MANAGEMENT STRATEGIES FOR DUAL-PURPOSE WINTER WHEAT PRODUCTION

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PREFACE

This thesis contains three essays, covering important management strategies in dual-purpose winter wheat production. The first paper evaluates the effect of lime, phosphorus and wheat variety in ameliorating acid soil conditions when wheat is grown for grain and grazing. These effects are further evaluated under different cropshare contracts and payment options for covering the cost of lime. The second paper uses standardized grazing inputs to determine the physical and economically optimum stocking densities in dual-purpose winter wheat production. The third paper describes and evaluates management practices in dual-purpose wheat production. The conclusions reached have meaningful implications to wheat farmers in Oklahoma and beyond.

I wish to extend my sincere appreciation to my major advisor, Dr Francis Epplin, for his patience and constructive guidance. I am indebted to the other members of my advisory committee, Drs B. Wade Brorsen, R. Joe Schatzer, and Eugene Krenzer, Jr. for the many useful suggestions and criticisms. Special thanks to Drs Krenzer and Gerald Horn for providing the data for these studies, the Department of Agricultural Economics for providing financial support, and Drs Larry Sanders, Brian Adam, Merritt Taylor and Raleigh Jobes for their support. This work is dedicated to my family and friends for their many sacrifices.

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ABSTRACT

After decades of continuous cropping, the pH of many soils used to produce continuous winter wheat (*Triticum aestivum* L.) in the southern plains of Oklahoma have declined to levels that limit wheat grain and forage yield. The objective of this research is to determine the effect of lime and diammonium phosphate application on both fall-winter forage yield and grain yield of winter wheat grown in acid soil. Economic analyses were conducted to determine the economically optimal strategy for dual-purpose wheat production under different crop-share contracts. When lime costs were fully assessed in one year, among the multiple optimal strategies was one that applies 65 lb/ac DAP in seed furrow without lime. When lime costs were amortized over a 5-year period one of the optimal strategies was to broadcast lime and apply DAP in seed furrows. These optimal strategies were statistically indistinguishable from a group of other strategies. Generally, crop-share contracts did not influence the choice of optimal strategy.

ECONOMICALLY OPTIMAL SOIL PH MANAGEMENT STRATEGIES IN DUAL-PURPOSE MONOCULTURE WHEAT PRODUCTION UNDER VARYING LAND CROP-SHARE CONTRACTS

I.1. Introduction

Wheat is a major food grain in the United States. It has been consistently ranked among the top four United States field crops in both planted acreage and value of production, along with hay, corn and soybeans. Depending on the season in which it is cultivated, wheat may be classified as winter wheat or spring wheat. Nearly 80 percent of total United States wheat production consists of winter wheat. In Oklahoma, The United States Department of Agriculture estimates that in 2000 nearly 6.1 million acres of winter wheat were cultivated, of which about 4.2 million were harvested for grain. Among the major classes of winter wheat, hard red winter wheat accounts for nearly 40 percent of total production, and is grown primarily in the Great Plains, a region that stretches from Texas through West Central Oklahoma to Montana. In this region wheat is produced either for forage, forage and grain, or grain alone. Some surveys (eg. Epplin, True and Krenzer; Pinchak et al.,) have concluded that up to two-thirds of all wheat is grown for forage and grain. This makes dual-purpose wheat production the most important wheat production concept in the state of Oklahoma. Epplin, True and Krenzer surveyed wheat production in Oklahoma, while Pinchak, et al., surveyed wheat production in the Southern Great Plains.

When wheat is cultivated for forage and grain, among the strategies available to the farmer are the cut-and-carry system[1], and conventional grazing. The cut-and-carry system is a flexible but high cost system that results in high production per head; it allows the farmer to directly determine monetary revenues obtained from grazing. If the farmer chooses conventional grazing, livestock may graze the pasture up to the point where the first hollow stem develops. Some studies (eg. Redmon et al.) show that wheat yield, and net revenues will significantly decline if grazing continues beyond the presence of first hollow stem.

Wheat in the United States has been intensively monocropped in an area known to be highly subject to the process of soil acidification. According to Johnson, Zhang and Krenzer, approximately 39 percent of Oklahoma wheat fields have soils with a pH below 5.5. An earlier but similar survey of Oklahoma fields cropped continuously to winter wheat found that more than 30 percent of 17,000 samples had a pH less than 5.5 (Johnson et al.). Historically, soil pH was sufficiently high that it did not limit wheat grain and forage yields. After years of continuous cropping, pH has declined in many fields to levels that may be limiting grain and forage yields. Farmers and landowners in the region have limited experience with managing dual-purpose wheat in low pH soils. The economic effects resulting from ensuing low wheat yields can be adverse.

Among the reasons cited for soil acidity, is the accumulated effect of soil nutrient removal by high-yielding crops such as wheat. Wolf suggests that the average wheat grain harvest of 45 bushels removes approximately 63 lb of potassium, 15 lb of calcium

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[1] Heavily practiced by Asian farmers, cut-and-carry describes the system of harvesting forage and transporting it to steers in pens that are located away from pastures, for feeding purposes, in appropriate amounts and intervals to effect maximum growth.

and 27 lb of magnesium. This condition is often exacerbated with the application of acid-forming fertilizers such as ammonium nitrate, diammonium phosphate, and urea. Other reasons include leaching of cations from surface soils, and organic matter decomposition. In the end, low soil pH conditions do not only decrease the availability of important nutrients such as nitrogen and phosphorus, but also increase the availability of toxic elements such as aluminum and manganese.

The risks associated with cultivating depleted or highly toxic lands, and the resulting yields have important implications for tenancy. The yields obtained from such lands are generally low, therefore the risk averse farmer would be unwilling to assume a larger proportion of input costs even if he gets the same proportion of output. Share contracting is widely practiced among United States farmers. However, Allen and Lueck opine that relatively little is known about them, especially in relation to sharing input costs. According to Cheung, risky crops should be sharecropped while stable crops should be cash rented. But Eswaran and Kotwal suggest that the concept of risk sharing as the motivation behind sharecropping lacks empirical support. They conclude, in a study of contractual structure in agriculture, that the factor share is relatively insensitive to variation in technology and market characteristics across different regions.

Some studies, eg Bliss and Stern, and Eswaran and Kotwal, suggest that the choice of factor share may be rooted in tradition and equity. But Allen and Lueck who could not support risk as a reason for sharing, instead, suggest that the decision to share may be best explained by contract enforcement costs. Their model is a variant of the principal-agent model postulated by Stiglitz, which suggests a risk-neutral landowner leasing land to a risk-averse farmer. Instead, they assume that both the landowner and the farmer are risk neutral, even though uncertainty remains as a major component of the model. Hence farmers and landowners would participate in crop share contracts to maximize the value of exchange.

Low Soil pH Amelioration Strategies

In most regions where soil acidity is a problem, the typical economical solution is to apply agricultural limestone. Field experiments have demonstrated that lime application changes the soil pH over time, and helps to remove negative effects of soil acidity for a number of years (Coventry et al,; Krenzer and Westerman).

In many cases, lime is applied to ameliorate soil acidity by increasing soil pH. The active ingredient in lime is the Effective Calcium Carbonate Equivalent, ECCE. Johnson, Zhang and Krenzer suggest that the most commonly used material is agricultural limestone, which is relatively inexpensive and easy to manage. Agricultural limestone is not very corrosive to machinery and other equipment, nor does it have a harmful effect on crop yield even when applied in high amounts. If wheat is the only cultivated crop, it may be economical to apply just enough lime to raise the soil pH to 5.5. In very low soil pH conditions the effect of liming is evident within a very short period.

