Management of sheep grazing annual pastures in Western Australia: Pasture deferment and optimal stocking rate

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Abstract

Deferring grazing of annual pastures to allow better establishment can increase subsequent pasture production, but at the cost of increased supplementary feeding and, perhaps, a lower stocking rate. This study uses a deterministic dynamic optimization framework to address this trade-off. A dynamic simulation model of pasture growth and animal production (PGAP) was used to investigate the effects of climate and grazing pressure on pasture production. Simulation runs for different grazing management strategies and initial plant densities were used to estimate mathematical equations representing relationship between pasture production and animal production for use in the optimization model. It was found that the optimal combinations of stocking rate and length of deferment maximizing the present value of expected returns vary widely under different circumstances.

Keywords: grazing management, farming systems, farm management

Introduction

Grazing management is the control of pastures and livestock and their movements in a pasture ecosystem (Morley, 1966). For annual pastures in Mediterranean climates, potential elements of an overall grazing management strategy include: deferment of grazing in autumn during pasture establishment (Smith and Williams, 1974; Fortune, 1993), provision of supplementary feeds (Bishop and Kentish, 1966), adjustment to the stocking rate, fencing to control the spatial pattern of grazing, planting of improved pasture species, and selection of particular crop/pasture rotations.

There have been many studies on these management practices. Rossiter (1958) investigated the benefits of autumn deferment of grazing. He concluded that, under average weather conditions, autumn deferment gave insignificant benefits to an annual- type subterranean clover pasture. However, when early pasture growth was restricted by poor weather conditions, autumn deferment was superior to continuous grazing. Bishop and Kentish (1966), Brown (1970) and Smith et al (1973) observed the effect of autumn deferment on sheep liveweights and wool production, concluding that there are positive responses in liveweight and wool production. On the other hand, Brownlee and Robards (1968) and Cannon (1970) found that autumn deferment gave no benefits in improving liveweight and wool production.

The focus of these studies was primarily on the response of pastures and animals to deferred grazing. Factors known to affect this response include stocking rate (Brown, 1970) and pasture species (Smith et al. 1973). It has been postulated that the positive response, when it does occur, is due to increased leaf area and light interception during early growth (Donald and Black, 1958). In general, the biological field studies have neglected the impact of early grazing on subsequent pasture growth and animal production.

Smith and Williams (1974) have addressed this issue with a computer modelling approach. Using a dynamic simulation model representing the early growth of subterranean clover and liveweight gain of grazing sheep, they examined the response of an animal production system under various stocking rates, initial plant densities and the periods of grazing deferment. They estimated the combinations of stocking rate and length of grazing deferment which maximized economic return under various initial plant densities. They found that total liveweight change per hectare is significantly dependent on stocking rate and length of deferment; that the economically optimal stocking rate was positively related to initial plant density and output price; and that the optimal duration of grazing deferment increased with increasing output price but was insensitive to initial plant density.

One important finding of Smith and Williams (1974) was that the optimal combination of stocking rate and length of grazing deferment could vary widely at one site due to variations in initial plant density and prices of feeds and animal products. It was recommended that in a practical situation an optimal combination of stocking rate and length of deferment will need to be estimated for each site and system of production. This study is concerned with this recommendation, particularly in developing an economic framework that can be used to determine an optimal combination of stocking rate and length of deferment in relation to seasonal pasture production.

The Model

The focus of this study is on the two of the sheep grazing management options: stocking rate and deferment of grazing. Smith and Williams (1974) have shown that the liveweight of sheep highly dependent on both stocking rate and length of deferment of grazing. Rowe (1982) has found that there is a linear relationship between wool production per animal and the annual pasture dry matter production per animal. Trenbath and Stern (1995) noted that there are relationship between stocking rate, biomass at the end of growing season, biomass at the beginning of (the following) season and pasture production. Accordingly the dynamics of animal and pasture production can be written in the following equations.

