Staff Paper

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ECONOMICS OF ALTERNATIVE STOCKING DENSITIES FOR DIRECT-SEEDED CENTRAL MICHIGAN ALFALFA PASTURES[1]

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ABSTRACT

A framework which permits estimation of economically optimal stocking rates for alternative economic parameters and alfalfa forage availability was developed and applied to a controlled grazing experiment conducted with Holstein steers (243 kg) placed on direct seeded alfalfa pastures in Central Michigan. Responses of ADG to alternative levels of forage availability per standard livestock unit (FA) were summarized by a quadratic function and the associated gains/ha were calculated.

The ADG decreased as standard stocking rate (SSR; SLU/ha) increased except for the combination of the lowest observed SSR and highest FA, where ADG was curvilinear as SSR increased. The trend for gain/ha was curvilinear for all FA. The SSR which maximized gain/ha increased with FA and was greater than that which maximized ADG. Net returns to fixed resources(NRFR)/ha ($/ha)were calculated for alternative SSR and the economically optimal SSR were identified under various levels of herbage mass (kg/d). The SSR's which maximized NRFR were between the SSR's which maximized ADG and gain/ha.

The magnitude of the sale price discount for heavier weight calves (slide) influenced the economically optimal SSR and the sensitivity of net return to SSR. The economically optimal SSR increased as slide increased because animals stocked under higher SSR weighed less off pasture and therefore received less price discount.

Key Words

Alfalfa, Grazing method, Stocking rate, Economics

INTRODUCTION

From the late 1950's through the early 1970's, a number of investigators (Harlan, 1958; Peterson et al., 1965; Hart, 1972; and Jones and Sandland, 1974) developed and implemented a conceptual framework for evaluating the impact of stocking rates on animal and pasture performance. However, management systems which maximize animal or pasture production are not economically optimal except under very unique circumstances. Dillion and Burley (1961) and Chisholm (1974) were among early researchers to incorporate economic variables into the specification of optimal stocking rate (SR) for grazing systems. Two approaches have been employed to investigate the relationship between animal and economic performance. One approach includes the direct use of experimental (Utley and McCormick, 1978; Coombs et al. 1989; Lewis, et al., 1990; Burton et al, 1994) or bio-physically simulated (Doren et al., 1985; Parsch and Loewer, 1987) performance data in an economic budget. An alternative is to use data to develop response functions that are then incorporated into an economic model (Izac et al., 1990). This paper adopts the latter alternative which has the advantages of being more general for our application.

The objective of this paper is to elucidate and compare the optimal SR when ADG, gain/ha and profitability are maximized for an intensively managed alfalfa grazing system.

Materials and Methods

The animal response results of a four year controlled-grazing experiment were evaluated within an economic framework.

Animal Production Response

Schlegel, et al. (1999a,b) grazed Holstein steers (243 kg) in Michigan on a direct-seeded alfalfa pasture on well drained soils capable of producing corn yields of 7.3 t/ha. Details of the experiment including pasture site, grazing management, experimental design, forage availability and animal production are described in Schlegel et al. (1999a). Animal units were expressed as standard livestock units (SLU) which was defined as a 500 kg non-lactating bovine (The Forage and Grazing Terminology Committee, 1990). Standard stocking rate (SSR) was defined as the number of standard livestock units/ha and calculated with the following equation (1)

(1) $$SSR = (SR \cdot INWT)^{\zeta\Lambda K} \cdot (SLU^{\zeta\Lambda K})^{-\Theta} \cdot ha^{-\Theta}$$

where:

SR = number of steers per ha

INWT = average weight of steers at the beginning of the grazing season

SLU = 500 kg no-lactating bovine.

Herbage mass (HM) estimates were collected during the first three years of the four year experiment, which allowed calculation of a daily forage availability (FA; kg/d) for each animal with equation (2).

(2) $$FA\ (kg/d) = HM \cdot d^{-\Theta} \cdot SSR^{-\Theta}$$

Herbage mass, standardized to a 110 grazing season, ranged from 6 to 12 t/ha. Forage availability ranged from 7.6 to 36.3 kg/day.

