Within-paddock variation in pasture growth: landscape and soil factors

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Abstract

The continuing development of precision farming promises much in the way of efficient resource (input) use in cropping systems. However, extension to pasture agronomy is some way off. In order to obtain background information on within-paddock variation in pasture growth, and the main factors responsible, two paddocks in southern NSW (one with naturalised pasture, "Yaven" and the other improved, "Cootamundra") were closely monitored over the major growth period (winter-spring) in 1998. Sampling locations (~ 100) were approximately evenly spaced over the 60 ha of the Yaven paddock and 40 ha of the Cootamundra paddock. In May, soils were sampled for pH, available phosphorus (Olsen P), exchangeable cations, electrical conductivity and organic carbon as well as soil depth and profile description. At Yaven the percentage of gravel (> 2mm) was also measured. At each sampling location pasture growth (June – November), peak spring dry matter and spring botanical composition were measured. Growth over the measurement period ranged from 470 – 9560 kg/ha for Yaven and 1830 – 15,720 kg/ha for Cootamundra. Similarly there was wide variation in all of the landscape and soil characteristics measured. All subsets multiple regression was used to identify those site characteristics that were related to productivity. At Yaven 30% of the variation in growth could be accounted for by two variables: % gravel in the profile and soil pH. At the more uniform Cootamundra site, landscape and soil factors (only two: calcium as a proportion of exchangeable cations and position in paddock, Northing) explained 24% of variation in growth. However, if the species growing at each site were taken into account then the proportion of variation accounted for, increased by 30 % and 9 %, respectively. These results are discussed in relation to the complex species associations at the sites and the possibility of applying resources (particularly fertiliser) in a more strategic fashion to these permanent pastures.

Introduction

Much has been made of the potential of precision agriculture to increase productivity and resource use efficiency on farms where cropping is the major enterprise (eg Cook and Bramley 2001). While within paddock variability in yield was self-evident, the development of yield monitoring technology in concert with geographical information systems, has provided the basis upon which more detailed analyses of spatial variability and its management can be made. In cropping systems the measured crop variable is relatively simple – it is yield and usually pertains to the single sown species.

Response in pasture systems is more complex because yield is hard to determine and pasture systems can markedly vary in botanical composition within a paddock. In addition, the range of landscape factors (eg. slope, aspect, soil type, depth) that influence pasture performance can also vary widely within a single paddock. For the most part, farmers and advisors have tended to treat paddocks as single units and not manage variability across the landscape. For instance, in the moderately hilly areas of the higher rainfall zone of southern NSW, superphosphate is the most widely applied fertiliser and is usually applied at rates determined by whole paddock stocking rates or point measurements of soil phosphate content. Sub-paddock scale management of superphosphate applications is not attempted even though it is a major input in permanent pasture-based grazing systems. Presumably this occurs because so little is known about within paddock variability of pasture growth.

In contrast, studies in New Zealand have demonstrated variable responses to the application of fertiliser due to the impact of aspect and slope on botanical composition and microclimate (eg. Roach et al 1996). As a result, economic benefits of adopting differential fertiliser application strategies as opposed to using a uniform rate across variable landscape areas have also been demonstrated either with field experimentation or modeling (Gillingham et al 1999; Barker et al 1999; Gillingham and Betteridge 2001).

In the study reported here, we examined the within-paddock variability in growth rate and spring biomass accumulation at two sites in southern NSW. The aim of the study was to identify easily measured paddock-based factors that could be used to explain the variability in productivity.

Materials and Methods

Two paddocks were selected in the higher rainfall zone of southern NSW based on pasture type, variability in slope and aspect and botanical composition. Both paddocks were grazed (Cootmaundra more heavily than Yaven) over the period in which measurements took place. Some characteristics of each of the paddocks are summarised in Table 1

Table 1. Characteristics of the two trial sites at Yaven and Cootamundra.

