ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE

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PREFACE

The wheat pasture system is complex because: (1) it involves the joint production of grain and cattle, and (2) stocker cattle weight gains are uncertain due to variability in the amounts of forage available. This study was conducted to investigate the use of supplemental energy to reduce production risk from growing cattle on winter wheat pasture.

This thesis is composed of three papers. The first paper uses a stochastic production function to model wheat pasture stocker cattle production risk. The second paper employs the certainty equivalent model to determine daily optimal energy supplementation rates under both price and production risk. The third paper uses numerical integration with Guassian quadrature to determine optimal energy supplementation strategies under conditions of declining forage production.

I would like to sincerely thank my major advisor, Dr Daniel J. Bernardo, for his patience and intelligent guidance. I wish to express my gratitude to my other advisory committee members, Drs. Wade Brorsen and Harry Mapp, for their useful comments. To my parents and friends, thank you for your invaluable support.

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Abstract

A Just-Pope type stochastic production function was estimated to determine the effect of energy supplement inputs on weight gain variability of wheat pasture stocker cattle. The null hypothesis that the variability of weight gains does not depend on levels of energy supplement inputs was rejected. Energy supplements are risk-reducing inputs.

RISK ANALYSIS IN WHEAT PASTURE STOCKER CATTLE PRODUCTION

Introduction

Grazing stocker cattle on winter-wheat pasture is an important production activity for farmers in the US Southern Plains. During the vegetative growth stage of wheat (typically early-November through mid-March), stocker cattle can be grazed on wheat pasture until the initiation of jointing, when they must be removed to avoid reduction in grain yield (Croy, 1984). In years of adequate forage production, stocker cattle performance can be excellent because of the high quality of wheat forage (Tarrant, 1990). However, stocker cattle production is risky[1] due to several factors; most notably, forage production uncertainty. Production risk resulting from forage production occurs because stocker cattle are grazed during the fall/winter season, when forage growth is sporadic. Establishing wheat pasture may be slowed due to poor moisture conditions in the fall, wheat may go dormant for an extended portion of the winter season, or wheat forage may not be accessible due to snow. In addition, harsh weather conditions may impede the conversion of wheat forage to weight gain. In years of inadequate forage production, the general practice of farmers

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[1]Production risk occurs in that stocker cattle weight gains are uncertain.

is to remove stockers from the pasture early. However, by shortening the grazing season, farmers may incur a significant loss of returns from cattle grazing.

Several management practices for wheat pasture stocker cattle production have been reported in empirical studies (e.g., Rodriguez et al, 1990; Tarrant, 1990). Recently, research has focused on developing energy supplementation programs "for delivery of new technologies that will decrease production risk of growing cattle on wheat pasture..." (p. 1, Horn et al., 1993). Supplementation of cattle grazing wheat pasture may provide a more balanced nutrient supply and can serve as a carrier for feed additives such as ionophores and bloat preventive compounds. Both the digestible organic matter (DOM) and crude protein content (CP) of wheat pasture are high. Wheat forage commonly contains 75 to 80% DOM and 25 to 30% CP during the fall and early spring grazing periods, resulting in a DOM:CP ration of 3:1 (Horn, 1990). Previous research has indicated that ruminal ammonium concentrations and large net losses of nitrogen occur at such low DOM:CP ratios (Hogan, 1982). Accordingly, supplemental energy should improve the balance between nitrogen and energy supply from wheat forage in the rumen, and hence, increase cattle performance. An additional benefit is that the supplemental energy ration can be used as a carrier for ionophores (e.g. monensin). Previous research indicates that monensin decreases the incidence and severity of bloat from wheat pasture (Branine et al., 1990).

Because of the complexity of the grazing system, it is useful to empirically examine the effects of supplementation programs on wheat pasture stocker cattle production. Indeed, supplementation programs may increase expected weight gain, but also increase variance of weight gain. Similarly, the nature of the interaction between level of forage availability and energy supplements may not support the use of energy supplements as a means of replacing forage deficits. Past studies have not addressed such empirical questions. The objective of this study is to empirically determine the effect of energy supplementation on stocker cattle production risk.

A Just-Pope type production function is estimated to determine the effect of energy supplements on production risk. Applying this procedure allows evaluation of the effect of supplementation on risk independent of its effect on expected weight gains. The findings reported in this paper should prove useful for farmers concerned with reducing the risk of growing stocker cattle on wheat pasture.

Materials and Methods

Source and Nature of Data

Data were obtained at the Oklahoma State University Wheat Pasture Research Facility in Marshall, Oklahoma from a project designed to evaluate a grain-based, high-starch energy supplement versus a high-fiber energy supplement for growing cattle on wheat pasture. The experiment was conducted over three grazing seasons (1989-90, 1990-91, 1991-92). Control cattle received no supplement other than free-choice access to a commercial mineral mixture. The other cattle were hand-fed either a corn-based energy supplement (i.e., high-starch supplement) or a high-fiber energy supplement that contained about 47% soybean hulls and 42% wheat middlings (as-fed basis). Composition of the supplements is shown in table 1. All of the supplements contained monensin (about 40 mg/lb). The target level of consumption was .75 to 1% of mean body weight. The 1989-90 grazing experiment also included a fourth treatment consisting of a high-fiber energy supplement *ad libitum.*

Each treatment was randomly assigned to four 40-acre pastures in each of the three years. Fall-weaned steer calves were randomly allocated to the appropriate number of grazing groups based upon breed and initial weight. The number of head comprising each group varied by treatment and year. In 1989-90 and 1991-92, stocking densities were 2.0 ac/head for control cattle and 1.5 acre/head for supplemented cattle; in 1990-91, control and supplemented cattle were each allocated to three stocking densities (2.0, 1.64, and 1.38 acre/head). Fall-weaned crossbred steer calves grazed clean-tilled wheat pasture for 115, 107, and 84 days, during 1989-90, 1990-91, and 1991-92, respectively. Supplemented steers received supplemental feed for 96, 100, and 70 days, during the 1989-90, 1990-91 grazing seasons, respectively. For additional details of the experimental procedures, see Horn et al. (1991).

Data employed in the analysis are forage available per steer day, quantities of feed supplements, initial calf weights, and final weights. Data reflect the average over all cattle in the 40-acre pasture. Weight gains are calculated as final weights minus initial calf weights. The summary statistics for seasonal weight gains are presented in table 2. To account for differences in the quality of the alternative supplements, the quantity of each supplement fed is multiplied by its net energy for gain (Mcal/kg). Thus, average daily supplementation levels are expressed in net energy terms (Mcal/day). Seasonal weight gains are converted to daily weight gains since the number of grazing days and supplementation days are different within and across years.

Model Specification and Procedures

Most agricultural crop and livestock production occurs in an uncertain environment; thus, incorporating risk in production analysis has been a major focus among researchers. Risk has been incorporated in production analysis in many ways. In this study, a Just-Pope type production function is used to model wheat pasture stocker cattle production risk. Just and Pope (1979) argued that the popular specifications of stochastic production functions are overly restrictive because they impose the a priori restriction that inputs increase risk. That is, if any input has a positive effect on output, then a positive effect on the variability of output is also imposed. Just and Pope proposed an alternative specification of stochastic production functions which allows determining the effect of inputs on risk independently of the effect on expected output.

In this paper, a Just-Pope type production function is used to determine the effect of forage availability and energy supplement on the expected value and variability of stocker cattle weight gains. Given that time series and cross-sectional data are used, time effects are accounted for in the production function specification. Plot effects are not necessary since the cross-sectional units were in close proximity in the original experiment. Time effects are important since the different cross-sections were affected by the same weather conditions each year. With these assumptions, the following production model applies:

$$(1) \quad G_{it} = \beta_0 + \lambda^d{}_t + \sum_{k=1} \beta_k X_{it} + e_{it}, \; i=1,2,\ldots,N; \; t=1,2,\ldots,T,$$

with

$$(2) \quad e_{it} = \epsilon_{it} h^{1/2}(Z_{it}, \alpha),$$

where G_{it} is daily rate of weight gain, X_{it} is a vector of inputs, $Z_{it} = (1, \lambda^s{}_t, Z_{1t} \ldots Z_{nt})'$ is a vector of exogenous input

input variables[2], β and α are vector of parameters to be estimated, the λ_t's represent time effects in the deterministic and stochastic terms, e_{it} is the error term, N is the number of cross-sectional units, T is the number of years, and ϵ_{it} is assumed normally distributed with mean zero and variance one (Just and Pope, 1979). Equation (2) implies that the error term is heteroskedastic since its variance depends on input levels. In this specification, the deterministic component is represented by $E(G_{it}) = \beta_0 + \lambda^d{}_t + \Sigma_k\beta_k X_{it}$ and the stochastic component by $V(e_{it}) = V(G_{it}) = h(Z_{it}, \alpha)$, where V(.) denotes the variance operator.

Production function characteristics and statistical properties determine the choice of the functional form of the deterministic component. Marginal products must be positive over some range of the sample data; second derivatives should be negative since each additional unit of supplement input may result in less additional weight gain than the previous one. For the stochastic component, it is assumed that the logarithm of the variance of weight gains is a linear function of the exogenous variables energy supplement, initial calf weight, and pounds of available forage[3]. In addition, time effects are assumed fixed (which implies the use of year dummy

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[2]The Z_{it}'s may be the same as X_{it}, a transformation of the X_{it}, or even include other exogenous variables.