A quadratic response function describing the relationship between ADG and FA was estimated by Schlegel et al. as

(3) $$\begin{aligned} ADG\ (kg/d) &= \beta_{\eta} + \beta_{\Theta} FA + \beta_{\theta} FA^{\theta} \\ &= -.46 + .092\ FA - .001553 FA^{\theta} \qquad R^{\theta} = 0.82 \\ &\quad (0.15)\ (0.016) \quad (0.00036) \end{aligned}$$

where β_0, β_1 and β_2 are parameters and the values in parentheses are standard errors of the parameters. The estimated equation was based upon annual replicate treatment means for the 1989 to 1991 grazing seasons (n = 24). Herbage mass, standardized to a 110 grazing season, ranged from 6 to 12 t/ha. Forage availability ranged from 7.6 to 36.3 kg/day.

The standard stocking rate which maximized ADG (SSR_{ADG})was calculated by finding a solution to equation (1) when ADG per animal was greatest. The resultant equation (4) is shown below.

$$SSR_{\Pi\rho\Sigma} = -2 \bullet \beta_{\theta} \bullet \beta_{\Theta}^{-\Theta} \bullet HM/d \tag{4}$$

In this experiment, β_1 and β_2 are .0920 and .001553, respectively.

Similarly, the standard stocking rate which maximized gain/ha ($SSR_{gain/ha}$)was determined by finding a solution to equation (1) after transformation of ADG to total weight gain per ha. Solution of equation (5) provides the SSR where weight gain per unit of land area is maximized.

$$SSR_{\varepsilon\Upsilon\chi\Phi\Upsilon} = [\beta_{\theta} \bullet \beta_{\eta}^{-\Theta} \bullet (HM/d)^{\theta}]^{\eta\zeta\kappa} \tag{5}$$

The values for β_0 and β_2 were .46 and .001553, respectively.

The optimal SSR for ADG and gain/ha are nonlinear functions of the parameters; thus, linear statistical model procedures for constructing confidence intervals could not be used. Bootstrap methods (Efron and Tibshirani, 1993; Davidson and Hinkley, 1997) were employed to calculate 95 percentile confidence intervals (STATA, 1997).

Economic Model

The economic evaluation criteria used was maximum net return to fixed resources (NRFR); fixed resources are those whose use does not vary with SR. These include pasture establishment and maintenance, fencing, water system, and land. NRFR was calculated with equation (6).

$$NRFR = (GM - CostVar_{\Pi\varphi}) \bullet SR \tag{6}$$

where:

GM ($/hd)	=	$P_{sale} \bullet W_{final} - P_{purchase} \bullet W_{initial}$
W_{final}	=	weight off pasture, kg;
P_{sale}	=	price off pasture, $/kg;
$W_{initial}$	=	weight on pasture, kg;
$P_{purchase}$	=	price on pasture, $/kg;
$CostVar_{An}$	=	variable cost per animal for pasture period; and
SR	=	stocking rate (animal/ha)

In contrast to the optimal SSR_{ADG} and $SSR_{gain/ha}$, the economically optimal SSR (SSR_{NRFR})does not have a direct solution; the optimal rate must be solved for iteratively. Also, because sale value, purchase cost, and $CostVar_{An}$ are on a per animal basis, the actual SR, as well as the SSR, must be taken into account. The iterative procedure can be embedded into bootstrapping procedures and confidence intervals can be calculated for the economically optimal SSR.

The parameters used in the economic model are presented in Table 1. Sensitivity analyzes were conducted to determine the impact of the discount in sale price for heavier weight animals (slide) on SSR_{NRFR}.

Table 1. Parameters Used in the Economic Model

Measure	Parameter/Equation
Weight on pasture, kg	243
Weight off pasture, kg	Based upon response function
Gross margin (234 kg - 328 kg)	$86.60 avg $28 standard deviation
Price adjustment for weight	- $0.00165/kg per kg deviation from 328 kg.
Commission, $/kg [a]	$0.0023
Interest rate, % [b]	7.0
Preconditioning, $/animal [c]	$5.50
Mineral and bloat suppressant, $ × steer^{-1} × d^{-1}	$0.10
Veterinary and medical, $/steer	$2.00

a Commission charge was assessed at the time of purchase and of sale of steers.

b Interest on the purchase value for the grazing period was calculated using the historic rate for non-breeding livestock (Federal Reserve, various years).

c Preconditioning cost includes materials needed to ear tag, dehorn, vaccinate, implant, and treat each animal for parasites.

