expected trends in both the SOI and the PDO should allow earlier prediction of pasture production levels and the user can plan management strategies accordingly.

This paper has only looked at the traditional spring and autumn scenarios. It is recognised that any other 3 month period may also be important, especially where they change SOI phase. The early indication from this herbage growth model, and the PDO and SOI interaction, is that the model may be a useful tool in both monitoring and predicting the effects of climate change in the future. If there is an "oscillation" effect outside of the predicted increase in the levels of carbon dioxide and expected changes in both rainfall and temperature, then an easy calculation of past and future pasture production will exist. This will allow more in-depth analysis in pasture and crop production of the financial implications that can be expected to emerge under climate change.

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