[3]This is referred to as multiplicative heteroskedasticity because different components of the variance are related multiplicatively (Judge et al., p. 365, 1988).

Test 1: Test for Multiplicative Heteroskedasticity[5]

H_0: $\alpha_1 = \alpha_2 = \alpha_3 = 0$

H_1: not all α_i's are zero, $i = 1, 2,$ or 3.

Similarly, the significance of time effects on mean and variance of weight gains is tested. The hypothesis concerning the significance of time effect on the mean is tested separately of the significance of time effect on output variance.

Test 2: Significance of Time Effect on Expected Weight Gain

H_0: $\lambda^d{}_t = 0, \quad t = 1, 2$

H_1: $\lambda^d{}_t \neq 0, \quad t = 1$ or 2.

Test 3: Significance of Time Effect on Variance of Weight Gains

H_0: $\lambda^s{}_t = 0, \quad t = 1, 2$

h_1: $\lambda^s{}_t \neq 0, \quad t = 1$ or 2.

A failure to reject the null hypothesis in test 1 would imply that the variability of weight gains does not depend on the specified exogenous variables. The null hypothesis in test 2 should be rejected if time effects do not significantly affect the mean. Similarly, the null hypothesis in test 3 should be

[5] See appendix for proof. α_1, α_2, and α_3 are the parameter estimates of the independent variables $INWT_{it}$, EN_{it}, and PF_{it}, respectively, in the variance equation.

rejected if time effects do not significantly affect the variance of weight gains. All of the tests are carried out by using a Wald test (Judge et al., p.106, 1988).

Empirical Results

The parameter estimates of the stochastic production function are reported in table 3. The signs of the estimated parameters of the deterministic term conform with the maintained hypotheses (positive and diminishing marginal product expectations over the relevant range of the sample data). The coefficient of the interaction term is negative, indicating a trade-off between level of forage availability and energy supplements. In addition, the model allows a good prediction of the observed weight gains; the squared correlation coefficient between the predicted and the observed weight gains is 0.89.

Table 4 summarizes the results of the specification tests. The null hypotheses of all of the three tests are rejected at the 2.5% level. These results imply that the variance of the error term is heteroskedastic and depends upon the levels of the specified exogenous variables. In addition, time effects significantly affect expected weight gain and also variance of weight gains.

Following Just and Pope (1978), decreasing, increasing, or constant marginal risk for energy supplements can be determined based on the sign of the first derivative of the stochastic term with respect to energy supplements. Indeed, changes in the variability of stocker cattle weight gains are given by:

$$(5) \quad \frac{\partial V(G)}{\partial EN} = \frac{\partial h(Z_{it}, \alpha)}{\partial EN} = h_{EN},$$

where G denotes weight gain. A positive (negative) sign of h_{EN} implies increasing (decreasing) variability of weight gains with increased use of energy supplement. Given the functional form used for the stochastic component, the sign of h_{EN} can be determined without ambiguity based on the results of the estimated variance equation:

$$(6) \quad V(G) = \exp(15.989 - 0.043INWT - 0.883EN - 0.074PF + 0.084D1 + 1.119D2)$$

Partially differentiating equation (6) with respect to the energy supplement variable (EN) yields:

$$(7) \quad h_{EN} = -0.883\exp(15.989 - 0.043INWT - 0.883EN - 0.074PF + 0.084D1 + 1.119D2)$$

Equation (7) implies that the variability of weight gains decreases with increased use of energy supplement, over all energy supplement levels. Thus, energy supplement is a risk-reducing input.

The results presented above are consistent with the summary statistics reported in table 2. For example, the high-fiber ration is associated with a higher mean weight gain and a lower standard deviation, as compared to the control. The same is true for the high starch ration, relative to the control.

Results also indicate that as more forage is available less variability of weight gain is observed. Similarly, animals with higher initial calf weights are subject to less variability of expected daily weight gains.

To obtain additional insight into the effects of energy supplement on weight gains variability, one may consider how the variance of the marginal product changes as more supplement inputs are used. Partially differentiating the marginal products of energy supplement and forage availability yields[6]:

$$(8) \qquad \frac{\partial V(\frac{\partial G}{\partial EN})}{\partial EN} = \frac{(\alpha_2)^3}{4}h,$$

$$(9) \qquad \frac{\partial V(\frac{\partial G}{\partial PF})}{\partial EN} = \frac{\alpha_2(\alpha_3)^2}{4}h.$$

Equations (8) and (9) indicate that the variability of the marginal products of energy supplement and forage availability depends on the sign of α_2 only (α_3 is squared). Results

[6]See appendix for proof.

indicate that α_2 is negative (Table 3). Thus, the variability of the marginal products decreases with increased use of energy supplement. This result is of particular interest because uncertain forage availability is associated with large variations in the marginal products. By feeding supplement inputs, an additional source of energy is provided which helps decrease the variance of the marginal product of forage, and thus reduce the variability of stocker cattle weight gains due to forage deficits.

Implications For Management Decisions

The results presented above have important implications for the identification of efficient production practices by wheat pasture stocker producers. The risk-reducing character of energy supplement inputs implies that risk-averse producers can use energy supplement to reduce production risk of growing cattle on wheat pasture.

As a result of reducing weight gain variability, producers can more reliably project weight of cattle at the end of the fall-winter grazing season. This should improve the manager's ability to make better decisions in selecting among ownership and marketing alternatives after the wheat pasture grazing season. By increasing the certainty of the ending weight of cattle coming off wheat pasture, more accurate break-even calculations can be made for retained ownership alternatives. In addition, the profitability of forward contracting and other marketing alternatives can be improved by increased certainty of ending weights.

The fact that the variability of the marginal products decreases with increased use of energy supplements also has management implications. Producers should select energy supplementation levels such that the marginal value product of supplement equals its marginal factor cost. Similarly, stocking densities should be set to equate the marginal value product of wheat forage with its marginal factor cost. Since energy supplement reduces the variability of the marginal products, the precision with which optimal input levels can be identified should be increased.

The substitutability between energy supplements and forage availability implies that supplementation programs can be used to replace forage deficits. This avoids removing cattle from wheat pasture too early. The substitution opportunities also imply that producers may consider the possibility of increasing their stocking density in combination with adopting a supplementation program.

Summary and Conclusions

This paper has determined the effects of energy supplements on wheat pasture stocker cattle production risk. A Just-Pope type production function for stocker cattle was estimated, and the effects of energy supplements on the expected value and variability of weight gain were determined. The specification test results indicate that the variance of weight gain depends on the level of energy supplementation. Supplemental energy is a risk-reducing input.

In years of low forage production, energy supplements can replace forage deficits. In addition, if a supplementation program is adopted, stocking densities can be increased (i.e., more animals can be grazed). The results reported in this paper suggest that farmers concerned with uncertain stocker cattle weight gain should incorporate supplementation programs in their wheat pasture stocker enterprise.

Table 1. Composition of Energy Supplements[1], Rations Fed in Wheat Pasture Supplementation Experiments, Marshall, Oklahoma.

Treatment	High Starch	High fiber
	% As-fed	
Ground corn	78.94	
Soybean Hulls		46.94
Wheat Middlings	8.90	41.74
Molasses	4.95	4.95
Calcium Carbonate	1.75	1.50
Dicalcium Phosphate	0.60	
Micro-lite	4.15	4.15
Salt	0.65	0.65
Rumensin 60 Premix	0.07	0.07
Calculated Nutrient Content (As-fed basis)		
NEgain (Mcal/cwt)	52.80	39.30
Crude Protein (%)	8.20	11.50
Calcium (%)	0.89	0.89
Phosphorus (%)	0.44	0.53
Magnesium (%)	0.46	0.55
Monensin content (mg/lb)	40.00	40.00

[1]All supplements were fed as 3/16-inch pellets.

Table 2. Mean and Standard Deviation of Seasonal Weight Gains (lb/head) for Control, High-fiber, and High-Starch Supplemented Wheat Pasture Stocker Cattle, (1989-90, 1990-91, and 1991-92).

Feed Type	Mean	Standard Deviation
Control (No supplement)	236.92	39.42
High Fiber	274.92	36.03
High Starch	264.45	33.83

Table 3. Parameter Estimates of the Stochastic Production Function, Time Series and Cross-Section Data Over Three Grazing Seasons (1989-91, 1990-91, 1991-92)[1].

Dependent Variable	Independent Variable	Coefficient	Standard Error
Log of Weight Gains	Constant	-13.841**	1.095
	ln(Energy)	1.482**	0.390
	ln(Forage)	0.038	0.042
	ln(In-Weight)	2.386**	0.181
	ln(ENERGY)* ln(FORAGE)	-0.546**	0.125
	D1	-0.166	0.028
	D2	-0.200	0.029
Log of Variance of Weight Gains	Constant	16.342**	4.657
	In-Weight	-0.044**	0.009
	Energy	-0.867*	0.693
	Forage	-0.059*	0.046
	D1	-0.144	0.602
	D2	0.878	0.630
R-Square Adjusted		0.84	
Number of Observations		45.00	

[1]D1 and D2 denote year dummy variables for 1989-90, 1990-91, respectively.