Cattle Prices. Purchase and sale prices and sale price discounts (slide) for heavier weight animals were adapted from yearling beef steer prices from 1987 to 1997 for the appropriate weight categories and purchase (May)and sale (late August) months at Kentucky auctions (USDA, 1987-1997). The Kentucky market was used because it represents large number of feeder cattle and most cattle fed in Michigan are imported from the southeastern states (Ritchie, et al., 1992). Beef steer prices were used for the historical price series as Holstein feeder steers prices were unavailable. It was assumed that the price relationships between Holstein and beef cattle prices maintained equivalent gross margins. Sale prices are a function of animal characteristics including weight, muscling, potential for marbling, and condition (Schroeder et al., 1988). Parsch and Loewer (1987), in a simulation study of a grazing system, modeled sale prices as a function of weight, with discounts for heavier weights. A similar adjustment was warranted in this study.

Two points of evidence support this adjustment. First, the price versus weight relationship for the August-September period for steer calves weighing more than 250 kg from the Kentucky auction market data showed a \$0.074/kg price discount per 45 kg increase in sale weight. The price and weight relationship is defined as:

$$
\begin{aligned}
P_{sale}\ (\$/kg) &= \sum_{yr=1}^{11} \theta_{yr} I_{yr} + \theta_{12}(W_{final} - 328_{kg}) + \theta_{13}DPM1 \\
&= \theta_{avg} + \theta_{12}(W_{final} - 328_{kg}) + \theta_{13}DPM1 \qquad (7) \\
&= \underset{(0.03)}{\$1.87} - \underset{(0.00008)}{\$0.00165}(W_{final} - 328_{kg}) - \underset{(0.0002)}{0.0010}\,DPM1 \quad R^2 = 0.95
\end{aligned}
$$

where:

P_{sale} = sale price, \$/kg

I_{yr} = indicator variable (1 if year, 0 otherwise)

328_{kg} = average weight off experiment

θ_{avg} = intercept average (across years)

θ_{12} = slide, \$/kg

θ_{13} = change in P_{sale}/day past May 1

DPM1 = days past May 1

The second point of evidence supporting a steer sale price adjustment for weight was the difference in feed efficiency for different weight steers entering the feedlot (Schlegel, 1999a). Higher levels of FA resulted in higher weight off pasture and lower levels of subsequent feed efficiency in the feedlot. Gain/feed in the feedlot decreased as pasture FA increased up to a FA value of 15 kg/d and then plateaued. The spline function is defined in the following equation

$$\text{Gain/feed} = \gamma_{\eta} + \gamma_{\Theta} * \text{FA\_adj} \tag{8}$$

$$= \underset{(0.015)}{0.183} - \underset{(0.0011)}{.00304} * \text{FA\_adj} \quad R^{\theta} = 0.26$$

where:

$$\text{FA\_adj} = \begin{cases} \text{FA if} \leq 15 \\ 15 \text{ if FA}>15 \end{cases}$$

Also, ADG in the feedlot was inversely related to ADG on pasture, a result consistent with the results of Coffey et al. (1990).

Increased feedlot performance associated with lower FA and therefore weight off pasture translates into higher break-even feeder cattle prices for lighter weight cattle off pasture. Sale price off pasture was adjusted for weight as shown in Equation 6. To reflect that the sale price versus weight off pasture relationship differs across years due to variations in corn price, interest rate, and stage of the cattle cycle, separate annual equations were also estimated. The slide ranged from zero, when August/September corn prices were at the sample high (1996) to $0.0029/kg when August/September corn prices were at the sample low (1991). Economic simulations were performed using price slides of zero, $0.00165/kg, and $0.0032/kg for deviations in weight from 328 kg. Prices of feeder cattle were adjusted to a Central Michigan location by assessing an inbound transportation cost of $1.20/loaded km for a 22,700 kg load.

Variable Costs. Variable cost was charged per steer and included purchase and sale commissions, interest on steer ownership, materials associated with pre-conditioning a steer prior to placement on pasture, mineral and bloat suppressant, and veterinary and medicine costs. Pasture costs per hectare were similar across SR or HM and, therefore, were not considered in the analysis.

Results and Discussion

Animal Performance. Graphs depicting estimated ADG and gain/ha versus SSR/ha based on a 110 d grazing period are shown in Figures 1 and 2. A range of HM from 6 to 12 t/ha was considered where 6 t/ha approximates the HM produced in 1989, when the trial was initiated, and 12 t/ha approximates the greatest HM produced during the third year of the trial.