Lime does not contain primary nutrients and is classified as a soil amendment rather than a fertilizer. Unlike many fertilizers, lime has a strong carryover effect. So, lime is an investment that produces benefits for many years into the future. For farmers who own their own land (owner operators) lime application may be the most practical solution to the problem. However, many wheat producers in Oklahoma do not own their land.

Nearly 60% of the wheat produced in Oklahoma is on leased land. About 80% of the leases are oral contracts and 80% are annual leases (True et al., p. 23). Farmers who have only a one-year lease on land are expected to be very reluctant to pay for the cost of lime that has long-term benefits. These farmers may be interested in alternative approaches, other than liming, to producing wheat in low pH soils. Alternatives that have been proposed are to apply phosphorus in the seed furrows and to seed tolerant varieties. The major cause of crop failure in extremely acid Oklahoma soils is aluminum toxicity (Boman et al.). Application of phosphorus reduces metal toxicity in the vicinity of the plant roots; when applied in the seed furrow, phosphorus becomes more readily available to the crop (Johnson et al.). Current tolerant wheat varieties at Oklahoma State University produce some grain in soils with pH values as low as 4.0 (Johnson, Zhang and Krenzer).

Whether or not it is economically optimal to cultivate some acid-tolerant wheat varieties, or apply lime, or apply phosphates, or undertake some combination of the aforementioned is the object of this study. Prior studies have considered wheat grain yield response to pH (Mahler and McDole; Johnson et al.). However, none has simultaneously evaluated the alternative management strategies of lime application and phosphorus banding for dual-purpose winter wheat production on extremely acid soils. Are dual-purpose wheat forage and grain yields different across the different strategies? What is the economically optimal strategy for an (a) owner-operator, (b) farmer with a cash lease, and (c) farmer with a share-lease? This research will answer these questions.

Objectives of the Study

The objective of this study is to determine the economically optimal soil pH management strategies for farmers who own their land and for tenant farmers who produce dual-purpose wheat in Oklahoma. Strategies to be considered include seeding tolerant varieties, application of lime, application of phosphorus in seed furrows, and broadcast application of phosphorus. In addition, this study determines whether the choice of sharecropping contract would lead to a change in the landowner and the tenant farmer's choice of optimal soil pH management strategy.

It is envisaged that the application of lime, or diammonium phosphate or any combination thereof, to a susceptible or tolerant wheat variety would lead to significantly higher wheat grain and forage yields. This in turn would lead to higher net returns depending on the market price structure for all outputs and inputs. Amortizing the cost of lime should make it more affordable by reducing its relative cost to the farmer. The persistent effect of lime implies benefits to the farmer beyond the year of application. Amortization is an attractive option that allows the farmer to equally split up the principal costs of lime over the years in which the benefits accrue. The farmer would be less likely to select a high cost strategy if he bears a disproportionate fraction, unless perhaps under a share contract that gives him the same proportion of output.

The Field Experiments

The experiments constituted two trials: the winter wheat variety trial and the lime-DAP application trial. The former was designed to determine how wheat cultivars with varying degrees of tolerance to low soil pH respond to lime and phosphate applications. The latter was designed to investigate the effect of application method on wheat yield response to phosphorus.

The experiments were conducted near Eakly, Oklahoma, a locality whose initial soil pH level and phosphorus were measured at 4.6, and 96, respectively (refer to Table 1). The soils were classified as Carey silt loam (fine-silty, mixed, superactive, thermic Typic Agriustolls).

For soils used to produce continuous winter wheat with a pH level of 4.6, the Oklahoma State University Soil, Water, and Forage Analytical Laboratory would recommend a lime application of 1.25 tons per acre of ECCE for the purpose of raising the pH to 5.5 (Zhang et al.). Based upon the results of prior research a pH of 5.5 is considered to be sufficient for continuous wheat (Mahler and McDole; Westerman). The initial phosphorus level of 96 was considered relatively high, such that the Oklahoma State University Soil, Water, and Forage Analytical Laboratory would report a 100% sufficiency level for small grains production (Zhang et al.).

The wheat variety experiments were conducted in a split-split-plot experimental design, with three replications. Lime, at 0 and 1.25 tons of ECCE per acre, was applied in the main plots. Limed blocks were 43 ft by 69 ft with a 20-feet buffer between limed and unlimed blocks. The wheat varieties constituted the sub-plot factors, while diammonium phosphate, 18-46-0 was applied in the sub-sub-plots. The latter was applied in the seed furrow at two levels, 0 and 130 lb per acre. Compared to triple superphosphate, diammonium phosphate is a more common and relatively less expensive source of phosphorus for Oklahoma farmers, Initial application of lime was carried out in July 1997, followed by the application of diammonium phosphate in seed furrows. Lime was broadcast and immediately incorporated with a rototiller. Both limed and unlimed blocks were tilled. Because of its importance to growth and development of the wheat crop, nitrogen was applied preplant, at a rate of 120 lb per acre across all experimental units. By applying 120 lbs of nitrogen, it is expected that all crop nitrogen needs will be exceeded, limiting any effect the small amount of nitrogen in the DAP might have on forage yield.

Aluminum toxicity generally affects root development, so that one method of assessing tolerance is to measure root development of plants grown in different concentrations of aluminum (Bolt). Table 2 contains wheat varieties with varying levels of tolerance to aluminum toxicity. On a scale of 1 to 4, 1 and 2 were classified as tolerant while 3 and 4 were classified as susceptible.

The experiment was conducted for a three-year period. There were four tolerant varieties and eight susceptible varieties (table 3). These groupings were deemed necessary for analytical purposes for the following reasons: First, to determine their average effect rather than their individual effects, and second to ensure adequate degrees of freedom for analysis of variance.

In the lime – DAP application trials, the same experimental design was used, with some differences in factor levels. There were four levels of diammonium phosphate: 0, 65 lb per acre applied in the seed furrow, 130 lb per acre applied in the seed furrow, and 130 lb per acre applied as broadcast. In addition only two wheat varieties, the susceptible Tonkawa and the tolerant 2137 were seeded. Each sub-sub-plot contained eight 6-inch rows by 21 feet. The Oklahoma Agricultural Statistics Service showed that in 2000 variety 2137 constituted 8.8 per cent of seeded wheat acres while Tonkawa accounted for only 0.9 % (Table 2).

Measurements of fall-winter forage yields were obtained by two hand clippings removing all above ground matter. Two 3.28 ft row areas were clipped from each plot, dried and forage yield computed and reported as lb per acre oven dry forage. The first clippings were conducted in the late fall. The second clippings were conducted on the same 3.28 ft row segments of the plot prior to first hollow stem in late winter after emergence from dormancy. Hence, the estimate of dry matter forage was based on the sum of the two clippings. Cattle removed forage from the unharvested portion of the plot within three days after clipping. The plants were permitted to mature and produce grain. Grain yield was obtained with a small plot combine harvesting the center 21 ft of all eight rows.