Table 4. Specification Test Results[1].

Null hypothesis	Test-statistic	Critical value at the 2.5% level
Variance does not depend on input levels (Test 1)	28.026	9.348
No time effect on mean (Test 2)	46.872	7.378
No Time Effect on Variance (Test 3)	8.690	7.378

[1]Under the null hypothesis, the Wald statistic is distributed chi-square with three degrees of freedom for test 1, and two degrees of freedom for tests 2 and 3.

Appendix

Test for Multiplicative Heteroskedasticity

Consider the variance equation:

$$h_{it} = \exp(\alpha_0+\lambda^s{}_t).\exp(\alpha_1 INWT_{it}).\exp(\alpha_2 EN_{it}).\exp(\alpha_3 PF_{it}).$$

Letting $\exp(\alpha_0+\lambda^s{}_t) = \sigma^2$ (see e.g., Judge et al; Griffiths and Anderson), then the variance equation becomes:

$$h_{it} = \sigma^2\exp(Z^{*\prime}{}_{it}\alpha^*)$$

$$= \sigma^2\Psi = diag(\exp(Z^{*\prime}{}_{1t}\alpha^*),\ \exp(Z^{*\prime}{}_{2t}\alpha^*), \ldots, \exp(Z^{*\prime}{}_{nt}\alpha^*)),$$

where $Z^{*\prime}{}_{it} = (INWT_{it},\ EN_{it},\ PF_{it})$, $\alpha^* = (\alpha_1,\ \alpha_2,\ \alpha_3)'$. If $\alpha^* = 0$, the variance equation reduces to $h_{it} = \sigma^2 I$ (where I is the identity matrix), which implies homoskedasticity. Thus, test 1 is a test for multiplicative heteroskedasticity ($\alpha^* = 0$ against $\alpha^* \neq 0$).

Derivation of Equation (8) and (9)

Following Just and Pope (p.278):

$$V(\frac{\partial y}{\partial X_i}) = \frac{h_i^2(X)}{4h(X)}$$

Thus, for $i \neq j$,

Let $y \equiv G$, $X_i \equiv X_j \equiv EN$, then

$$v = \frac{\partial v(\frac{\partial y}{\partial X_i})}{\partial X_j} = \frac{2h_i h_{ij} h - h_{ij} h_i^2}{4h^2}$$

$$v = \frac{2h_{EN} h_{ENEN} h - h_{EN} h_{EN}^2}{4h^2} = \frac{2(\alpha_2 h)(\alpha_2^2 h)h - (\alpha_2 h)(\alpha_2^2 h^2)}{4h^2}$$

$$= \frac{h^3(2\alpha_2^3 - \alpha_2^3)}{4h^2} = \frac{\alpha_2^3}{4}h$$

Similarly, if $X_i \equiv PF$ and $X_j \equiv EN$, then

$$v = \frac{2\alpha_3^2\alpha_2 h^3 - \alpha_3^2\alpha_2 h^3}{4h^2} = \frac{\alpha_3^2 h(2\alpha_2 - \alpha_2)}{4} = \frac{\alpha_2\alpha_3^2}{4}h$$

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Paper II

ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER PRICE AND PRODUCTION RISK

ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER PRICE AND PRODUCTION RISK

Abstract

A stocker-cattle decision model was developed to determine optimal energy supplementation strategies for wheat pasture stocker cattle production under both production and cattle price risk. A Just-Pope type stochastic production function was used to model production risk. The variance of stocker cattle weight gains is shown to decrease as the quantity of energy supplement increases. Despite the risk-reducing character of energy supplements, optimal supplementation levels are shown to be relatively insensitive to risk preferences. Optimal supplementation levels differ by a maximum of 0.6 l/head/day as risk preferences increase from risk neutrality to high level of risk aversion. Optimal supplementation levels are significantly affected by forage availability and feed costs. At moderate levels of forage availability and average feed costs, supplementation rates range between 1.65 and 1.75 lb/head/day. Optimal supplementation rates increase to 6.53 lb/head/day when low amounts of forage are available. It is not optimal for producers to feed cattle supplemental energy when conditions of high levels of forage availability prevail.

ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER PRICE AND PRODUCTION RISK

Introduction

A common practice in the Southern Plains is grazing stocker cattle on winter wheat pasture during the vegetative stage of wheat growth (November through early March). This practice allows farmers to derive income from both wheat grain and forage production. Bernardo and Wang (1991) reported that grazing stocker cattle on winter wheat pasture has been one the most profitable cattle enterprises available to Oklahoma stockmen during the last two decades. However, because of the uncertainty inherent in forage production during the late fall and winter seasons and the volatility of cattle markets during this period, returns from grazing stocker cattle on winter wheat pasture are also extremely volatile, relative to other enterprises available to farmers in the region (Bernardo and Wang, 1991).

Feeding cattle a supplemental energy ration has been proposed to reduce wheat pasture stocker cattle weight gain variability, and hence, decrease production risk (Horn et al., 1991). Supplemental energy provides a means to improve the balance between nitrogen and energy supply from wheat forage in the rumen, and hence, improve cattle performance. In addition, supplemental energy can be used as a carrier for an ionophore, such as monensin. Monensin reduces the incidence and severity of bloat from wheat pasture (Branine et al., 1990).

Because energy supplements represent a significant cost, their inefficient use may reduce profitability. Thus, the general objective of this paper is to determine optimal supplementation strategies for stocker cattle production on winter wheat pasture. The specific objective is to determine optimal energy supplementation rates under both price and production risk. The model developed here should prove useful for stocker cattle producers concerned with reducing income variability.

Theoretical Background

Incorporating risk in the production decision analysis can be done in several ways. Numerous risk efficiency criteria (e.g., stochastic dominance, mean-variance efficiency, stochastic dominance with respect to a function) have been used to identify optimal production decisions under alternative risk preferences. Alternative approaches to modeling production decision-making under risk use expected utility maximization models. This latter approach is used in the present paper.

Freund (1956) showed that when profits are normally distributed, maximizing expected utility of profits is equivalent to maximizing certainty equivalent of profits. The certainty equivalent of profit is the amount of profit that a producer would accept in lieu of a higher but uncertain amount of profit. The certainty equivalent model has been widely used in empirical models to investigate optimal inputs usage under risk (Robison and Barry, 1987; Lambert, 1990; Olson and Eidman, 1992). Preckel et al. (1987) also used the certainty equivalent model to determine the value of information for microeconomic production decisions. The certainty equivalent of profit is expressed as follows:

$$(1) \quad CE(\pi) = E(\pi) - \frac{\lambda}{2}\sigma^2(\pi),$$

where CE denotes certainty equivalent, E is the expectation operator, σ^2 denotes variance, π is profit, and λ is the Pratt-Arrow absolute risk aversion coefficient.

Following Robison and Barry (1987), let the production function be represented by $Y = f(X) + e$, where e is distributed with mean zero and variance σ_e^2 and where the signs of the derivatives of f conform with the usual assumptions (positive marginal products and negative second derivatives). Let the output price be $P + \xi$, where ξ is a random variable distributed with mean zero and variance σ_ξ^2. Under these assumptions, profit can be expressed as:

$$(2) \quad \pi = (P+\xi)Y - rX.$$

Expected profit is defined as:

$$(3) \quad E(\pi) = E(P)f(X) + \sigma_{YP} - rX,$$

where σ_{YP} is the covariance between output and price. If price and output are independently distributed, σ_{YP} equals zero and the variance of profit is defined as (Mood et al., 1974, p. 180):

$$(4) \quad \sigma^2(\pi) = [f(X)]^2\sigma^2_\xi + [E(P)]^2\sigma^2_e + \sigma^2_\xi\sigma^2_e.$$

Under both price and output risk, optimal input choice can be determined by solving the following problem:

$$(5) \quad \underset{X}{Max}\ CE[\pi(Y)] = E(P)f(X) - rX - \frac{\lambda}{2}[E(P)^2\sigma^2_e + E(Y)^2\sigma^2_\xi + \sigma^2_\xi\sigma^2_e].$$

Research Procedures

A stochastic production function is first estimated using experimental data from a three-year project designed to evaluate alternative supplementation programs for wheat pasture stocker cattle. The production function is then incorporated into the certainty equivalent model to determine optimal supplementation levels under alternative feed price-cattle price combinations.

Production Function Estimation

In this paper, a Just-Pope type production function is used to model wheat pasture stocker cattle production risk. Just and Pope (1979) argued that the popular specifications of stochastic production functions are overly restrictive because they impose the *a priori* restriction that inputs increase risk. Just and Pope proposed an alternative specification of stochastic production functions which allows determining the effect of inputs on output variance independently of the effect on expected output.