Based on the estimated animal response function, ADG increased with FA and decreased with SSR for HM levels of 6, 8, and 10 t/ha. This result is consistent with Cowlishaw (1969), Marten and Jordan (1972), Jones and Sandland (1974), Whittier and Schmitz (1990) and Bates, et al. (1996). In the current trial, for HM of 12 t/ha, ADG increased as SSR increased to 3.5, plateaued and then decreased for SSR greater than 4.0.

At very low SSR, predicted ADG was lower with HM of 12 t/ha than 8 or 10 t/ha. These results are contrary to Conniffe et al. (1970) who argued that, at very low SR, production per animal will be unrelated to SR because animals with unrestricted intake will achieve maximum weight gains. However, the findings are supported by those of Michaud and Conrad (1984) who found that, while forage intake and ADG increased curvilinearly with FA, the highest ADG would be reached at points below the highest levels of FA. That is, increased FA does not necessarily increase ADG, especially when FA is greater than expected animal intake. When ADG does not increase as FA increases, it may be due to reduced forage quality as suggested in Schlegel et al. (1999a,b).

Gain/ha increased and then decreased as the SSR increased for all levels of HM. The initial increase in gain/ha was not found by Bates et al. (1996) and Marten and Jordan (1972) who reported only increasing gain/ha with decreasing FA. This suggests the lowest FA considered in these studies was higher than that which would reduce individual animal gain enough to outweigh the increase in total gain resulting from a higher SR. As with ADG, gain/ha increased with HM except at very low SSR.