I.2. Methods

The Linear Mixed Regression Model

The SAS MIXED procedure was used to estimate a linear MIXED model by the method of maximum likelihood, to determine the effects of lime, variety and phosphorus on wheat grain yield, and on wheat forage yield. The method is appropriate because cross-sectional time series data are prone to the twin problems of autocorrelation and heteroskedasticity. The estimator is asymptotically efficient, consistent, and asymptotically normal under assumptions of normality. Littell et al. presented a basic linear mixed model that is based on a split-plot experimental design. The split-split-plot design derives from this design.

The factors lime, variety, and diammonium phosphate were classified as fixed effects, together with all possible combinations of the three, while the replication by year interaction was identified as random effects. Because the experimenter sacrifices precision in the main plots to achieve precision in the subplots, subplot errors must be lower than whole plot errors. Means of significant treatment factors were separated using Tukey's test.

Net Returns

Two levels of lime, two varieties and four levels of DAP resulted in sixteen different (possible combinations of) soil pH management strategies. Expected returns above variable costs were estimated for each strategy. Based on the economic assumption that the farmer maximizes expected returns above variable costs, optimal input levels that maximize these returns are calculated.

The returns due to each soil pH management strategy are estimated according to the following multi-product non-allocable factor returns function:

$$(1) \qquad \pi(l,d,v) = p_g Y_g(l,d,v) + p_f Y_f(l,d,v) - c_l l - c_d d - c_a A(l,d) - c_h h(Y_g),$$

where π is the farmer's net returns, as determined by the variable factors of production lime (l), DAP(d) and variety (v). Farm revenues were obtained from wheat grain yield, Y_g and forage yield, Y_f. Even though variety was a variable factor the different levels were assumed to have no differences in input costs or output prices. The differences between the two levels, susceptible and tolerant, would be manifested in output alone.

Following economic theory, the total cost function may be separated into fixed and variable costs. If the fixed costs are assumed to be constant, the variable costs can be incorporated into the profit function, to give a net returns function, with robust outcomes. c_l, and c_d, represent the marginal costs of the inputs lime and DAP; c_a represents the marginal costs of application for both inputs, and the total cost is dependent on the level of input use. c_h is the grain marginal harvest cost. The total cost of harvest is a function of grain yield. These conditional variable cost functions may violate the assumption of continuous differentiability, but allow us to account for additional harvest costs, and input application costs that may not otherwise be accounted for.

Oklahoma City market June wheat prices for the years 1998, 1999 and 2000, $2.62, $2.31 and $2.39 per bushel, respectively, were used in the analyses. Forage prices were assumed fixed at $ 0.03 per lb for all three years. Lime costs, including delivery and application, were estimated at $20.00 per ton for all three years. The cost of diammonium phosphate was determined to be $0.13 per lb, with an additional $2.50 per acre application cost. It was assumed that there were no differences in application costs between applying 65 lb per acre and 130 lb per acre in seed furrow, because the drill with its fertilizer attachment would cover the same time and distance per unit area. However, seed furrow application at $4.00 per acre is more expensive than broadcasting at $2.50 per acre (J.C. Hobbs, Personal Communication, 3/15/2001). The seed furrow application costs include the variable and fixed costs of the fertilizer attachment on a grain drill and the additional cost of handling the fertilizer in the field. Custom harvest values were based on \$13.00 per acre and \$0.13 per bushel for each additional bushel above 20 bushels per acre.

To determine the economically optimal soil pH management strategy or strategies, average net revenues for all pH management strategies were separated using Duncan's Multiple Range test. This test controls type 1 error better than least squares means. The economic analyses were limited to the lime-DAP trials because these offered more choice of strategies, with two unique wheat varieties.

The Land Tenure/Sharecropping Contract

The chemical effects of lime generally persist for several years after its initial application. Under such circumstances annual farmland leases could prove more beneficial to the landowner, and less profitable to the farmer, at least in the long run. This problem becomes more obvious if the cost of liming is high. Equity may be achieved if the cost of lime is shared between the farmer and the landowner in the same proportion as benefits from lime application. The resulting lease arrangements have been the object of many studies.

Sharecropping contracts are becoming increasingly important in regions in the United States where cash crops such as wheat and soybeans are grown. Risks (Cheung; Puadel, Lohr and Martin), economies of size and share contract and enforcement costs (Allen and Lueck) are some reasons that have been suggested for sharecropping. The economically efficient form of the optimal share contract is not always known.

Under the twin assumptions of risk neutrality and zero contract enforcement costs, Allen and Lueck postulated a regular production function of the general form:

(2) $$Y = g\,(f,\, l,\, k_i)\varepsilon, \quad \text{such that } \varepsilon \sim (1,\ \sigma^2),$$

where f and l are composite input functions representing non-priced farmer attributes and land attributes respectively, and k is one of n physical inputs such as lime and diammonium phosphate. This model derives from the principal-agent model (Stiglitz) which is based on a risk-averse farmer leasing land from a risk-neutral landowner. The inputs are assumed independent to avoid cases where prices could be adjusted to influence farmer behavior.

The crop yield at harvest is distributed between the farmer and the landowner so that the farmer gets αY and the landowner gets $(1-\alpha)Y$, where $0 < \alpha < 1$ is the farmer's share of output. If c is the opportunity cost of the *ith* input, then the farmer incurs $\beta[ck]$ in input costs while the landowner's input costs are $(1-\beta)[ck]$, where $0 \le \beta \le 1$ is the farmer's share of input costs. Under a sharecropping contract with zero transactions costs, the farmer's objective is to maximize his net returns according to:

(3) $$Max\ \pi(f,l,k) = p\alpha Y(f,l,k) - wf - rl - \beta ck,$$

where w is the opportunity cost of the farmer's non-priced attributes and r is the opportunity cost of the land's non-priced attributes. Allen and Lueck postulate that the tenant farmer faces lower opportunity costs of land attributes, and will therefore be more inclined to exploit the land's unpriced attributes. Because farmer attributes and land attributes are not priced, assumed non-variable and are therefore not included in the contract specification, they can be dropped from further consideration.

With all other factors remaining constant, output is assumed to depend on the variable factors alone. At the optimum,

$$\frac{\partial \pi}{\partial k} = p\alpha\frac{\partial Y}{\partial k} - \beta c = 0; \tag{4}$$

If the farmer's objective is to maximize net returns, he must choose an optimal k that achieves this objective, such that:

$$\frac{\partial Y}{\partial k} = \frac{\beta c}{p\alpha}. \tag{5}$$

This may be repeated for the other choice variables. The optimal solution may be first or second best from the farmer's perspective, depending on his choice of share contract. If he chooses $\beta > \alpha$, then k is less than k^* typifies a second-best solution. A second-best solution generally arises from a constrained optimization problem. In this case $\beta > \alpha$ because k is less than k^*, the optimal input use level. The less-than-optimal level input use is characteristic of a risk-neutral farmer (Paudel, Lohr, and Martin).

However, the farmer has any number of options. If he chooses $\beta = \alpha$, then $k = k^*$, and he operates at the optimum, although probably based only on private costs. Thus the optimal share contract (an arrangement between the farmer and the landowner) may not be socially optimal. At this point the marginal product is equal to the price ratio.

This is characteristic of the input-output model of sharecropping, and is independent of the risk attributes of the farmer.

Manipulating the joint net returns function shows that the optimal value of k is k^*, so that $\beta = \alpha$ is a Pareto optimal solution, for both the farmer and the landowner in a sharecropping contract. If $\alpha = 1$ then the sharecropping contract represents a cash rent or a landowner-farmer.