In this paper, the choice of the deterministic term of the Just-Pope production function is essentially based on the usual production function properties (positive and decreasing marginal product expectations). For the stochastic component, it is assumed that the logarithm of the variance of weight gains is a linear function of the exogenous variables energy supplement, initial calf weight, and pounds of available forage[1]. In addition, given that time series and cross-sectional data are used, time effects are accounted for in the production function specification. In this case, time effects are assumed fixed, which implies the use of year dummy

[1]This is referred to as multiplicative heteroskedasticity because different components of the variance are related multiplicatively (Judge et al., p.365, 1988).

variables. The specified model is:

$$(6)\quad \ln(G_{it}) = \beta_0 + \beta_1\ln(INWT_{it}) + \beta_2\ln(PF_{it}) + \beta_3\ln(EN_{it}) +$$

$$\beta_4\ln(PF_{it})\ln(EN_{it}) + \sum_{t=1}^{T-1}\delta_t D_t + e_{it}$$

with

$$(7)\quad e_{it} = \epsilon_{it}h^{1/2}(Z_{it}, \alpha),$$

where G_{it} denotes daily rate of weight gain (lbs/head/grazing day), $INWT_{it}$ is the initial calf weight (lbs/head), EN_{it} is daily quantity of energy supplement fed (Mcal/grazing day), and PF_{it} is level of forage availability (lbs/steer day) on the i^{th} cross-sectional unit, in year t[2]. The error term, e_{it}, is normally distributed with mean zero and variance $h(Z_{it}, \alpha) = \exp(Z'_{it}, \alpha)$ (where $Z'_{it} = (1, INWT_{it}, EN_{it}, PF_{it}, D_t)$, with the D_t's representing year dummy variables), and ϵ_{it} is normally distributed with $E(\epsilon_{it}) = 0$ and $E(\epsilon^2_{it}) = 1$.

The model is estimated using maximum likelihood. Given the importance of the stochastic component in modeling production risk, it is useful to test the assumption that variance depends on the specified exogenous variables.

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[2]The amounts of forage available are calculated as:

$$PF = F * \frac{SD}{GDAYS},$$

where F is total forage production (lb/acre), SD is stocking densities (acre/head), and GDAYS is grazing days.

Test 1: Test for Multiplicative Heteroskedasticity[3]

H_0: $\alpha_1 = \alpha_2 = \alpha_3 = 0$

H_1: not all α_i's are zero, $i = 1, 2,$ or 3.

Similarly, the significance of time effects on mean and variance of weight gains is tested. The hypothesis concerning the significance of time effect on the mean is tested separately of the significance of time effect on output variance.

Test 2: Significance of Time Effect on Expected Weight Gain

H_0: $D_t = 0$, $t = 1, 2$

H_1: $D_t \neq 0$, $t = 1$ or 2.

Test 3: Significance of Time Effect on Variance of Weight Gains

H_0: $D_t = 0$, $t = 1, 2$

H_1: $D_t \neq 0$, $t = 1$ or 2.

A failure to reject the null hypothesis in test 1 would imply that the variability of weight gains does not depend on the specified exogenous variables. The null hypothesis in test 2 (test 3) should be rejected if time effects do not significantly affect the mean (variance of weight gains). All

[3]See appendix for proof. α_1, α_2, and α_3 are the parameter estimates of the independent variables $INWT_{it}$, EN_{it}, and PF_{it}, respectively, in the variance equation.

of the tests are carried out by using a Wald test (Judge et al., p. 106, 1988).

Determining Optimal Energy Supplementation Rates

Let average daily net returns per head be:

$$(8) \quad \pi_a = pG - 5.64 * r_s * EN - OC,$$

where G is the estimated production function, r_s is the feed price, and OC represents other costs incurred by grazing cattle on wheat pasture ($/day). EN, the daily quantity of energy supplement fed (Mcal/head), is calculated as (SCONS*SDAYS*0.39)/(2.2*GDAYS), where SCONS is the amount of supplements fed (lb/day), SDAYS is the number of days on feed, GDAYS is the number of grazing days[4]. Let SDAYS equal GDAYS; then, 5.64 represents a factor used to convert quantities of feed supplement to energy levels[5]. Define E(G) = f(EN, PF, INWT) and $h(Z_{it},\alpha)$ the deterministic and stochastic terms, respectively, of the Just-Pope production function. Under both cattle price and production risk, mean and variance of π_a are:

[4]The energy content of the high fiber ration used in the study is 0.39 Mcal/kg, and 2.2 is a conversion factor (lb/kg).

[5]Given EN is in Mcal/head/grazing day, 5.64*EN must be multiplied by 2.2 to obtain SCONS in lbs/grazing day.

$$(9) \quad E(\pi_a) = E(p) f(EN, PF, INWT) + \sigma_{pG} - 5.64 * r_s * EN - OC$$

$$\sigma^2(\pi_a) = [f(EN, PF, INWT)]^2 \sigma^2_\xi + [E(p)]^2 h(Z_{it}, \alpha) + \sigma^2_\xi h(Z_{it}, \alpha)$$

where σ_{pG} equals zero under the assumption that, for an individual stockman, the distributions of cattle prices and daily rates of weight gain are independent. Optimal energy supplementation decisions can be determined by maximizing the following objective function:

$$(10) \quad \underset{EN}{Max}\ CE[\pi_a(EN \mid PF)] = E(p) f(EN, PF, INWT) - 5.64 * r_s * EN - OC$$

$$-\frac{\lambda}{2}[[f(EN, PF, INWT)]^2 \sigma^2_\xi + [E(p)]^2 h(Z_{it}, \alpha) + \sigma^2_\xi h(Z_{it}, \alpha)$$

Energy supplementation levels (EN) are solved for three levels of expected forage availability: 11, 14, and 22 lb per steer day. These forage availability are reflective of low, moderate, and high levels of forage availability[6].

Data and Variable Transformation

Experimental Data

Time series and cross-sectional data from a grazing study

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[6]Estimation uncertainty is not accounted for in this analysis. Babcock (1992) argued that uncertainty is inherent in any estimated relationship. Estimation uncertainty is ignored when the marginal value product of any estimated production function (assuming that the estimated function is accepted as the "true" production function) is equated to the input price to determine optimal input use.

conducted by Oklahoma State University (OSU) animal scientists are used in this analysis. The experiment was conducted over three grazing seasons (1989-1990, 1990-1991, 1991-1992) at the OSU Wheat Pasture Research Facility in Marshall, Oklahoma. Four 40-acre pasture were allocated to one of three treatments: (1) a control (no supplement), (2) a high-starch supplement, or (3) a high-fiber supplement. The composition of energy supplements is reported in table 1. Stocking densities were increased from 2 to 1.5 acres/head (33% increase) on pastures where energy supplements were fed. The target level of consumption was set at 0.75 to 1 % of mean body weight.

Cross-bred steer calves grazed clean-tilled wheat pasture for 115, 107, and 84 days, during 1989-90, 1990-91, and 1991-92, respectively. Control calves received no supplement other than a free choice access to a commercial mineral. Supplemental cattle were hand fed the high-starch or high-fiber ration six days per week for 96, 100, and 69 days of the 1989-90, 1990-91, and 1991-92 grazing seasons, respectively. The 1989-1990 grazing experiment included a fourth treatment consisting of a high-fiber energy supplement ad libitum. All of the supplements contained monensim (40 mg/lb).

Data are forage available per steer day, quantities of feed supplements, initial calf weights, and final weights. Weight gains are calculated as final weights minus initial calf weights. The summary statistics for seasonal weight gains are presented in table 2. To account for differences in the quality of the alternative supplements, the quantity of each supplement fed is multiplied by its net energy for gain (Mcal/kg). Thus, average daily supplementation levels are expressed in net energy terms (Mcal/day). Seasonal weight gains are converted to daily weight gains since the number of grazing days and supplementation days are different within and across years.

Production costs and receipts are estimated for a representative stocker enterprise in central Oklahoma. Calves are purchased in November at 450 pounds and grazed through the fall-winter season (November - March) for 125 days. Operating costs (excluding the cost of the calf and supplemental feed) include expenses for veterinary medicine, hay, machinery and equipment, labor, and interest on operating capital. Operating costs total $49.75 over the grazing season or $0.40 per grazing day. The high-fiber ration is used to derive optimal energy supplementation levels.

Feed costs include the ingredient cost, a milling charge, and a delivery charge. Mineral expenses for the supplemented calves were included in supplement costs. The high-fiber ration is used to derive optimal energy supplementation levels. Feed costs were approximated at $0.07 per pound (Tarrant, 1993). To these costs were added a $0.01/lb cost of labor required to feed energy supplements (Tarrant, 1993). Therefore the total cost of energy supplement was $0.08/lb.

Optimal supplementation levels are determined for two other supplemental feed costs; \$0.04 and \$0.06/lb.

The cattle prices represent prices received over the past 17 years at the Oklahoma City Livestock Auction for No. 1 medium-framed steers. The purchase price of the calf is known with certainty by the producer at the beginning of the grazing season; therefore, price uncertainty results from volatility in the spread between the purchase and the selling price. The calf price is set at the average November price received (in real terms) for 400-500 pound calves. Cattle price spreads are then calculated as the difference between March and November cattle prices. The average calf price is then added to each of the price spreads to obtain the distribution of cattle sale prices. These prices are used to obtain the mean and variance of cattle prices used in the analysis.

The risk aversion coefficients are taken from table 1 of Raskin and Cochran (1986). The risk aversion coefficients range from 0 to 0.00125 for the class of almost risk neutral farmers and from 0.02 to 0.03 for the class of strongly risk averse farmers. Since these coefficients were elicited used for annual returns in the original study, they are scaled to reflect the unit of the outcome space used in this analysis (\$/day).