(1) $B_t = f(SR_t, LOD_t, AB_t)$

where B_t is biomass at the end of season t (kg DM/ha), SR_t is stocking rate at season t (hd/ha), LOD_t is length of deferment of grazing at the start of season t (weeks), and AB_t is biomass at the beginning of season t (kg DM/ha) which is primarily a function of initial plant density.

Wool production also depend on a range of factors:

(2) $WY = g(B_{t-1}, LWT_t, LOD_t, AB_t)$

where WY_t is wool yield (kg/sheep) per year.

Sheep liveweight is treated primarily as a function of stocking rate:

(3) $LWT = h(B_{t-1}, SR_t, LOD_t, AB_t)$

where LWT is liveweight (kg/sheep) at the end of the year.

Based on these relationships a dynamic model of sheep grazing management is developed. The relationship were estimated using multiple regression to summarize the result of a detailed dynamic simulation of pasture growth and utilization. The estimation of the multiple regression equations is described in the following section.

The profit per hectare of the pasture enterprise is given by:

(4) $Profit = (WY*WP)*SR - FC + (VC*SR)$

where WY is wool yield (kg/sheep), WP is wool price ($/kg greasy wool), FC is fixed costs per hectare of pasture which includes shearing shed, shearer's quarters, shearing plant, fences, dams, yards, building and insurance ($/ha) , Vc is variable cost which includes shearing and husbandry cost and feed supplements ($/hd), SR is stocking rate (hd/ha).

The model was solved as a finite time period, discrete time step optimal control model. It was constructed with state variables which carry information regarding the system across years, and decision variable (stocking rate and length of deferment of grazing) which are selected to achieve the objective of this study. The objective is to maximize the net present value (NPV) of present and future farm profits. Solver facilities in the Microsoft Excel 5® were used to solve this optimization problem.

Estimation of functions of the Model

A dynamic simulation model of pasture growth and animal production (PGAP) (Curtis, 1986) is used to obtain data on pasture production (biomass at the end of each year of simulation) and animal production (sheep liveweight at the end of each year of simulation). The model is based on the farming system in the Shire of Kojonup, in a sheep dominated region of the agricultural area. Annual climatic data from 1960 to 1979 (20 year period) for Kojonup, WA (which are readily available in the simulation model) were used to obtain annual pasture production and sheep production in a wide range of climatic and management scenarios.

Twenty five different grazing management systems were simulated over 20 years: five stocking rates (4, 5, 6, 7 and 8 sheep per hectare) by five lengths of deferment of grazing (0, 2, 4, 6 and 8 weeks). These simulations were repeated for five levels of available green dry matter at germination (50, 150, 250, 350 and 450 kg DM/ha). Based on the output of these simulation runs (20 x 25 x 5) multiple regression equations for equations (1), (2) and (3) were estimated. The multiple regression equation for (1) is:

$$(5) \qquad B_t = \underset{(105.04)}{4315.23} - \underset{(15.71)}{391.66}\, SR_t + \underset{(7.67)}{38.74}\, LOD_t + \underset{(0.16)}{2.94}\, AB_t$$

Since the PGAP model does not provide wool production output but provides liveweight output, wool yield was calculated based on liveweight and liveweight-change data obtained from the PGAP model output using the following equation from Canon (1969) in Allden (1979)

$$(6) \qquad wy = -2.221 + 0.729\, M^{0.75} + 0.216 LWC$$

where wy is wool growth (g/day), M is mean liveweight during the simulation period (kg) and LWC liveweight change (g/day). This wool growth was aggregated for the simulated period for each scenario and used to estimate the following equations:

(7) $$WY = -5.25 + 0.00003B_{t-1} - 0.23SR_t + 0.01LOD_t + 0.007AB_t$$

(0.12) (1 E-5) (0.003) (0.005) (0.0001)

Liveweight was estimated as

(8) $$LWT_t = 45.76 + 0.0005B_{t-1} - 0.36SR_t + 0.19LOD_t + 0.0017AB_t$$

(0.65) (9 E-5) (0.08) (0.04) (0.001)

Standard errors of the parameter estimates are shown in brackets. Value of R for equations (5), (7) and (8) were 0.30, 0.79, and 0.10 respectively. Equation (8) is clearly capturing very little of the variance in liveweight. In particular the estimated impact of stocking rate on liveweight was extremely small. Given the conflict of this result with a priori expectations, and the importance of this function to the management question under consideration, it was decide to investigate the impact of alternative specifications of this relationship. In the model, liveweight was represented as

(9) $$LWT_t = k_1 - k_2SR_t$$

with k_2 varied over several values.