If the cost of an input, for example lime, is amortized over any period of time, and assuming $0 < d \leq 1$ is the amortization factor, equation (5) may be written as:

$$\frac{\partial Y}{\partial k} = \frac{\beta dc}{p\alpha}, \tag{6}$$

where d, the amortization factor is defined as

$$d = \left[\frac{i}{1-(1+i)^{-n}}\right], \tag{7}$$

hence the annual payment for input k for a farmer whose input share is β is βdck, while the landowner pays $(1-\beta)dck$. The interest rate, i, used in this analysis was 7 percent, with $n = 5$ years amortization period. The 5-year amortization period is a reflection of the length of time in which the effect of lime generally persists in the soil, after initial application (Dr Eugene Krenzer, personal communication). When d is equal to one, choosing $\beta = \alpha$, leads to the optimal use of the input k, ie $k = k^*$. However when $0 < d <$

1, choosing $\beta = \alpha$ would lead to $k > k^*$. Therefore, the evident imperfect market condition dictates that the farmer chooses $\beta > \alpha$ to at least achieve an optimal input use level, ie. $k \leq k^*$. Although this may represent a Pareto improvement to the landowner, the rational farmer is unlikely to do so unless he extracts additional concessions from the landowner. Amortizing the costs of lime allows for the principal and interest to be repaid in equal annual installments, to reflect the fact that lime effects persist in the soil for years after initial application. The PMT option in EXCEL was used to calculate annual payments. The cost of applying 1.25 tons ECCE lime per acre is estimated to be \$25. If amortized over five years at an interest rate of 7 %, the annual payment would be \$6.10.

Patterson, Hanson and Robison characterized farm leasing in North Central United States. They found that in some states, eg, Missouri, North and South Dakota, and Minnesota, the predominant share contract for wheat, allocated to the landlord a 33 percent share of output and a 33 percent share of fertilizer costs. These were used as benchmark values for $1-\alpha$ and $1-\beta$.

I.3. Results

Results of analysis of variance for both the wheat variety trials and the lime-DAP trials are given. However, no economic analyses were carried out on the wheat variety trials because of the limited number of treatment levels for phosphorus, and the perceived diluted factor effects on grain and forage yields resulting from aggregation. Economic analyses were limited to the two-variety trials with four phosphorus levels, which also included two application methods, and two lime levels. The effects of share contracting and risk on the choice of optimal strategy were analyzed.

Experiment 1: Effects of Lime, DAP and Variety on Wheat Grain and Forage Yield – The Wheat Variety Trials

Results of the analysis of variance (ANOVA) for forage yield and grain yield, are summarized in tables 3, 4, 5, 6, 7 and 8. In the wheat variety trials, analysis of variance shows that the only significant factors for grain yield were diammonium phosphate (phosphorus), and wheat variety. Separated means show that applying 130 lb per acre of DAP resulted in a significantly higher grain yield (table 3), and that the average yields of tolerant varieties were significantly higher than those of susceptible varieties. These results suggest that if maximum wheat grain yield is the objective on low pH (4.6) soils, the farmer may cultivate a tolerant variety alone; or simply apply 130 lb of DAP per acre by banding, to any wheat variety.

In the same experiment, forage yields were shown to increase when lime alone was applied. However, forage yields when DAP was applied with lime were no higher than when DAP was applied in the absence of lime. These forage yields in the presence of DAP were generally higher for susceptible varieties than for tolerant varieties. Table 3 shows that higher forage yields were achieved with the application of 130 lb per acre of diammonium phosphate. ANOVA by variety (table 4) confirmed that tolerant and susceptible wheat varieties had almost identical treatment effects for forage and grain yield. An application of 130 lb per acre DAP increased forage yield for both susceptible and tolerant varieties, as well as grain yield. These results are basically in conformity with those obtained from table 3. Table 5, which merely shows the simple effects would generally validate tables 3 and 4.

Application of DAP increases grain yield for susceptible but not for tolerant varieties. However, DAP in combination with lime increases grain yield for tolerant varieties. The results in table 4 bring into question the susceptible/tolerant classification scheme. Both grain and forage yields of designated tolerant varieties were significantly increased with the application of DAP and lime. Evidently these varieties are not fully 'tolerant' of acid soils.

Experiment 2: Effects of Lime, DAP and Variety on Wheat Grain and Forage Yield – The Lime-DAP Trials

In contrast to the first experiment, the second experiment used only two wheat varieties, the susceptible Tonkawa and the tolerant 2137. In addition there were four diammonium phosphate treatments: 0, 130 lb per acre applied in seed furrows, 130 lb per acre applied as broadcast, and 65 lb per acre applied in seed furrow. Table 6 shows that lime at 1.25 tons per acre increased grain yield. It also shows that DAP at 65 lb per acre applied in the seed furrow gave highest grain yield, even though this was not significantly different from 130 lb per acre broadcast; variety 2137 had a higher yield than Tonkawa. A very interesting finding is that the grain yield from the 65 SF treatment is significantly greater than the grain yield of the 130 SF treatment. However, the forage yield of the 130 SF treatment is significantly greater than the 65 SF forage yield. This indicates a possible substitution or tradeoff in production between forage and grain. The reason for this substitution is not known.

Lime at 1.25 tons per acre generally increased forage yield (table 6). However, when DAP was applied at 130 lb per acre in seed furrows, lime at 1.25 tons did not lead to a marked increase in forage yield. That notwithstanding, these combinations gave the highest forage yields. DAP increased forage yield, but the effect was more pronounced at 130 lb per acre in seed furrow. The other levels of DAP use showed higher forage yields in the presence of lime. Both wheat varieties had marked forage yield improvement in the presence of lime.

ANOVA by variety (table 7) showed that Tonkawa and 2137 had higher forage yields by applying 130 lb per acre of diammonium phosphate in seed furrows, whether limed or not. Highest grain yields for both Tonkawa and 2137 were obtained by applying 65 lbs per acre of diammonium phosphate in seed furrows. Tonkawa's yields were not significantly different from those obtained by applying 130 lbs of diammonium phosphate as broadcast plus 1.25 tons per acre of lime. For 2137 the highest yields were not significantly different from applying 130 lbs per acre of diammonium phosphate broadcast. The results in table 6 and table 7 are validated by the simple effects in table 8.

Net returns above variable costs under different share contracts

The dual-purpose wheat enterprise is one in which total revenue is obtained from both grain yield and forage yield. The variable factors that account for cost differences are lime and diammonium phosphate (DAP), and their application costs. The standard combine harvest costs which are a function of grain yield, are also included, but are solely paid by the farmer. The combination of two lime levels, four DAP levels and two wheat varieties yielded sixteen different strategies.

The net returns above variable costs were calculated by subtracting the costs (and application costs) of lime and diammonium phospate, and the harvest costs from the total revenue (table 9). Costs of inputs that did not change across treatments, such as the cost of seed and tillage operations are not included. The mean net returns, averaged over three years, were then separated using Duncan's Multiple Range Test. This procedure was repeated for different share contracts, and under conditions where lime costs are amortized over a five-year period. The results shown in tables 11 through 20 constitute the optimal strategies for the farmer/tenant and the landowner.