Empirical Results

The parameter estimates of the stochastic production function are reported in table 3. The signs of the estimated parameters of the deterministic term conform with the maintained hypotheses (positive and diminishing marginal product expectations over the relevant range of the sample data). The coefficient of the interaction term is negative, indicating a trade-off between level of forage availability and energy supplements. In addition, the model allows a good prediction of the observed weight gains; the squared correlation coefficient between the predicted and the observed weight gains is 0.89.

Table 4 summarizes the results of the specification tests. The null hypotheses of all of the three tests are rejected at the 2.5% level. These results imply that the variance of the error term is heteroskedastic and depends upon the levels of the specified exogenous variables. In addition, time effects significantly affect expected weight gain and also variance of weight gains.

For the stochastic term, the estimated coefficient of the energy variable is negative, indicating that energy supplement is a risk-reducing input. This result implies that energy supplement can be used to reduce weight gain variability. As a result, end-weight can be more accurately predicted and realistic break-even points can be calculated.

Economically optimal daily energy supplementation rates are reported in table 5 for alternative levels of risk aversion. Optimal supplementation levels are shown to be insensitive to risk preferences. For the moderate level of forage availability and low feed price, supplementation levels only slightly increase as the risk aversion coefficient increases. This relatively small change in supplementation levels may result from producers having a little control over the variance of weight gains (Babcock, 1992). Under average and high feed prices, optimal supplementation levels decrease as producers become more risk averse.

Decreasing optimal supplementation levels is contradictory with the fact that energy supplement is a risk-reducing input. However, as argued by Lambert (1992), this may occur because "effects of input reduction on expected yields, and consequently profit variance, outweighed the yield variance increases with reduced input use." (p. 236)[7]

Optimal supplementation levels were determined for three levels of forage availability. At a high level of forage availability (PF = 22 lb/steer day), supplementation levels

[7]To see why this might bet he case, consider the following comparative statics result:

$$c_{\lambda} = \frac{\partial^2 CE^*}{\partial EN \partial \lambda} = -\frac{1}{2}([E(P)]^2 + \sigma^2_{\xi})\frac{\partial h}{\partial EN} - \sigma^2_{\xi}\frac{\partial f}{\partial EN}f(EN, PF, INWT).$$

Since energy is risk-reducing, the first term is positive. The second term is negative since marginal products are positive. Thus, if the second term is greater than the first term (in absolute value), c_{λ} will be negative. That is, optimal supplementation rates will decrease with increasing risk aversion.

equal zero for the class of almost risk neutral producers, and only 0.04 lb/steer day for the strongly risk averse decision makers. Supplementation levels range between 1.14 and 2.68 lb/head/day at moderate levels of forage availability, depending on the feed costs and level of risk aversion. At low levels of forage availability, optimal supplementation levels increase to between 4.50 and 6.53 lb/head/day. Clearly, forage availability is a critical factor in determining optimal supplementation strategies, and energy supplements can be used to replace forage deficits.

In order to determine the impact of feed costs, optimal supplementation levels were determined for three feed costs. Under low forage availability, supplementation levels are at their upper limit when feed prices are at average ($0.06/lb) or low ($0.04/lb) levels[8]. Supplementation levels decrease over 1.5 lb/head/day from the upper limit when feed prices are increased to $0.08/lb. Under moderate forage availability, optimal supplementation levels range between 1.65 and 1.75 lb/head/day under average feed prices. Increase (decrease) in response to decrease (increase) feed costs average approximately 1.4 lb/head/day. These results illustrate the importance of feed costs in the adoption of supplementation programs. Producers employing supplementation programs must closely monitor feed costs to maximize the efficiency of

[8]Upper and lower bounds (0.526 and 0 Mcal per head, respectively) were placed on energy supplements. These bounds correspond to the range of energy supplements used in the experiment.

supplemental energy inputs.

Summary and Conclusions

This study has determined optimal supplementation practices for stocker cattle production on winter wheat pasture under both forage production risk and cattle price risk. A stochastic production function was used to model production risk. Energy supplements are determined to be risk-reducing inputs.

Optimal daily supplementation rates were only slightly sensitive to risk preferences. Supplementation levels were highly affected by forage supply conditions. At moderate forage availability levels, supplementation levels ranged between 1.14 and 2.68 lb/head/day; however, at low levels of forage availability, supplementation rates increased to between 4.53 and 6.53 but above 4.5 lb/head/day. Energy supplementation is not an economically efficient practice under high forage availability. Optimal supplementation levels are also sensitive to feed prices. Under moderate levels of forage availability, supplementation levels decrease (increase) by an average of 60% when feed prices increase (decrease) by $0.02 per pound. Producers must adjust supplementation levels to forage and feed cost conditions to efficiently incorporate energy supplementation in their wheat pasture stocker enterprise.

Table 1. Composition of Energy Supplements[1], Rations Fed in Wheat Pasture Supplementation Experiments, Marshall, Oklahoma[1].

Treatment	High Starch	High fiber
	--------- % As-fed	--------
Ground corn	78.94	
Soybean Hulls		46.94
Wheat Middlings	8.90	41.74
Molasses	4.95	4.95
Calcium Carbonate	1.75	1.50
Dicalcium Phosphate	0.60	
Micro-lite	4.15	4.15
Salt	0.65	0.65
Rumensin 60 Premix	0.07	0.07
Calculated Nutrient Content (As-fed basis)		
NEgain (Mcal/cwt)	52.80	39.3
Crude Protein (%)	8.20	11.50
Calcium (%)	0.89	0.89
Phosphorus (%)	0.44	0.53
Magnesium (%)	0.46	0.55
Monensin content (mg/lb)	40.00	40.00

[1]All supplements were fed as 3/16-inch pellets.

Table 2. Mean and Standard Deviation of Weight Gains (lb/head) for Control, High-Fiber, and High-Starch Supplemented Wheat Pasture Stocker Cattle (1989-90, 1990-91, 1991-92).

Feed Type	Mean	Standard Deviation
Control (No supplement)	236.92	39.42
High-Fiber	274.92	36.03
High-Starch	264.45	33.83

Table 3. Parameter Estimates of the Stochastic Production Function, Time Series and Cross-Section Data Over Three Grazing Seasons (1989-91, 1990-91, 1991-92)[1]

Dependent Variable	Independent Variable	Coefficient[2]	Standard Error
Log of Weight Gains	Constant	-13.841**	1.095
	ln(Energy)	1.482**	0.390
	ln(Forage)	0.038	0.042
	ln(In-Weight)	2.386**	0.181
	ln(ENERGY)* ln(FORAGE)	-0.546**	0.125
	D1	-0.166	0.028
	D2	-0.200	0.029
Log of Variance of Weight Gains	Constant	16.342**	4.657
	In-Weight	-0.044**	0.009
	Energy	-0.867*	0.693
	Forage	-0.059*	0.046
	D1	-0.144	0.602
	D2	0.878	0.630
R-Square Adjusted		0.84	
Number of Observations		45.00	

[1]D1 and D2 denote year dummy variables for 1989-90, 1990-91, respectively. Standard errors are in parentheses.

[2]Single asterisk denotes significant at the 10% and double asterisk significant at the 5%.

Table 4. Specification Test Results[1].

Null hypothesis	Test-statistic	Critical value at the 2.5% level
Variance does not Depend on Input Levels (Test 1)	28.026	9.348
No Time Effect on Mean (Test 2)	46.872	7.378
No Time Effect on Variance (Test 3)	8.690	7.378

[1]Under the null hypothesis, the Wald statistic is distributed chi-square with three degrees of freedom for test 1, and two degrees of freedom for tests 2 and 3.

Table 5. Optimal Energy (Mcal/head/day) and Feed Supplementation Rates[1] (lb/head/day) for Alternative Risk Aversion Levels and Feed prices (stocking density of 1.5 acre/head).

Feed Price ($/lb)	Almost risk neutral[2] λ = 0 Energy Feed	Almost risk neutral[2] λ = 0.5 Energy Feed	Strongly risk averse[2] λ = 7.3 Energy Feed	Strongly risk averse[2] λ = 11 Energy Feed
PF = 11 lb				
0.04	0.526 (6.53)	0.526 (6.53)	0.526 (6.53)	0.526 (6.53)
0.06	0.526 (6.53)	0.526 (6.53)	0.526 (6.53)	0.526 (6.53)
0.08	0.411 (5.10)	0.409 (5.07)	0.380 (4.72)	0.363 (4.50)
PF = 14 lbs				
0.04	0.216 (2.68)	0.216 (2.68)	0.223 (2.77)	0.228 (2.83)
0.06	0.141 (1.75)	0.141 (1.75)	0.136 (1.69)	0.133 (1.65)
0.08	0.105 (1.30)	0.104 (1.29)	0.097 (1.20)	0.092 (1.14)
PF = 22 lbs				
0.04	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.003 (0.04)
0.06	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.003 (0.04)
0.08	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.003 (0.04)

[1]Optimal feed supplementation rates are in parentheses.