	Yaven	Cootamundra
Paddock area (ha)	60	45
Mean Rainfall (mm)	700	650
Soil parent material	Shale	Granite
Elevation range (m)	70	45
Pasture	Naturalised (unsown)	Phalaris/sub clover
pH range	4.0 - 5.0 (4.6)*	3.9-5.1 (4.3)
Olsen P (ppm)	2 - 31 (6)	2-43 (9)
Organic carbon %	0.9 - 5.1 (2.2)	0.2-4.6 (0.9)
ECEC	2.4 - 14.9 (5.1)	1.7-11.7 (4.8)
Al as %ECEC	0 - 31.5 (3.0)	0.3-44.6 (9.6)

*number in brackets represents median

In each paddock approximately 100 sampling points were established in a regular grid and were marked with a steel fencepost. Around each location in a radius of 5 m (to be referred to as the ‘sampling area’), ten soil samples (to 100 mm depth) were collected in May 1998. These were air dried, ground and analysed for the following according to the methods described by Rayment and Higginson (1992): exchangeable cation concentrations (ECEC, cmol/kg, 0.01 M $BaCl_2$ using ICPAES), pH (1:5, soil: 0.01M $CaCl_2$ at 25?C) electrical conductivity (dS/m, 1:5 soil at 25?C) and Olsen phosphate (mg P/kg) and total carbon (per cent, determined by combustion ~ Leco). At each location, one soil core (50 mm diameter) was used to determine soil depth. In addition, for the Yaven site, the proportion of gravel (particles > 2mm) was also measured on these samples.

Commencing in mid-June 1998, 1 m x 1 m exclosure cages were placed within the sampling area in order to measure pasture growth (approximately every six weeks) using the matching quadrat technique. Over 14-15th October (Cootamundra) and 28-29th October (Yaven), botanical composition was estimated within each sampling area using the dry weight rank technique as modified by Jones and Hargreaves (1979). Above-ground dry matter was measured in each of the dry weight rank quadrats using a falling-plate meter (Cayley and Bird 1991) which was calibrated for each site (quadratic at Yaven, $r^2 = 0.80$, n=48; linear at Cootamundra, $r^2 = 0.91$, n=39). In addition, for each of the 20 quadrats (0.1 m^2) used for dry-weight ranks, all species present were identified and recorded allowing frequency to be calculated.

Site and soil characteristic variables (ie. non biological) as well as elevation, position in paddock (easting ands northing) and aspect were used in a principal components analysis. Principal component scores from the first 8 components were then correlated with peak spring biomass (mid-late October measurement), average winter-spring growth rate (mid June - mid November) and species number. Using these results, and the latent vectors of each component, a smaller number of site variables were identified for all subsets multiple regression using the Aikake information (Quinn and Keough 2002) to select the best model (variables were also selected so as to avoid collinearity). Cluster analysis (k-means or non-hierachical clustering) of the species frequency data was used to 'classify' the vegetation into six arbitrary clusters at each site. Multiple regression with groups was then performed using any of the variables that were found to explain a significant proportion of the variance in the multiple regression described above.

Results

Conditions for pasture growth over the winter-spring period in 1998 were good at both sites with rainfall of 508 mm at Yaven and 484 mm at Cootamundra over this period. Pasture growth rate, peak spring above ground dry matter and botanical composition varied widely within each of the paddocks (Table 2). Overall, growth and biomass were greater but species number lower at Cootamundra compared to Yaven. Inherent variability, measured either as coefficient of variation or interquartile distance, was larger for these three variables at Yaven than at Cootamundra. Pasture botanical diversity as indicated by species number, was more closely related to peak spring biomass (for Cootamundra, $r = -0.48$ $p < 0.001$; for Yaven, $r = -0.65$, < 0.001) than total winter/spring growth rate (for Cootamundra, $r = -0.29$ $p < 0.01$; for Yaven, $r = -0.58$, < 0.001). Peak spring biomass was closely related to winter-spring growth rate at Yaven ($r = 0.75$, $P < 0.001$) whereas at the more heavily grazed Cootamundra site the relationship between the two was weaker ($r = 0.53$, $P < 0.001$).

Many of the variables measured were closely related to each other. As a result, only a limited number could be legitimately used for multiple regression. Nonetheless, at both sites, a significant proportion of the variation of either total growth over the winter-spring period or peak spring biomass could be explained by a small number of soil fertility variables (pH, ECEC, %Ca, %Al), soil physical characteristics (soil depth or proportion of gravel, Gravel%) or position in paddock (Northing, Aspect) (Table 3). When the vegetation group or cluster that was prevalent in each sampling area was included as a factor in the analysis, the proportion of variation explained increased markedly (Table 3). The increase in variation accounted for was much greater for Yaven (up to 43 %) than for the Cootamundra site (up to 14 %).