While it was proved earlier that optimal input use is achieved when the farmer's share of output is the same as his share of input costs, a disequilibrium could be introduced into the model by letting the farmer bear all other costs not associated with lime and fertilizer. The decision to model the crop share contract that allowed the farmer to pay all the costs but keep only 2/3 of the output was borne out of this. Table 10 shows the crop share contracts that were analyzed. One contract being studied is a cash lease, where the farmer bears all costs and keeps all the output. The current cropland rental rate is a fair indication of the value of a cash lease. Another contract is the case of the owner-operator. Since the farmer is also the landowner, he pays all costs and keeps all the output. These two scenarios are not typically defined as share contracts because the farmer's share of output, α, is equal to one. Nevertheless, they constitute an important case study in contracting and land ownership. The fourth share contract assumes that the farmer pays half the costs and gets half the output. This is not a common contracting arrangement in wheat growing areas. The fifth share contract assumes that the farmer pays two-thirds of the costs and receives two-thirds of the output. This is a more common contract arrangement in wheat growing areas. The last two share contracts also satisfy the optimal input use criteria; the factor share is equal to the output share and the marginal product is equal to the price ratio.

Table 11 shows that when the cost of lime is not amortized, the farmer achieved highest net returns by cultivating 2137 and applying 65 lb of diammonium phosphate in the seed furrow and no lime. However this net return was not significantly different from the average net returns from five other strategies. The landowner, on the other hand, whose marginal input costs are zero, achieves highest net returns if the farmer cultivates 2137, and applies 65 lb DAP in the seed furrow and 1.25 tons of lime. This strategy produces net returns that are not significantly different from nine other strategies, including the farmer's optimal strategy. The result is a little different when lime costs are amortized over a five-year period for the same contract (table 12). The farmer and the landowner now achieve highest net returns for the same strategy: seeding 2137 and applying 65 lb DAP in the seed furrow and 1.25 tons of lime. Net returns to the farmer's strategy are statistically similar to those obtained from eleven other strategies; the landowner has ten statistically indistinguishable strategies.

Table 13 shows that variety 2137 plus 65 lb DAP in seed furrows gives the highest net returns for both the farmer and the landowner, when lime costs are not amortized. The farmer has eight strategies whose net returns are not statistically different, while the landowner has nine. When lime costs are amortized over a five-year period the farmer and the landowner have the same optimal strategy (table 14), applying 1.25 tons of lime and 65 lb of DAP in seed furrows to wheat variety 2137. There are multiple strategies with net returns that are not statistically different. The results are nearly identical with the 1/2- 1/2 farmer share contract, as shown in table 15 for single year operations and table 16 for five-year amortized lime costs.

A couple of scenarios were modeled where the farmer pays all the costs and gets all the output. In one case he pays a cash rent of $35.42 per acre to the landowner, and in the other scenario the farmer is the landowner. Oklahoma cropland rental rates for 1998-1999 were estimated at $35.42 per acre for the North Central region (Doye, Kletke and Fischer). When the farmer pays cash rent, the landowner is indifferent between strategies. The choice of cash lease over a crop share contract for the landowner, may be determined by production risks, as well as the ultimate magnitude of the returns to a pure share contract, at least of the predominant type. The farmer in a cash lease situation attains highest net returns by applying 65 lb DAP to wheat variety 2137 in single year leases where total lime costs are immediately assumed. The net returns from this strategy, as shown in table 17, are not statistically different from those obtained from eight other strategies. When lime costs are amortized over a five-year period applying 1.25 tons of lime and 65 lb DAP in seed furrows to variety 2137 gives the highest net returns. The net returns are statistically not different from those of twelve other strategies (table 18).

When the farmer is also the landowner, he achieves highest net returns by applying 65 lb DAP to variety 2137 when he assumes total lime costs in a single year. The returns are statistically identical to those for seven other strategies, as shown in table 19. When lime costs are amortized for a five-year period, net returns are highest when he applies 1.25 tons of lime and 65 lb DAP to variety 2137. Again, there are multiple optimal strategies (table 20).

The propensity to apply lime as part of an optimal strategy each time lime costs are amortized over a relatively long period of time such as five years, is a reflection of the lower marginal cost of lime per unit time. On the other hand, optimal strategies with the highest net returns had no lime treatments when lime costs were assumed in a single year. This was the same for nearly all the share contracts.

One finding is that farmers and landowners invariably had multiple optimal soil pH management strategies under all share contracts. It perhaps serves to validate the prairie wheat farmers' use of different soil pH management strategies.

I.4. Summary and Conclusions

Oklahoma farmers are faced with the problem of cultivating wheat in soils with low pH. Research has highlighted the cultivation of tolerant wheat varieties, application of lime, and application of phosphorus in seed furrow, as strategies that ameliorate the problem of soil acidity. The effects of lime generally persist for some years beyond the period of application, so that amortizing its costs becomes an attractive option for many Oklahoma farmers who are not landowners, but nevertheless engage in share cropping for multiple years. Soil pH management strategies are simultaneously compared for different crop-share contracts.

The farmer's choice of optimal soil pH management strategy depends on his objective. Both experiments show that the three factors lime, DAP and type of variety are important in formulating soil pH management strategies. Lime at 1.25 tons per acre, DAP at 65 lb per acre in seed furrow and a tolerant wheat variety like 2137 will significantly increase grain yield, even if they are treated as mutually exclusive. However the effect of DAP indicates a real trade-off between forage yield and grain yield, because DAP application from 65 SF to 130 SF significantly increases forage yield, but significantly decreases grain yield. Because the "tolerant" variety had such significant responses to DAP and lime, it's level of tolerance to low soil pH may be lower than originally thought.

While susceptible wheat varieties like Tonkawa appear to produce more forage, the monetary value of forage relative to grain may entice the farmer to cultivate tolerant varieties that still produce higher forage yield in the presence of lime or DAP. This would strike a balance between higher grain yields and relatively high forage yields..

These analyses assume that lime and DAP costs are the only costs that are shared in share contract. As expected, the choice of criteria used in determining the optimal strategy was important. Duncan's Multiple Range Test uses the expected values and the relative distances from each other. This showed that under all share contracts multiple economically optimal strategies were identified. In a farming systems concept this validates diverse farmer's strategies.

The choice of strategies has important implications for input use. There is a tendency to use additional inputs if the marginal cost is lower than the market price. The choice of optimal strategy does not depend on share contract, but on the marginal cost of the inputs that constitute the strategy. The share contracts themselves need only be based on the optimal input use criterion.

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Table 1. Initial Chemical Characteristics of the Eakly Experiment Site, Oklahoma, 1997

Location	Soil pH	NO_3-N	P	K
Eakly	4.6	72	96	453

Note: The soils have been classified as Carey silt loam (fine-silty, mixed, superactive, thermic Typic Agriustolls)

Table 2. Wheat Varieties and their Degree of Tolerance to Soil Acidity

Variety	Degree of Tolerance [a]	Patent Protected [b]	Percent Acreage [c]
Jagger	1	Yes	38.1
Custer	4	No	8.0
2137	1	Yes	8.8
Tomahawk	4	Yes	2.5
AgSeco 7853	2	No	2.9
Ogallala	3	Yes	1.5
2163	1	Yes	1.8
Karl 92	4	Yes	1.4
Chisholm	3	No	1.5
Tonkawa	4	No	0.9
Coronado	2	Yes	0.4
Dominator	3	No	<0.2
Star Champ	3	Yes	<0.2
2174	3	Yes	5.2
Oro Blanco	3	Yes	<0.2

[a] 1,2 = tolerant and 3, 4 = susceptible; Source: Krenzer, Wheat Variety Comparison Chart 2000.