Available green dry matter at germination was calculated based on the amount of biomass at the end of the year of simulation (dead dry matter) using equations developed by Trenbath and Stern (1995) with some modifications (Trenbath, pers. Com).

(10) $$AB = B * HI * GF$$

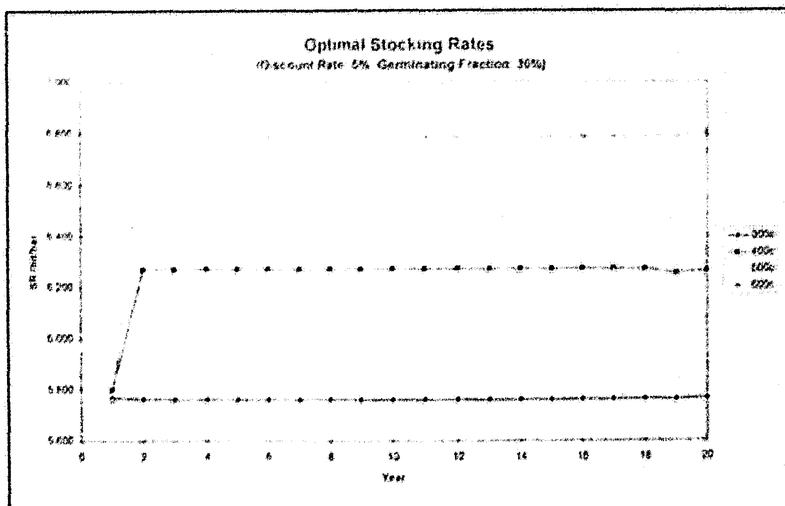
where AB is available green dry matter at germination (kg DM/ha), B is biomass at the end of year of simulation (kg DM/ha), HI is harvest index and GF is germinating fraction

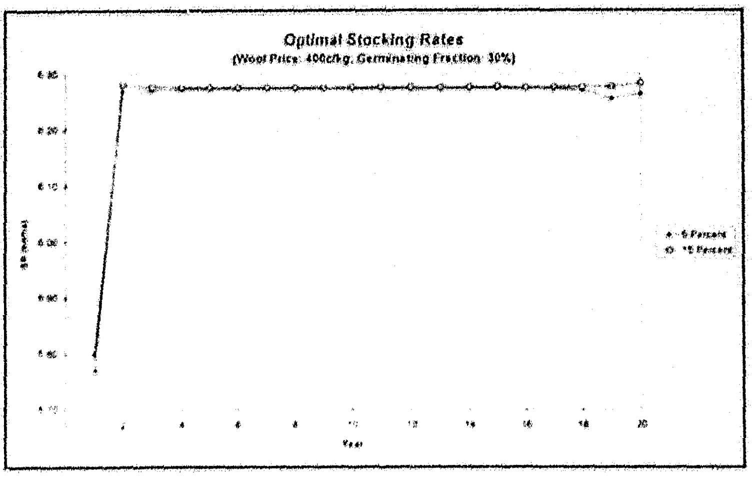
In this study pasture production is assumed to consist of 50% clover and 50% ryegrass, therefore HI for the pasture is calculated as follow:

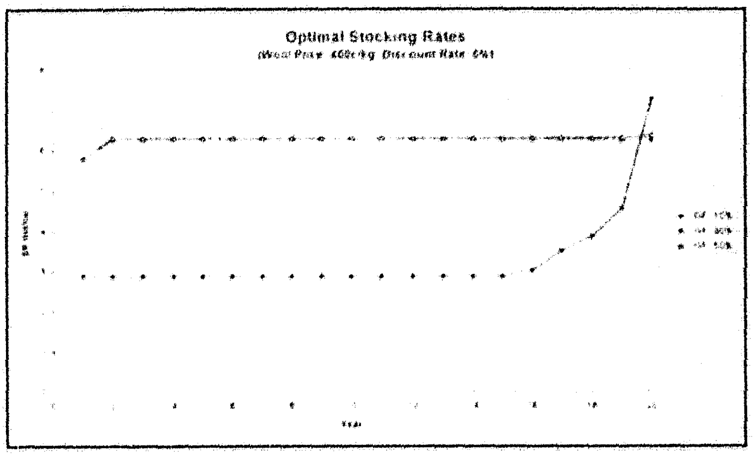
(11) PHI= (RHI + CHI)/2

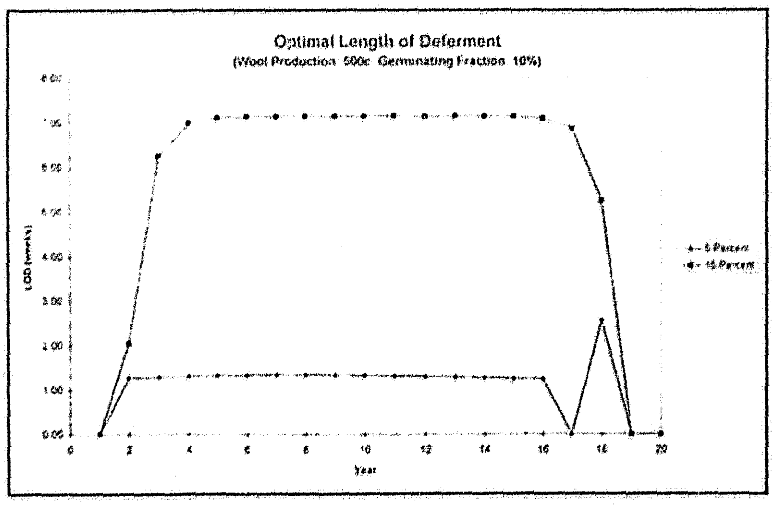
where PHI is harvest index of pasture. RHI is harvest index of ryegrass, and CHI is harvest index of clover (HI for ryegrass is 0.15 if log (SR/B)<-3; 0.15-0.0375*[log(SR/B)+3] if log (SR/B) between -3 and +1, and 0 if log (SR/B)> +1; HI for clover is 0.15 if log (SR/B)< -3, 0.15+0.133*[log(SR/B)+3] if log (SR/B) between -3 and -1.5, and 0.35-0.1*[log(SR/B)+1.5] if log (SR/B)>-1.5).