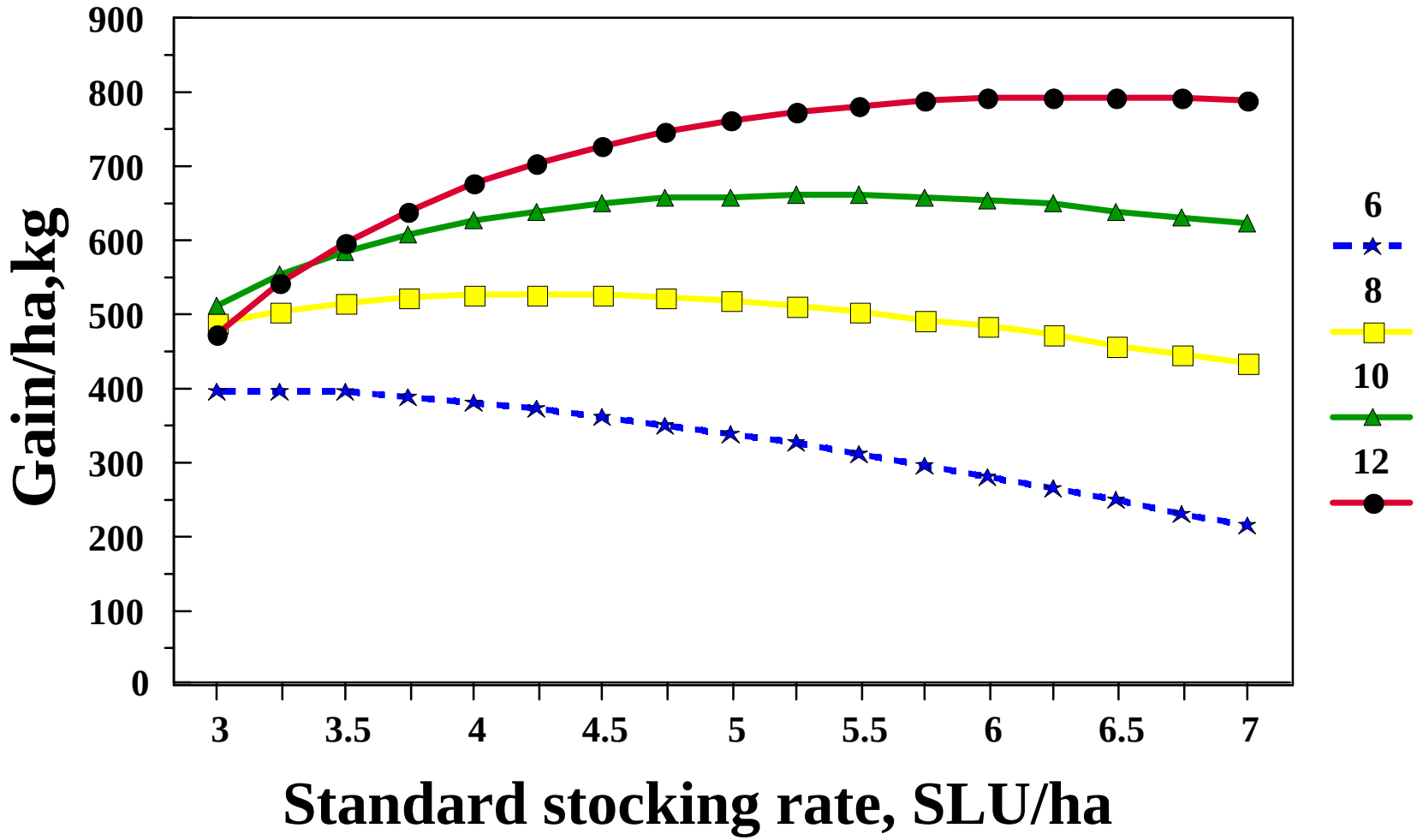

Figure 1. Average daily gain versus SSR(SLU/ha) with varying levels of herbage mass. Statistically estimated relationship between SSR and ADG from Schlegel et al. (1999). ADG = (-.46) + (.0920 x FA) - (.001553 x FA^2), P=.0001, R^2=.82. ADG is maximized at SSR_{ADG} = 2 x .001553 x .0920 x HM/d