[2]λ denotes the Arrow-Pratt absolute risk aversion coefficient. To obtain the quantities of feed supplements (lb/head/day), 5.64*EN is multiplied by 2.2 since EN is in Mcal/kg/day.

Appendix

Test for Multiplicative Heteroskedasticity

Consider the variance equation:

$$h_{it} = \exp(\alpha_0+\lambda^s{}_t) . \exp(\alpha_1 INWT_{it}) . \exp(\alpha_2 EN_{it}) . \exp(\alpha_3 PF_{it}) .$$

Letting $\exp(\alpha_0+\lambda^s{}_t) = \sigma^2$, then the variance equation becomes:

$$h_{it} = \sigma^2 \exp(Z^{*\prime}{}_{it}\alpha^*)$$

$$= \sigma^2 \Psi = diag(\exp(Z^{*\prime}{}_{1t}\alpha^*),\ \exp(Z^{*\prime}{}_{2t}\alpha^*), \ldots, \exp(Z^{*\prime}{}_{nt}\alpha^*)),$$

where $Z^{*\prime}{}_{it} = (INWT_{it}, EN_{it}, PF_{it})$, $\alpha^* = (\alpha_1, \alpha_2, \alpha_3)'$. If $\alpha^* = 0$, the variance equation reduces to $h_{it} = \sigma^2 I$ (where I is the identity matrix), which implies homoskedasticity. Thus, test 1 is a test for multiplicative heteroskedasticity ($\alpha^* = 0$ against $\alpha^* \neq 0$).

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PAPER III

OPTIMAL ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER FORAGE PRODUCTION UNCERTAINTY

OPTIMAL ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER FORAGE PRODUCTION UNCERTAINTY

Abstract

This study uses numerical integration with Guassian-quadrature to determine economically optimal energy supplementation levels for stocker cattle growing on wheat pasture. Under high cattle price scenario and low feed prices, optimal energy supplementation levels increase over 1 lb/head/day as risk preferences change from risk neutrality to a high level of risk aversion. At low feed prices, cattle should be fed more energy supplements if cattle price movements over the grazing period are favorable. At high feed prices and unfavorable cattle price conditions, cattle should not be fed energy supplements.

OPTIMAL ENERGY SUPPLEMENTATION STRATEGIES FOR WHEAT PASTURE STOCKER CATTLE UNDER FORAGE PRODUCTION UNCERTAINTY

Introduction

A common practice in the Southern Plains is grazing stocker cattle on winter wheat pasture during the vegetative stage of growth. Grazing stocker cattle on winter wheat pasture has been one of the most profitable cattle enterprise available to Oklahoma stockmen during the last two decades (Bernardo and Wang, 1991). However, returns from grazing stocker cattle on winter wheat pasture are also very volatile due to several factors, most notably, production uncertainty.

Production risk emerges in that rates of weight gain are uncertain due to volatile weather and forage supply conditions. Because wheat pasture stocker production occurs in the fall-winter period (November-March), considerable variability in forage supplies can occur. Inadequate soil moisture in the fall, prolonged winter dormancy, or extended periods of snow cover can greatly reduce forage availability. Fall-winter forage production observed in the last five years has ranged from less than 100 pounds per acre to over 4000 pounds per acre (Krenzer et al., 1992).

Recently, the use of energy supplements has been proposed as a means of reducing production risk of growing cattle on winter-wheat pasture (Horn et al., 1991). Supplemental energy provides a means of improving the balance between nitrogen and energy supply from wheat forage, and hence, improves cattle performance. When a supplemental energy ration is fed, an ionophore such as monensin can also be fed. Monensin reduces the incidence and incidence of bloat from wheat pasture (Branine et al., 1990). However, feed supplements are costly, and their inefficient use can reduce profitability. The objective of this study is to determine economically optimal energy supplementation levels under conditions of uncertain forage production. Since farmers' risk attitudes may affect the adoption of energy supplementation programs, the effect of risk aversion on optimal energy supplement levels is also investigated.

A decision model is developed that accounts for the probability density function of forage production. A beta density function is fit to the forage production data. Gaussian quadrature points are obtained for the beta density function with numerical integration procedures. These results are used to determine optimal daily energy supplementation rates. Because stocker cattle producers have not yet readily adopted supplementation programs, the economic cost of not adopting a supplementation program is also determined. These results should prove beneficial to stockmen faced with uncertain wheat pasture stocker cattle production.

Theoretical Model

Several approaches for modeling decision making under risk have been proposed. One approach is the Just and Pope stochastic production function. Certainty equivalent models have also been proposed; however, these models assume normally distributed returns, and thus ignore the effects of higher order moments. Alternatives to the above approaches are methods which explicitly include probability density functions for the stochastic variables. Dai et al. (1993) used this latter approach to determine the effects of soil moisture on optimal nitrogen use. However, their specification of the decision problem assumed risk neutrality, and thus did not evaluate the effects of risk preferences on optimal input levels.

In this paper, a model is developed which explicitly accounts for the random variability of forage production. Because risk preferences may affect optimal input decisions, stockmen are assumed to maximize expected utility. It is further assumed that, at the beginning of the grazing season, the stocking density is known when calves are purchased. However, amounts of forage available during the rest of the grazing season are not known. Producers may feed cattle supplemental energy as a response to declining forage availability. Thus, the producer's economic decision problem is to choose a quantity of energy supplement that maximizes expected utility of profit. Given that profit is a function of the random forage variable, the expected utility of profit can be obtained by integrating utility over the entire range of forage production. The decision problem is:

$$(1) \quad \underset{EN}{MaxE}[U(\pi)] = MaxE[U(p*G(EN,PF) - r_e*EN - OC)]$$

$$= MAX \int_a^b U(p*G(EN,PF) - r_e*EN - OC)\,\varphi(PF)\,dPF$$

where U is a Von-Neuman utility function, E is the expectation operator, EN is the daily quantity of energy supplement (Mcal/head), PF is the amount of forage available (pound per steer day), OC denotes other costs, r_e is the unit cost of energy supplement ($/Mcal), p is the expected cattle price ($/lb), G(EN, PF) is the estimated stocker-cattle production function, and φ(PF) is the probability density function of stochastic forage production. Supplement prices are assumed known at the beginning of the grazing season. Cattle price expectations are based on the past 17 years of price spreads between November calves and May feeders.

Procedures

A production function is estimated using experimental data from a three year project designed to evaluate alternative supplementation programs for wheat pasture stocker

The beta density is chosen to represent the distribution of forage production. For estimation, the forage production data is scaled from zero to one (0 < PF < 1). The beta density function is expressed as (Mood, Graybill, and Boes, 1974):

$$(3) \quad \varphi(PF) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} PF^{\alpha-1}(1-PF)^{\beta-1}, \; 0 < PF < 1$$

where $\Gamma(.)$ is the gamma function defined as:

$$(4) \quad \Gamma(x) = \int_0^{\infty} x^{t-1}e^{-t}dt.$$

The two parameters α and β are estimated by maximizing the log of the likelihood function[2]:

$$(5) \quad \underset{\alpha,\beta}{Max}\; LogL = (\alpha-1)\sum_t \log(PF_t) + (\beta-1)\sum_t \log(1-PF_t) + N\log\Gamma(\alpha+\beta)$$

$$- N\log\Gamma(\alpha) - N\log\Gamma(\beta), \quad s.t.\; \alpha > 0,\; \beta > 0.$$

[2]The log of the likelihood function is:

$$\log L = \sum_t^N l_t$$

where:

$$l_t = (\alpha-1)\log(PF_t) + (\beta-1)\log(1-PF_t) + N\log\Gamma(\alpha+\beta) - N\log\Gamma(\alpha) - N\log\Gamma(\beta).$$

is the log-density for observation t.

The producer's problem expressed in equation (1) requires choosing the energy supplement level (lb/day) which maximizes expected utility of average daily net returns. Assuming a negative exponential utility function, the maximization problem can be written as:

$$(6) \quad \underset{EN}{Max} E[U(\pi_a(EN, PF))] = Max \int_{\Omega} [1 - e^{-\lambda * \pi_a(EN, PF)}] \varphi(PF) dPF,$$

where λ is the Pratt-Arrow risk aversion coefficients, Ω is the support of PF, and π_a(EN, PF) denotes average daily net returns per head, defined as:

$$(7) \quad \pi_a = p*G(EN, PF) - 5.64*r_s*EN - OC,$$

where G(EN, PF) represents the estimated production function. The value 5.64 is a conversion factor used to convert the daily quantity of energy supplement (Mcal/head) to a supplemental feed quantity (lb/head), and r_s ($/lb) is the unit cost of supplemental feed[3].