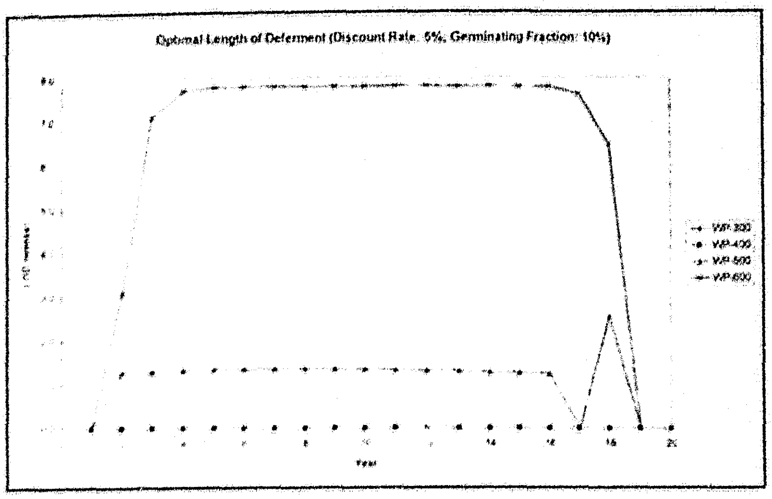
Results

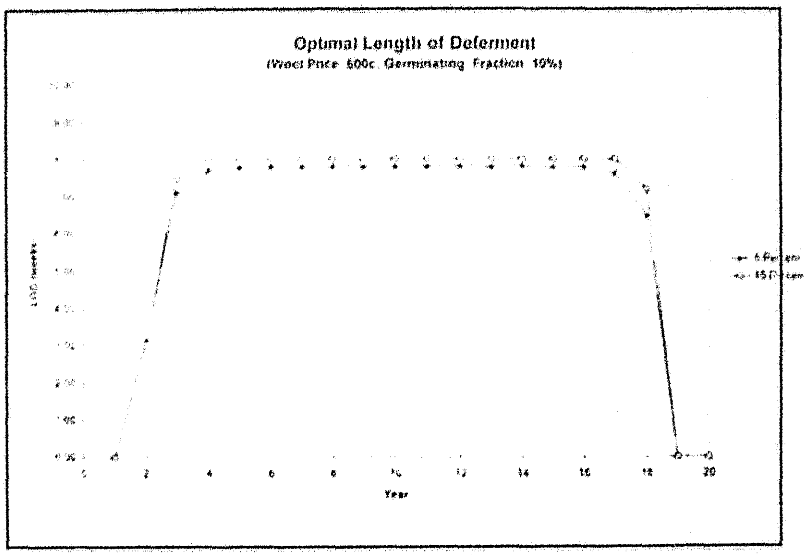



Optimal Stocking Rates
(Wool Price: 400c/kg, Germinating Fraction: 30%)
Year
5 Percent
15 Percent


Optimal Stocking Rates
Year


Optimal Length of Deferment
(Wool Production 500c Germinating Fraction 10%)
8.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0
2
4
6
8
10
12
14
16
18
20
Year
5 Percent
15 Percent





NPV ($/HA)

Wool Price	Germ. Fraction	Discount Rate 5%	Discount Rate 15%
300	10%	365.06	180.27
	30%	505.32	253.78
	50%	520.54	261.54
400	10%	564.76	271.54
	30%	812.19	397.50
	50%	832.19	407.85
500	10%	766.85	381.02
	30%	1125.82	544.36
	50%	1151.79	557.27
600	10%	1046.87	498.50
	30%	1442.82	692.82
	50%	1473.99	708.23

YEAR 5 LOD (WEEKS)

Wool Price	Germ. Fraction	Discount Rate 5%	15%
300	10%	0.00	0.00
	30%	0 00	0.00
	50%	0 00	0.00
400	10%	0 00	0.00
	30%	0.00	0.00
	50%	0 00	0.00
500	10%	1.34	7.13
	30%	0 00	0.00
	50%	0 00	0 00
600	10%	7.80	8.00
	30%	0 00	0.00
	50%	0 00	0.00

YEAR 5 PROFIT ($/HA)

Wool Price	Germ. Fraction	Discount Rate 5%	15%
300	10%	28 51	28 51
	30%	40 55	40 55
	50%	41 75	41 75
400	10%	45 18	45 18
	30%	67 21	67 21
	50%	68 87	68 87
500	10%	61.97	64.47
	30%	94 46	94 46
	50%	96 65	96 56
600	10%	86.16	86.13
	30%	121 99	121 99
	50%	124 53	124 53

YEAR 5 SR (HD/HA)

Wool Price	Germ. Fraction	Discount Rate 5%	15%
300	10%	2.90	2.90
	30%	5.76	5.76
	50%	5.80	5.80
400	10%	2.90	2 90
	30%	6.28	6.28
	50%	6.30	6.30
500	10%	3.02	4.16
	30%	6.58	6.58
	50%	6.60	6.60
600	10%	4.30	4.35
	30%	6.80	6.80
	50%	6.80	6.80

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