Table 2 Total growth (winter-spring), peak spring biomass (Spring DM) and species number (found in 2 m^2) at Yaven and Cootamundra. Total growth was calculated using estimates of growth rate from the pasture cage data.

	Yaven			Cootamundra		
	Total Growth (kg/ha)	Spring DM (kg/ha)	Species no. (/2m^2)	Total Growth	Spring DM (kg/ha)	Species no. (/2m^2)

				(kg/ha)		
Mean	4650	2910	16.9	7800	1690	11.5
Median	4360	2960	17	7250	1660	11
Minimum	470	900	8	1830	840	7
Maximum	9560	5280	29	15720	2710	19
25th Centile	2590	2040	14	5850	1440	10
75th Centile	6280	3700	20	9650	1930	13
CV*	48.5	38.7	23.7	34.9	23.0	21.5

*Coefficient of variability

Table 3 Coefficient of determination (r^2) and variables that were significantly related to either total winter-spring growth (Total growth) and peak spring biomass (Spring DM). All other variables explained in text. Multiple regression was used either without or with Groups (Groups refers to the six clusters based on species frequency data). All regressions significant at P < 0.001.

Response	Yaven		Cootamundra	
	Variables	r^2	Variables	r^2
Total growth	Gravel%, pH	29.4	%Ca, Northing	24.1
With groups	Gravel%, ECEC	59.4	%Ca, Northing	32.8
Spring DM	Ca, Soil depth	20.9	%Al, Aspect	29.1
With groups	ECEC, Soil depth	63.3	%Al, Olsen P	42.9

Discussion

It is clear from the results above that, for both pastures examined, there was large variability in all of the measured variables. Variability was smaller in the sown pasture of the Cootamundra site. Presumably during the establishment and ongoing management of the sown pasture, some of the inherent variability was reduced through use of herbicides and insecticides, lime and fertiliser. In addition, the range in elevation (Table 1) and aspect at the Cootamundra sites was much more limited than the Yaven site. For both sites, it is clear that a significant proportion of the paddock was underperforming in terms of total pasture production over the winter-spring period ie. 25 % of sampled areas yielded less than 60% of median yield at Yaven and less than 80% median yield at Cootamundra. Hence, the scope for applying zone management within a grazed paddock of either sown or naturalised pastures in the southern slopes of NSW would appear to be considerable. However, it is important that those factors that explain the variability in pasture yield be identified before management strategies can be devised (Gillingham 2001).

Because pasture growth data was inherently variable it was decided that both total winter-spring growth *and* peak spring biomass would be analysed to determine the factors that contributed to variability. The close relationship between growth and peak spring biomass at Yaven, was most likely due to the intermittent and low stocking rate of the grazing system. Either way, a limited number of site variables could account for a large proportion of the variability in either growth or spring biomass. In each case the variables identified were related to soil fertility (either directly as available P or through pH and/or cation concentrations) and soil physical properties (eg. soil depth, or proportion of gravel in the. Two other variables, aspect and position in the paddock were also related to growth and peak spring biomass at Cootamundra. It is likely that the variable related to position in the paddock ("Northing") is a surrogate for some other (unmeasured) factor not accounted for in the data set (eg. sub-surface soil constraints).

There was a strong negative relationship between species number (or biodiversity) and either growth or peak spring biomass. For the most part this arises due to underlying variation in site factors and is not indicative of a negative relationship between biodiversity and productivity. However, the strong relationship between productivity and species number could be helpful in the assessment of potential productivity but this was not attempted in the current analysis because species number was collinearly related to many of the site factors. Nevertheless, the inclusion of vegetation characteristics (through species association) significantly improved the proportion of variability accounted for in growth and peak spring biomass. This means that it is possible to combine botanical information with general site factors (eg. aspect) as well as soil physical and chemical characteristics in order to determine management units at the sub-paddock level. The high level of variability in pasture production and the factors found to account for variability suggest that the currently practiced management strategy of applying inputs uniformly to achieve production objectives should be reviewed. The allocation of resources based on productive capacity of management zones could then be optimised to provide greater resource use efficiency and improved economic and environmental outcomes as has been done for cropping systems.

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