[b] Source: Krenzer, Wheat Variety Comparison Chart 2000.

c Percent acreage seeded in Oklahoma in 2000. Source: Oklahoma Agricultural Statistics Service.

Table 3. Treatment Means for Forage and Grain Yields, Eakly Variety Trials, 1997-2000 [1]

Treatments			Grain Yield [2]		Forage Yield [3]	
Lime (t/ac)	DAP (lb/ac)	Variety	DAP (bu/ac)	Variety (bu/ac)	Lime*DAP (lb/ac)	DAP*Variety (lb/ac)
	0		43.2^{b}			
	130		44.9^{a}			
0	0				1250^{c}	
0	130				2122^{a}	
1.25	0				1655^{b}	
1.25	130				2160^{a}	
	0	Susceptible [4]				1424^{c}
	0	Tolerant [5]				1482^{c}
	130	Susceptible				2230^{a}
	130	Tolerant				2051^{b}
		Susceptible		42.4^{b}		
		Tolerant		45.7^{a}		

[1] Identical letters in the same column indicate no significant difference at $p = 0.05$.

[2] DAP and variety were the only significant factors on grain yield.

[3] The significant factors are: Lime, DAP, and the interactions Lime*DAP and DAP*Variety.

[4] Susceptible wheat varieties: 2174, Chisholm, Custer, Dominator, Ogallala, Oro Blanco, Tomahawk and Tonkawa.

[5] Tolerant wheat varieties: AgSeco 7853, Jagger, Coronado and 2137.

Table 4.Treatment Means for Forage and Grain Yields, by Variety, Eakly Variety Trials, 1997-2000 [1]

Treatments		Susceptible [2]		Tolerant [3]	
Lime (tons/acre)	DAP (lb/acre)	Forage (lb/acre)	Grain (bu/acre)	Forage (lb/acre)	Grain (bu/acre)
0	0	1181 ^{c}	40.5 ^{b}	1333 ^{c}	42.7 ^{b}
0	130	2219 ^{a}	43.0 ^{a}	2023 ^{a}	45.3 ^{ab}
1.25	0	1678 ^{b}	41.9 ^{ab}	1639 ^{b}	45.2 ^{ab}
1.25	130	2257 ^{a}	42.9 ^{a}	2073 ^{a}	46.0 ^{a}

[1] Identical letters in the same column indicate no significant difference at $p = 0.05$.

[2] Susceptible wheat varieties: 2174, Chisholm, Custer, Dominator, Ogallala, Oro Blanco, Tomahawk, and Tonkawa.

[3] Tolerant wheat varieties: AgSeco 7853, Jagger, Coronado, and 2137.

Table 5. Simple Effects of Lime and DAP on Lime*DAP Interactions for Forage and Grain Yields, Eakly Variety Trials, 1997-2000 [1,2]

			Susceptible [3]		Tolerant [4]	
Factor	Lime	DAP	Forage	Grain	Forage	Grain
DAP	0		*	*	*	ns
DAP	1.25		*	ns	*	ns
Lime		0	*	ns	*	ns
Lime		130	ns	ns	ns	ns

[1] Simple effects analyzed using SAS MIXED procedure with SLICE option of the LSMEANS statement; for instance, Lime 0 shows the effect of DAP when no lime was applied.

[2] * imply significant at p = 0.05 and ns not significant at p = 0.05.

[3] Susceptible wheat varieties: 2174, Chisholm, Custer, Dominator, Ogallala, Oro Blanco, Tomahawk, and Tonkawa.

[4] Tolerant wheat varieties: AgSeco 7853, Jagger, Coronado, and 2137.

Table 6. Treatment Means for Forage and Grain Yields, Eakly Lime-DAP Trials, 1997-2000 [1]

Treatments			Grain Yield [2]			Forage Yield [3]	
Lime (t/acre)	DAP (lb/acre)	Variety	Lime (bu/ac)	DAP (bu/ac)	Variety (bu/ac)	Lime*DAP (lb/ac)	Lime*Variety (lb/ac)
0			44.1 ^{b}				
1.25			48.4 ^{a}				
	0			42.0 ^{b}			
	130 SF			44.0 ^{b}			
	130 B			48.6 ^{a}			
	65 SF			50.3 ^{a}			
		Tonkawa			41.6 ^{b}		
		2137			50.8 ^{a}		
0	0					1102 ^{d}	
0	130 SF					2237 ^{a}	
0	130 B					1572 ^{c}	
0	65 SF					1611 ^{c}	
1.25	0					1664 ^{c}	
1.25	130 SF					2190 ^{a}	
1.25	130 B					1934 ^{b}	
1.25	65 SF					1924 ^{b}	
0		Tonkawa					1545 ^{c}
0		2137					1716 ^{bc}
1.25		Tonkawa					2092 ^{a}
1.25		2137					1764 ^{b}

[1] Identical letters in the same column indicate no significant difference at $p = 0.05$.

[2] The significant factors are: Lime, DAP and variety.

[3] The significant factors are: Lime, DAP, and the interactions Lime*DAP and Lime*Variety.

Table 7. Treatment Means for Forage and Grain Yields, by Variety, Eakly Lime-DAP Trials, 1997-2000 [1]

		Tonkawa [2]		2137 [3]	
Lime (tons/acre)	DAP (lb/acre)	Forage (lb/acre)	Grain (bu/acre)	Forage (lb/acre)	Grain (bu/acre)
0	0	974^{d}	36.0^{c}	1299^{d}	45.4^{c}
0	130 SF	2352^{a}	38.4^{c}	2151^{a}	46.6^{c}
0	130 B	1466^{c}	40.0^{cb}	1680^{c}	51.1^{abc}
0	65 SF	1430^{c}	41.0^{abc}	1793^{bc}	53.6^{abc}
1.25	0	1747^{bc}	39.2^{c}	1587^{c}	47.2^{c}
1.25	130 SF	2433^{a}	40.9^{cb}	1954^{ab}	49.4^{bc}
1.25	130 B	2087^{ab}	46.9^{ab}	1781^{bc}	56.3^{ab}
1.25	65 SF	2116^{ab}	48.5^{a}	1733^{bc}	57.8^{a}

[1] Identical letters in the same column indicate no significant difference at p = 0.05.
[2] Tonkawa is a susceptible wheat variety
[3] 2137 is a tolerant wheat variety

Table 8. Simple Effects of Lime and DAP on Lime*DAP Interactions for Forage and Grain Yields, Eakly Lime-DAP Trials, 1997-2000 [1,2]

			Tonkawa [3]		2137 [4]	
Factor[3]	Lime	DAP	Forage	Grain	Forage	Grain
DAP	0		*	ns	*	ns
DAP	1.25		*	*	*	*
Lime		0	*	ns	*	ns
Lime		130 SF	ns	ns	ns	ns
Lime		130 B	*	ns	ns	ns
Lime		65 SF	*	ns	ns	ns

[1] Simple effects analyzed using SAS MIXED procedure with SLICE option of the LSMEANS statement. For instance, Lime 0 shows the effect of DAP when no lime was applied.

[2] * imply significant at $p = 0.05$ and ns not significant at $p = 0.05$.