The integral in equation (6) is approximated using the Gaussian quadrature method of numerical integration (Preckel and DeVuyst, 1991). Let utility of average daily net returns

[3] EN = (SCONS*SDAYS*0.39)/(2.2*GDAYS), where SCONS is feed supplement (lb/day), SDAYS is supplementation days, and GDAYS is grazing days. Letting SDAYS equals GDAYS, SCONS = 5.64*EN. Thus, daily supplementation costs are calculated as r_s*5.64*EN; r_s is now the supplemental feed cost ($/lb), rather than energy supplement cost ($/Mcal), r_e, as defined in equation (1)

be represented by Φ(EN, PF), then expected utility of π_a can be expressed as:

$$(8) \quad E[U(\pi_a(EN, PF))] = \int_0^1 \Phi(EN, PF)\,\varphi(PF)\,dPF = \sum_{i=1}^{n} \omega_i \Phi(EN, PF_i),$$

where the PF_is are the Gaussian quadrature points and the ω_is are the associated weights. Nine Gaussian quadrature points and associated weights are determined using the procedure of Preckel and DeVuyst (1991). To determine if the nine points are sufficient to give a good approximation of the integral, the solutions obtained with the Gaussian quadrature approximation (in terms of the values of the maximized expected utility) were compared to the solutions obtained using a more accurate numerical integration routine in Maple V. The percentage error between the two solutions was approximately zero.

The objective function to be maximized is:

$$(9) \quad \underset{EN}{Max}\, E[U(\pi_a(EN, PF))] = \underset{EN}{Max} \sum_{1}^{9} \omega_i [1 - e^{-\lambda \pi_a(EN, PF_i)}].$$

The maximum of equation (9) is found with the GAMS/MINOS software package. Given that PF was scaled from zero to one for the estimation of the beta distribution, the Gaussian-quadrature points are scaled to match the forage production data.

Under risk neutrality, the objective would be to maximize expected average daily net returns:

$$(10) \quad \underset{EN}{Max}\, E[\pi_a(EN,\ PF)] = \underset{EN}{Max} \sum_{1}^{9} \omega_i [\pi_a(EN, PF_i)] \, .$$

Data and Variable Transformations

Data were obtained at the Oklahoma State University Wheat Pasture Research Facility in Marshall, Oklahoma from a project designed to evaluate a grain-based, high-starch energy supplement versus a high-fiber energy supplement for growing cattle on wheat pasture. The experiment was conducted over three grazing seasons (1989-90, 1990-91, 1991-92). Control cattle received no supplement other than free-choice access to a commercial mineral mixture. The other cattle were hand-fed either a corn-based energy supplement (i.e., high-starch supplement) or a high-fiber energy supplement that contained about 47% soybean hulls and 42% wheat middlings (as-fed basis). Composition of the supplements is shown in table 1. All of the supplements contained monensin (about 40 mg/lb). The target level of consumption was .75 to 1% of mean body weight. The 1989-90 grazing experiment also included a fourth treatment consisting of a high-fiber energy supplement *ad libitum*.

Each treatment was randomly assigned to four 40-acre pastures in each of the three years. Fall-weaned steer calves were randomly allocated to the appropriate number of grazing groups based upon breed and initial weight. The number of head comprising each group varied by treatment and year. In 1989-90 and 1991-92, stocking densities were 2.0 ac/head for control cattle and 1.5 acre/head for supplemented cattle; in 1990-91, control and supplemented cattle were each allocated to three stocking densities (2.0, 1.64, and 1.38 acre/head). Fall-weaned crossbred steer calves grazed clean-tilled wheat pasture for 115, 107, and 84 days, during 1989-90, 1990-91, and 1991-92, respectively. Supplemented steers received supplemental feed for 96, 100, and 70 days, during the 1989-90, 1990-91 grazing seasons, respectively. For a additional detail of the experimental procedures, see Horn et al. (1991).

Time-series and cross-sectional data on pounds of forage available per steer day, quantities of feed supplements, initial calf weights, and final weights are used to estimate the steer weight gain production function. Weight gains are calculated as final weights minus initial calf weights. The summary statistics for seasonal weight gains are presented in table 2.

To account for differences in the quality of the alternative supplements, the quantity of each supplement fed is expressed in net energy terms (Mcal/grazing day). That is, the quantity of each supplement fed per day (in pounds) is multiplied by its energy content (Mcal/pound) and the number of days of supplementation. The value obtained is the total amount of energy fed (Mcal/head) during the fall-winter grazing season (November-March). The total amount of energy fed is then divided by the number of grazing days to obtain the average quantity of net energy fed (Mcal/grazing day). This procedure accounts for the fact that the number of grazing and supplement days are different across and within the three years of the grazing experiment.

Twenty years of simulated seasonal forage production data are used to estimate the beta density function. The simulated biomass levels (combined weight of leaves and stems) is estimated using the CERES-wheat process growth model. Historical weather data (1971-1990) and soil data from Kingfisher, Oklahoma are used. The seasonal forage production data is converted to daily quantities of forage supplied assuming a grazing season of 125 days. The forage availability per steer day (PF) is then calculated for the stocking density of 1.5 acre/head[4].

Production costs and receipts are calculated for a representative stocker enterprise in central Oklahoma. Calves

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[4]A stocking density of 1.5 acre/head is the recommended level of stocking density to be used in conjunction with a supplementation program (horn et al., 1991).

are purchased in November at a weight of 450 pounds and grazed through the fall-winter season (November-March) for 125 days. Operating costs (excluding the cost of the calf and supplemental feed) total $49.75 over the grazing season or $0.40 per grazing day. Optimal supplementation levels are derived for the high-fiber energy supplement.

Feed costs include the ingredient cost, a milling, and a delivery charge. Mineral expenses for the supplemented calves were included in supplement costs. Feed costs were estimated as $0.07/lb. To these costs were added a $0.01/lb cost of labor required to feed energy supplements (Tarrant, 1993). Optimal supplementation levels are determined for two other supplemental feed prices; $0.04 and $0.06/lb.

The cattle prices represent average prices received over the past 17 years at the Oklahoma City Livestock Auction for No. 1 medium-framed steers. The purchase price of the calf is known with certainty by the producer at the beginning of the grazing season; therefore, price uncertainty results from volatility in the spread between the purchase and the selling price. The calf price is set at $0.91/lb, the average November price received (in real terms) for 400-500 pound calves over the 17 years period. Cattle price spreads are then calculated as the difference between March and November cattle prices. The average calf price is then added to each of the price spreads to obtain the distribution of cattle sale prices. These prices are used to obtain the three cattle price scenarios used in the analysis (low, average, and high). The low and high price scenarios are calculated as the average of the four lowest and highest cattle price spreads. The average price scenario is calculated as the mean of the cattle price spreads. Low, average, and high cattle prices are 0.65, 0.79, and $0.94/lb, respectively.

The risk aversion coefficients are taken from table 1 of Raskin and Cochran. The risk aversion coefficients range from 0 to 0.00125 for the class of almost risk neutral farmers and from 0.02 to 0.03 for the class of strongly risk averse farmers. Since in the original study these coefficients were used for annual returns, they are scaled to reflect the unit of the outcome space used in this study ($/day).

Empirical Results

Maximum likelihood parameter estimates of the production function are presented in table 3. The estimated coefficients are significant at the 5% level, except the interaction term. The coefficient of the interaction term is negative, indicating a trade-off between forage availability and energy supplement. The mean, variance, and skewness of the wheat forage distribution are 18, 70.3, and -26.5, respectively. The estimated parameters of the beta density function indicates that the distribution of forage production is asymmetric[5].

Figure 1 illustrates three energy-forage isoquants, showing possible energy-forage availability combinations for obtaining a targeted average daily gain. These combinations are used to analyze the substitutability between energy and forage. For example, 2.2 lbs of daily gain can be obtained by feeding either 0.01 Mcal/day of supplemental energy with 19 lbs of forage available per steer day or 0.31 Mcal/day of supplemental energy when 15 lbs of forage per steer day are available. The isoquant map also illustrates the marginal contribution of supplementation. Holding PF constant at 19 lbs/day, daily gain is increased by 0.1 lbs/day as a result of increasing supplementation rates from 0.01 to 0.18 Mcal/day. An additional 0.45 Mcal/day of supplemental energy is required to increase daily gain another 0.1 lbs/day. Also, supplementation is required to achieve weight gains of 2.4 lbs/day. Even at high levels of forage availability (e.g. 25 lbs/day), 0.14 Mcal/day of supplemental energy are required to reach this level of animal performance. Economically optimal energy supplementation levels are presented below.

Economically optimal energy supplementation rates are reported in table 4. These optimal energy supplementation rates were determined for alternative levels of risk aversion in order to evaluate the effects of risk preferences of

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[5]The parameter estimates of the beta distribution function are 1.16, and 1.26 and their standard errors are 0.341 and 0.375, respectively.

optimal quantities of energy supplements. Optimal supplementation levels increase as the risk aversion increases, indicating that a more risk averse producer would supplement more than a less risk averse producer. However, increases in the optimal supplementation levels are small. Optimal daily supplementation rates only increase 0.45 lb/head in moving from almost risk neutral to strongly risk averse preferences. This is probably because producers do not have a large amount of control over the variance and higher order moments of cattle weight gains distributions (Babcock, 1992).

Optimal supplementation levels were determined for three alternative feed price scenarios and three cattle prices (low, average, and high). Supplementation levels are highly affected by changes in feed prices. Under average cattle price conditions, optimal supplementation rates increase (decrease) approximately 2 lb/day as a result of a $0.02 decrease (increase) in feed costs. Optimal supplementation levels are also sensitive to cattle price conditions. Under average and high cattle price scenarios, optimal supplementation levels are close to yield maximizing input levels, when the feed price is low ($0.04/lb). Under the low cattle price scenario, optimal supplementation levels are below 5 lb/head/day, regardless of feed prices. Supplementation levels are zero when high feed prices are combined with low cattle prices. At this price ratio, the marginal value product of energy supplement does not cover the

Summary and Conclusions

This study has determined optimal supplementation practices for stocker cattle production on winter wheat pasture. A stocker cattle decision model was developed that explicitly accounts for the probability density function of stochastic forage production. The producer's expected utility maximizing decision problem was solved with Gaussian quadrature numerical integration and nonlinear programming.