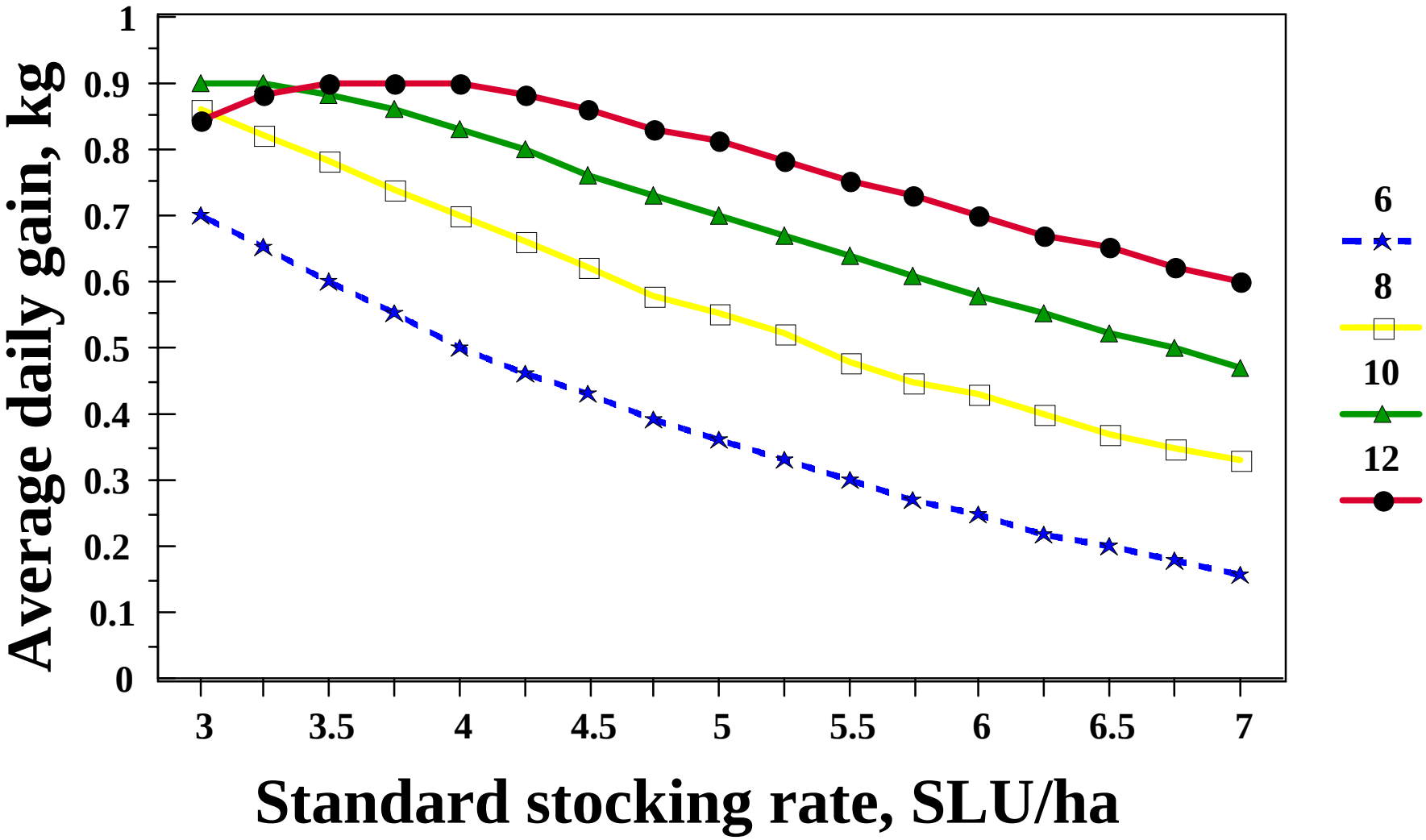

Figure 2. Gain per hectare versus standard stocking rate (SLU/ha) with varying levels of herbage mass. Gain/ha is maximized at $SSR_{gain/ha} = [.001553 \times .4599 \times (HM/d)^2]^{.5}$.

The SSR which maximized ADG was less than that which maximized gain/ha, a result consistent with the work of Marten and Jordan(1972) with lambs and Whittier and Schmitz (1990). It also is consistent with the work of Jones and Sandland (1974) who concluded, after an analysis of many grazing trials, that SSR which maximizes gain/ha is never that which maximizes gain/animal.

Economic Performance. NRFR varied by HM and SSR (Figure 3). Results are initially reported with a price slide of $0.00165/kg for each kg sale weight increase over 328 kg. The SSR for maximum ADG, gain/ha, and NRFR are shown in Table 2. SSR_{NRFR} was greater than SSR_{ADG} but less than $SSR_{gain/ha}$. The SSR_{NRFR} was less than $SSR_{gain/ha}$ because the additional variable costs associated with acquiring, maintaining, and selling additional steers outweighed the revenue received from the additional gain/ha. This finding is consistent with Izac et al. (1990) who found that the biological optimum (defined as maximizing gain/ha) corresponds to a much higher intensity of pasture use than the economic optimum.

The SSR_{NRFR} for HM of 6, 8, 10, and 12 t/ha were 2.50, 3.35, 4.17, and 5.0 SLU/ha, respectively. SSR_{NRFR} increased with increasing HM. The NRFR increased with increasing HM over the range of SSR observed in the experiment with the exception of the 12 t/ha case. NRFR for 12 t/ha HM was less than 8 to 10 t/ha HM at very low SSR.

Net return to fixed resources/ha was relatively insensitive to modest departures from SSR_{NRFR}. The rate of decline increased as the departure became larger. The range of insensitivity of NRFR to departures from the economically optimal SSR increased as FA increased.

Table 2. Optimal standard stocking rate under alternative optimization criteria: maximum ADG, net return to fixed resources and gain/ha[a]

Herbage mass (metric ton ha^{-1})	Optimization Criteria		
	ADG, kg	NRFR, $/ha	Gain, kg/ha
	Optimal SSR (SLU/ha)		
6	1.84[b] (1.55-1.98)	2.50[b] (2.30-2.84)	3.17 (2.79-4.84)
8	2.46[b] (2.07-2.64)	3.35 (3.08-3.78)	4.23 (3.72-6.46)
10	3.07 (2.58-3.29)	4.15 (3.85-4.73)	5.28 (4.65-8.07)
12	3.68 (3.10-3.95)	5.00 (4.60-5.66)	6.34 (5.58-9.67)

[a] Values in parentheses are 95% confidence intervals.
[b] Optimal SSR are less than the lowest observed values the in Schlegel et al. (1999a)data.