[3] Tonkawa is a susceptible wheat variety

[4] 2137 is a tolerant wheat variety

Table 9. Base Budget for Dual-Purpose Wheat Production, Eakly 1997-2000

Item	Unit	Price	Quantity	Value
Gross Receipts				
Grain	bu	2.62 [a]	47.50	124.45
Forage	lb	0.03	3073	92.19
Total Revenue	$ / acre			216.64
Variable costs [b]				
Diammonium phosphate (18-46-0)	lb	0.13	130	16.90
DAP broadcast cost	acre	2.50	1	2.50
DAP banding cost	acre	4.00	1	4.00
Lime + application cost	ton	20.00	1.25	25.00 [d]
Custom harvest	ac	13.00	1	13.00
Custom harvest	bu	0.13	27.50	3.58
Total variable cost	$ / acre			64.98
Returns above variable costs	$ / acre			151.66 [c]

[a] Grain prices were $2.62, $2.31 and $2.39 in 1998, 1999 and 2000, respectively. Shaded regions refer to variables that vary across growing seasons.

[b] Costs for inputs that did not change across treatments, such as costs of seed and tillage operations, are not included.

[c] Returns above variable costs were averaged over three years for each soil pH management strategy.

[d] When amortized over 5 years at 7 %, this value is $6.10.

Table 10. Examples of Crop Share Contracts Used to Analyze the Eakly Lime – DAP Study, Eakly, 1997-2000

Farmer's Share	
Lime costs [a] + DAP costs	Output
1 + cash lease of $ 35 per acre	1
1 [b]	1
1/2	1/2
2/3	2/3
1	2/3

[a] This exercise is repeated when lime costs are amortized over a five-year period.

[b] This is the owner-operator.

Table 11. Expected Returns to Soil pH Management Strategies when the Farmer Pays all Costs, Receives 2/3 Crop Share, and Lime Costs are not Amortized, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	67 ^{bcde}	41 ^{f}
		2137	83 ^{ab}	49 ^{def}
	130 SF	Tonkawa	74 ^{abcd}	55 ^{abcde}
		2137	81 ^{ab}	59 ^{abc}
	130 B	Tonkawa	60 ^{cde}	48 ^{ef}
		2137	79 ^{abc}	58 ^{abcd}
	65 SF	Tonkawa	68 ^{bcde}	48 ^{ef}
		2137	92 ^{a}	61 ^{ab}
1.25	0	Tonkawa	59 ^{de}	50 ^{cdef}
		2137	67 ^{bcde}	54 ^{bcde}
	130 SF	Tonkawa	52 ^{e}	57 ^{abcde}
		2137	56 ^{de}	60 ^{abc}
	130 B	Tonkawa	57 ^{de}	59 ^{abcd}
		2137	65 ^{bcde}	63 ^{ab}
	65 SF	Tonkawa	67 ^{bcde}	60 ^{ab}
		2137	73 ^{abcd}	64 ^{a}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 12. Expected Returns to Soil pH Management Strategies when the Farmer Pays all Costs, Receives 2/3 Crop Share, and Lime Costs are Amortized over a Five-Year Period, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	67^{bc}	41^{f}
		2137	83^{ab}	49^{def}
	130 SF	Tonkawa	74^{abc}	55^{abcde}
		2137	81^{ab}	59^{abc}
	130 B	Tonkawa	60^{c}	48^{ef}
		2137	79^{abc}	58^{abcd}
	65 SF	Tonkawa	68^{bc}	48^{ef}
		2137	92^{a}	61^{ab}
1.25	0	Tonkawa	78^{abc}	50^{cdef}
		2137	86^{ab}	54^{bcde}
	130 SF	Tonkawa	71^{bc}	57^{abcde}
		2137	75^{abc}	60^{abc}
	130 B	Tonkawa	76^{abc}	59^{abcd}
		2137	84^{ab}	63^{ab}
	65 SF	Tonkawa	86^{ab}	60^{ab}
		2137	92^{a}	64^{a}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 13. Expected Returns to Soil pH Management Strategies when the Farmer Pays 2/3 Costs of Lime and DAP, Receives 2/3 Crop Share, and Lime Costs are not Amortized, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	67^{c}	41^{bcd}
		2137	83^{abc}	50^{ab}
	130 SF	Tonkawa	81^{abc}	46^{abcd}
		2137	88^{ab}	50^{ab}
	130 B	Tonkawa	67^{c}	40^{cd}
		2137	86^{abc}	50^{ab}
	65 SF	Tonkawa	72^{bc}	41^{bcd}
		2137	96^{a}	54^{a}
1.25	0	Tonkawa	68^{c}	42^{bcd}
		2137	75^{bc}	46^{abcd}
	130 SF	Tonkawa	68^{c}	39^{d}
		2137	71^{bc}	42^{bcd}
	130 B	Tonkawa	72^{bc}	43^{bcd}
		2137	79^{abc}	47^{abcd}
	65 SF	Tonkawa	79^{abc}	46^{abcd}
		2137	86^{abc}	50^{abc}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 14. Expected Returns to Soil pH Management Strategies when the Farmer Pays 2/3 Costs of Lime and DAP, Receives 2/3 Crop Share, and Lime Costs are Amortized over a Five-Year Period, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	67^{c}	41^{cd}
		2137	83^{abc}	50^{abc}
	130 SF	Tonkawa	81^{abc}	46^{abcd}
		2137	88^{ab}	50^{abc}
	130 B	Tonkawa	67^{c}	40^{d}
		2137	86^{abc}	50^{abc}
	65 SF	Tonkawa	72^{bc}	41^{cd}
		2137	96^{a}	54^{ab}
1.25	0	Tonkawa	80^{abc}	48^{abcd}
		2137	88^{ab}	52^{ab}
	130 SF	Tonkawa	80^{abc}	46^{bcd}
		2137	84^{abc}	48^{abcd}
	130 B	Tonkawa	84^{abc}	49^{abcd}
		2137	92^{a}	54^{ab}
	65 SF	Tonkawa	92^{a}	52^{ab}
		2137	98^{a}	56^{a}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 15. Expected Returns to Soil pH Management Strategies when the Farmer Pays ½ the Costs of Lime and DAP, Receives ½ Crop Share, and Lime Costs are not Amortized, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	46^{c}	62^{bc}
		2137	58^{abc}	75^{abc}
	130 SF	Tonkawa	57^{abc}	71^{abc}
		2137	62^{ab}	77^{ab}
	130 B	Tonkawa	46^{c}	61^{c}
		2137	60^{abc}	76^{ab}
	65 SF	Tonkawa	50^{bc}	64^{bc}
		2137	68^{a}	83^{a}
1.25	0	Tonkawa	47^{c}	63^{bc}
		2137	52^{bc}	69^{abc}
	130 SF	Tonkawa	47^{c}	61^{c}
		2137	49^{bc}	65^{bc}
	130 B	Tonkawa	50^{bc}	65^{bc}
		2137	55^{abc}	72^{abc}
	65 SF	Tonkawa	55^{abc}	70^{abc}
		2137	60^{abc}	76^{ab}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 16. Expected Returns to Soil pH Management Strategies when the Farmer Pays ½ the Costs of Lime and DAP, Receives ½ Crop Share, and Lime Costs are Amortized over a Five-Year Period, Eakly, 1997-2000

Factor Levels			Expected Returns [1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner
0	0	Tonkawa	46 ^{c}	62 ^{de}
		2137	58 ^{abc}	75 ^{abcde}
	130 SF	Tonkawa	57 ^{abc}	71 ^{abcde}
		2137	62 ^{ab}	77 ^{abc}
	130 B	Tonkawa	46 ^{c}	61 ^{e}
		2137	60 ^{abc}	76 ^{abcd}
	65 SF	Tonkawa	50 ^{bc}	64 ^{cde}
		2137	68 ^{a}	83 ^{ab}
1.25	0	Tonkawa	56 ^{abc}	73 ^{abcde}
		2137	62 ^{ab}	79 ^{abc}
	130 SF	Tonkawa	56 ^{abc}	71 ^{bcde}
		2137	59 ^{abc}	74 ^{abcde}
	130 B	Tonkawa	59 ^{abc}	75 ^{abcde}
		2137	65 ^{ab}	82 ^{ab}
	65 SF	Tonkawa	65 ^{ab}	80 ^{ab}
		2137	69 ^{a}	86 ^{a}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different.