Optimal supplementation levels were determined for alternative risk aversion levels. Optimal supplementation levels increase as risk aversion increases. Expected seasonal returns for the supplemented cattle were greater than expected seasonal returns for the unsupplemented cattle. Supplementation levels were highly affected by changes in cattle prices. Cattle should be fed more energy supplements when feed prices are low and cattle price movements favorable over the grazing period. Results also indicated that it is not optimal to feed cattle energy supplements under low cattle price and high feed price conditions.

Table 1. Composition of Energy Supplements, Rations Fed in Wheat Pasture Supplementation Experiments, Marshall, Oklahoma[1].

Treatment	High Starch	High fiber
	-------- % As-fed --------	
Ground corn	78.94	
Soybean Hulls		46.94
Wheat Middlings	8.90	41.74
Molasses	4.95	4.95
Calcium Carbonate	1.75	1.50
Dicalcium Phosphate	0.60	
Micro-lite	4.15	4.15
Salt	0.65	0.65
Rumensin 60 Premix	0.07	0.07
Calculated Nutrient Content (As-fed basis)		
NEgain (Mcal/cwt)	52.80	39.3
Crude Protein (%)	8.20	11.50
Calcium (%)	0.89	0.89
Phosphorus (%)	0.44	0.53
Magnesium (%)	0.46	0.55
Monensin content (mg/lb)	40.00	40.00

[1]All supplements were fed as 3/16-inch pellets.

Table 2. Mean and Standard Deviation of Weight Gains (lb/head) for Control, High-Fiber, and High-Starch Supplemented Wheat Pasture Stocker Cattle (1989-90, 1990-91, 1991-92).

Feed Type	Mean	Standard Deviation
Control (No supplement)	236.92	39.42
High-Fiber	274.92	36.03
High-Starch	264.45	33.83

Table 3. Parameter Estimates of the Production Function, Time Series and Cross-Section Data Over Three Grazing Seasons (1989-90, 1990-91, 1991-92)[1].

Variables	Method of estimation: OLS	MLE
Intercept	-6.3532	-6.2971*
	(0.6962)	(0.6721)
In-Weight	0.0163	0.016*
	(0.0011)	(0.0011)
Energy	0.6832	0.6884*
	(0.3752)	(0.3233)
Forage	0.0983	0.1041*
	(0.0034)	(0.0277)
$(\text{Energy})^2$	-0.5013	-0.4456*
	(0.2430)	(0.2169)
$(\text{Forage})^2$	-0.0181	-0.0019*
	(0.0007)	(0.0006)
Energy*Forage	0.0006	-0.0017
	(0.0125)	(0.0109)
D1	-0.3847	-0.3773
D2	-0.4873	-0.4724
Estimated Variance		0.058
Glejser Stat.	15.788	
R^2-Adjusted	0.943	0.940
Number of Observations		45

[1]Standard errors are in parentheses and asterisks denote significant at the 5% level.
D1 and D2 represent dummy variables for period 1989-90 and 1990-91, respectively. Independent Variable: Daily Weight Gains (lb/head).

Table 4. Optimal Energy (Mcal/head/day) and Feed Supplementation Rates (lb/head/day) for Alternative Risk Preferences, Stocking Density of 1.5 acre/head[a]

Feed Price ($/lb)	Almost Risk Neutral[b] $\lambda = 0$ Energy Feed	Almost Risk Neutral[b] $\lambda = 0.5$ Energy Feed	Strongly Risk Averse[b] $\lambda = 7.3$ Energy Feed	Strongly Risk Averse[b] $\lambda = 11$ Energy Feed
Low Cattle Price				
0.04	0.341 (4.23)	0.343 (4.26)	0.375 (4.65)	0.379 (4.70)
0.06	0.146 (1.81)	0.148 (1.84)	0.180 (2.23)	0.183 (2.27)
0.08	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)	0.000 (0.00)
Average Cattle Price				
0.04	0.411 (5.10)	0.414 (5.14)	0.447 (5.55)	0.449 (5.57)
0.06	0.251 (3.11)	0.253 (3.14)	0.287 (3.56)	0.289 (3.59)
0.08	0.090 (1.11)	0.093 (1.15)	0.126 (1.56)	0.128 (1.59)
High Cattle Price				
0.04	0.461 (5.72)	0.464 (5.76)	0.499 (6.19)	0.500 (6.20)
0.06	0.326 (4.05)	0.329 (4.08)	0.363 (4.50)	0.365 (4.53)
0.08	0.191 (2.37)	0.194 (2.41)	0.228 (2.83)	0.229 (2.84)

[1]To obtain the quantities of feed supplement in lb/grazing day, 5.64*EN is multiplied by 2.2, since EN is in Mcal/kg/grazing day. Optimal feed supplementation levels are in parentheses.

[2]λ is the Arrow-Pratt absolute risk aversion coefficient.

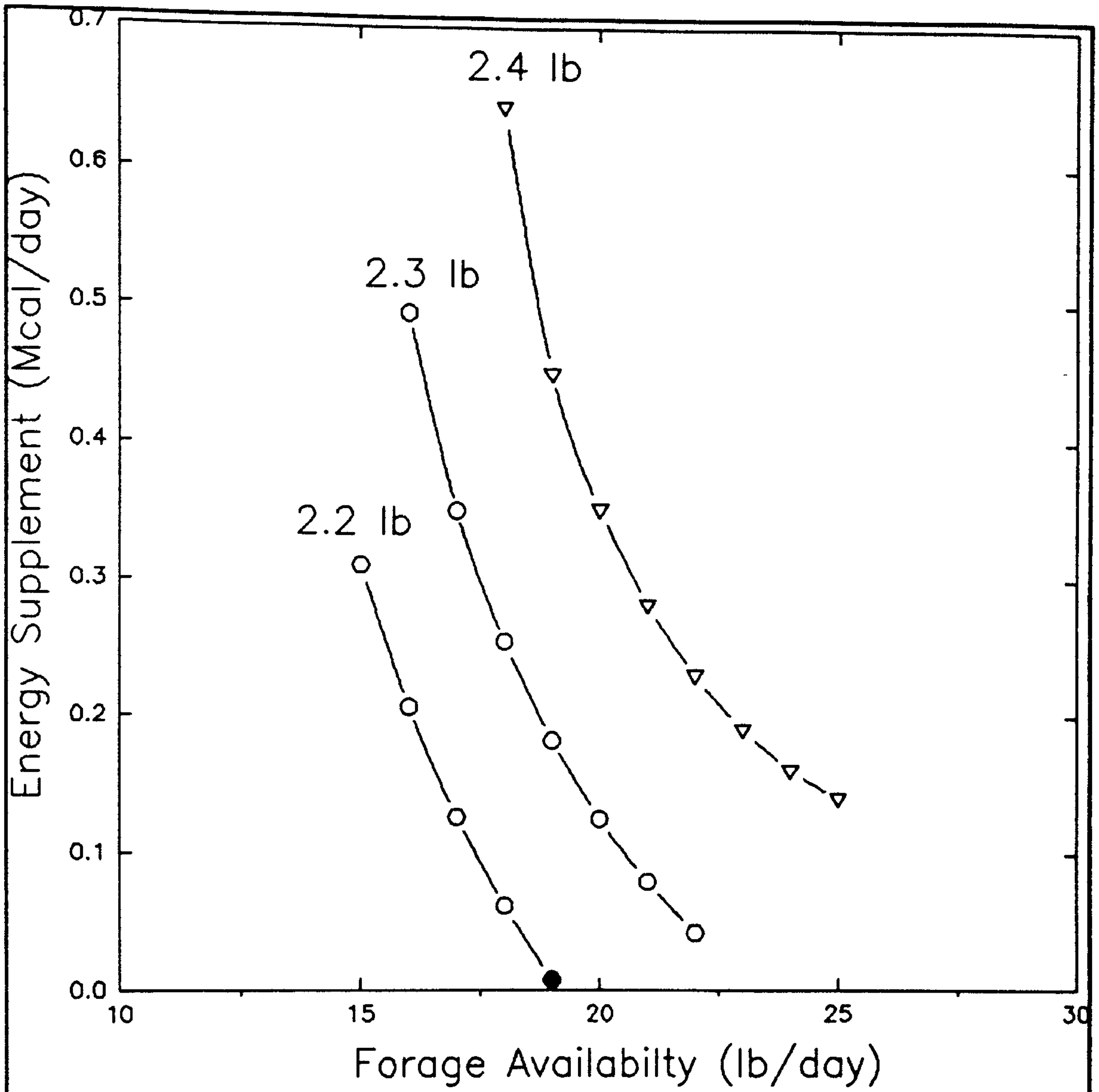

Figure 1. Daily Weight Gain Isoquants, Quadratic Production Function

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