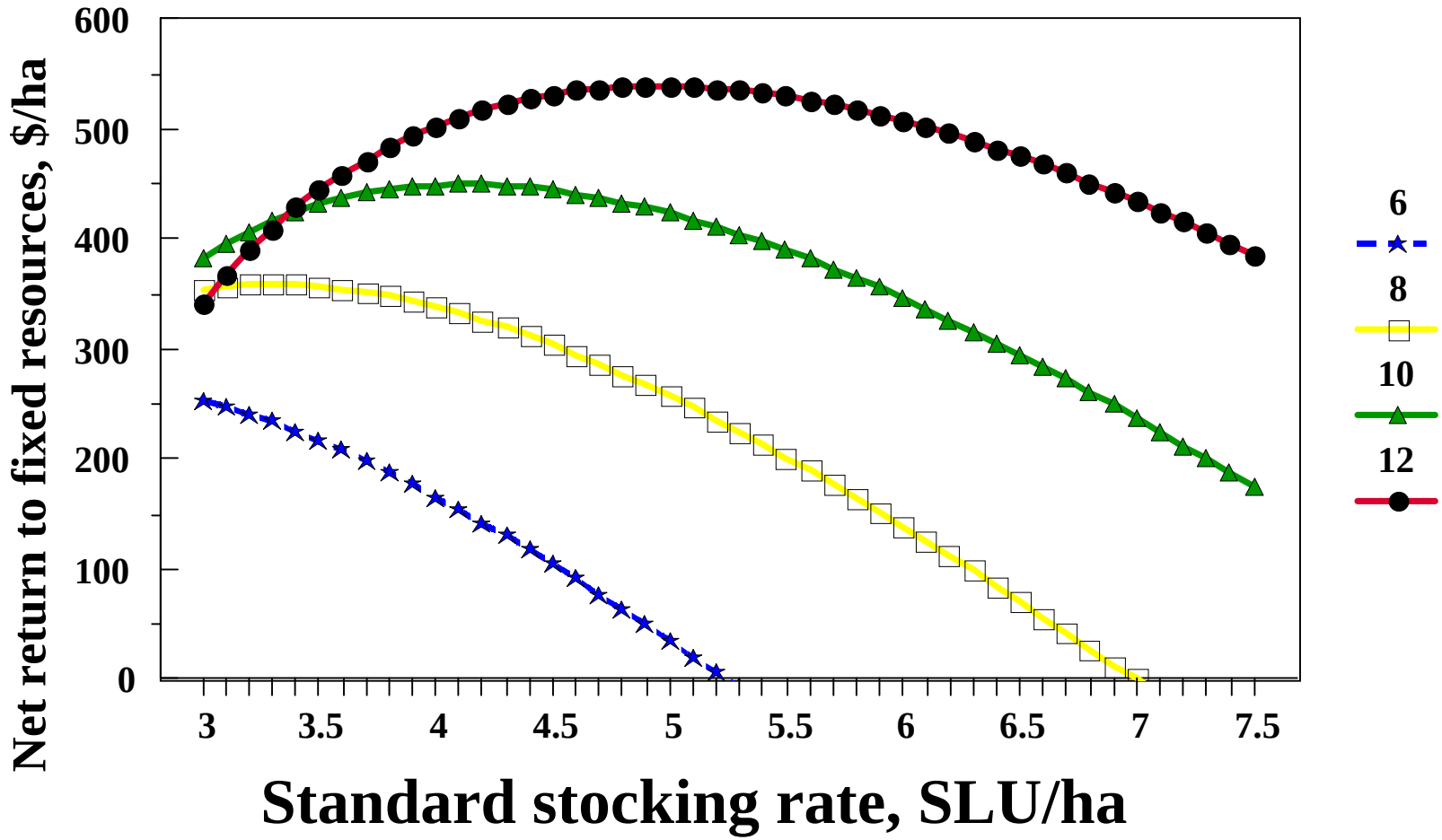

Figure 3. Net return to fixed resources versus SSR (SLU/ha) under different levels of herbage mass. Steer price discount is $0.00165/kg for each kg over 328 kg weight off pasture.

The SSR_{NRFR} was also influenced by the magnitude of the price slide for cattle with heavier off pasture weights (Figure 4). As the magnitude of the price slide increased, increasing the SSR was beneficial because the lower weight animals received a relatively higher price. Net return to fixed resources was less sensitive to departures from the SSR_{NRFR} when heavier weight calves were discounted more.

Implications

The response function approach permits generalizing experimental results to accommodate alternative levels of HM and to solve for economically optimal stocking rates given changing economic variables. The economically optimal stocking rate, while sensitive to both HM and economic variables, is higher than that which maximizes individual animal performance and lower than that which maximizes pasture productivity. Modest departures from the economically optimal stocking rate do not result in large decreases in NRFR/ha.

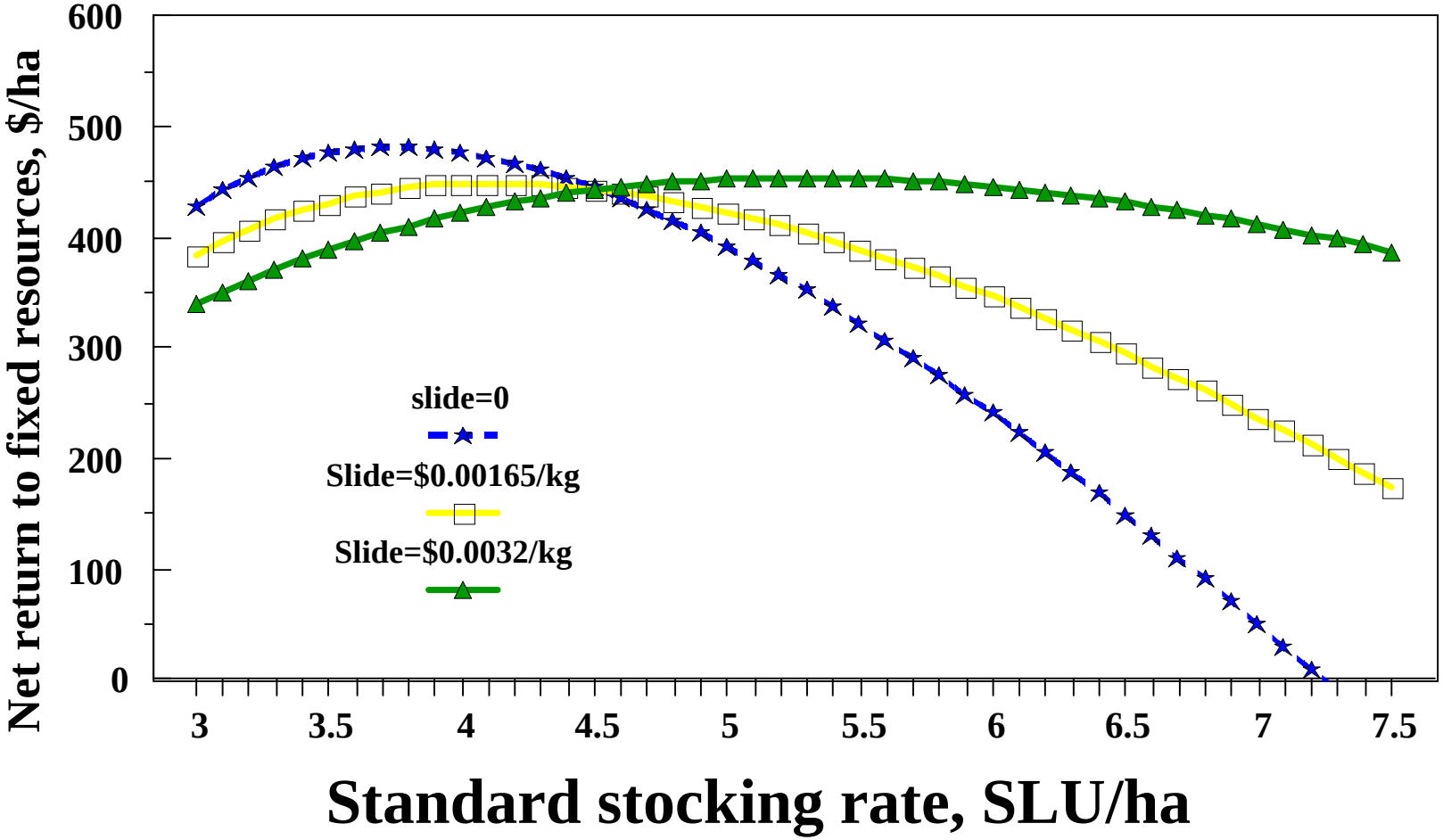

Figure 4. Net return to fixed resources versus SSR (SLU/ha) under different slides on steer price. The effect of three slides; zero, -$0.00156, and -$0.0032 $/kg for each kg difference in weight off pasture from 328 kg, on NRFR are shown. Herbage mass availability is 10 t/ha.

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