Table 17. Expected Returns to Soil pH Management Strategies when the Farmer Cash Leases ($35/acre) Land, and Lime Costs are not Amortized, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner[2]
0	0	Tonkawa	73 ^{c}	35
		2137	97 ^{abc}	35
	130 SF	Tonkawa	94 ^{abc}	35
		2137	105 ^{ab}	35
	130 B	Tonkawa	72 ^{c}	35
		2137	102 ^{abc}	35
	65 SF	Tonkawa	80 ^{bc}	35
		2137	117 ^{a}	35
1.25	0	Tonkawa	74 ^{c}	35
		2137	85 ^{bc}	35
	130 SF	Tonkawa	74 ^{c}	35
		2137	80 ^{bc}	35
	130 B	Tonkawa	80 ^{bc}	35
		2137	93 ^{abc}	35
	65 SF	Tonkawa	92 ^{abc}	35
		2137	102 ^{abc}	35

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different.

[2] Landowner is indifferent with respect to expected returns.

Table 18. Expected Returns to Soil pH Management Strategies when the Farmer Cash Leases ($35/acre) Land, and Lime Costs are Amortized over a Five-Year Period, Eakly, 1997-2000

Factor Levels			Expected Returns [1] ($ / acre)	
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer	Landowner [2]
0	0	Tonkawa	73^{c}	35
		2137	97^{abc}	35
	130 SF	Tonkawa	94^{abc}	35
		2137	105^{ab}	35
	130 B	Tonkawa	72^{c}	35
		2137	102^{abc}	35
	65 SF	Tonkawa	80^{bc}	35
		2137	117^{a}	35
1.25	0	Tonkawa	93^{abc}	35
		2137	104^{ab}	35
	130 SF	Tonkawa	93^{abc}	35
		2137	99^{abc}	35
	130 B	Tonkawa	99^{abc}	35
		2137	111^{a}	35
	65 SF	Tonkawa	111^{a}	35
		2137	121^{a}	35

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

[2] Landowner is indifferent with respect to expected returns.

Table 19. Expected Returns to Soil pH Management Strategies for the Owner-Operator where Lime Costs are not Amortized, Eakly, 1997-2000

Factor Levels			Expected Returns[1] ($ / acre)
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer/Landowner
0	0	Tonkawa	108 cd
		2137	133 abcd
	130 SF	Tonkawa	129 abcd
		2137	141 ab
	130 B	Tonkawa	107 d
		2137	137 abcd
	65 SF	Tonkawa	115 bcd
		2137	152 a
1.25	0	Tonkawa	109 cd
		2137	121 bcd
	130 SF	Tonkawa	109 cd
		2137	116 bcd
	130 B	Tonkawa	116 bcd
		2137	128 abcd
	65 SF	Tonkawa	127 abcd
		2137	138 abc

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

Table 20. Expected Returns to Soil pH Management Strategies for the Owner-Operator, where Lime Costs are Amortized over a Five-Year Period, Eakly, 1997-2000

Factor Levels			Expected Returns [1] ($ / acre)
Lime (tons / acre)	DAP (lb / acre)	Wheat variety	Farmer/Landowner
0	0	Tonkawa	108 ^{c}
		2137	132 ^{abc}
	130 SF	Tonkawa	130 ^{abc}
		2137	141 ^{ab}
	130 B	Tonkawa	108 ^{c}
		2137	137 ^{abc}
	65 SF	Tonkawa	116 ^{bc}
		2137	153 ^{a}
1.25	0	Tonkawa	128 ^{abc}
		2137	140 ^{ab}
	130 SF	Tonkawa	128 ^{abc}
		2137	135 ^{abc}
	130 B	Tonkawa	135 ^{abc}
		2137	147 ^{a}
	65 SF	Tonkawa	146 ^{a}
		2137	157 ^{a}

[1] Means separated using Duncan's Multiple Range Test; means with the same letter are not significantly different at $\alpha = 0.05$.

CHAPTER II

II. OPTIMAL STOCKING DENSITY FOR DUAL-PURPOSE WINTER WHEAT PRODUCTION

OPTIMAL STOCKING DENSITY FOR DUAL-PURPOSE WINTER WHEAT PRODUCTION

ABSTRACT

Dual-purpose winter wheat production is an important economic activity in Oklahoma. Because of the complex interactions involved in producing wheat and beef, one important decision is the choice of stocking density. The objective of the research reported in this chapter is to determine the stocking density that will maximize net returns from dual-purpose winter wheat production. Data were obtained from experiments conducted at the expanded wheat pasture research facility near Marshall, Oklahoma. Average daily gain response to forage allowance was estimated with stochastic and nonstochastic linear response plateaus, and quadratic based models. Optimal stocking density was determined to be greater under a stochastic plateau than under a nonstochastic plateau.

OPTIMAL STOCKING DENSITY FOR DUAL-PURPOSE WINTER WHEAT PRODUCTION

II.1. Introduction

The production of dual-purpose winter wheat is a major agricultural activity in the southern plains of the United States. In a dual-purpose forage plus grain system, wheat is planted in early September and is available for grazing by livestock from late November until development of the first hollow stem, usually in early March. If the livestock are removed prior to development of first hollow stem, the wheat will mature and produce a grain crop for harvest in June. When winter wheat is grazed between the period of proper root formation and the development of first hollow stem, the effect of stocking density on grain yield could remain relatively marginal. Under such conditions animal gain costs less than in some alternative feeding systems, depending on how costs are allocated.

The use of winter wheat as a dual-purpose forage plus grain crop is important in the agricultural economies of southern Kansas, eastern New Mexico, Oklahoma, southeastern Colorado, and the Texas Panhandle. Pinchak et al. estimate that 30 to 80 percent of the 9 million hectares seeded annually to wheat in the United States southern plains are grazed. True et al. report that livestock grazed about 50 percent of Oklahoma wheat hectares during the 1995-96 growing season, and that the most common use of fall/winter wheat pasture is for grazing young steers. Wheat grazing is also practiced in Argentina, Australia, Morocco, Pakistan, Syria, and Uruguay.

The importance of winter wheat production as a dual-purpose crop is abundantly chronicled by Redmon et al. In 2000, beef cattle values for the state of Oklahoma were estimated at approximately $1.4 billion while winter wheat grain yield values were estimated at approximately $386 million (OASS). The combined value of production suggests that the dual-purpose winter wheat production enterprise is an important economic opportunity for Oklahoma farmers.

The fall-winter wheat pasture produced by dual-purpose wheat is a valuable source of high-quality forage available for grazing during a time period when perennial pastures in the region and elsewhere in the country are dormant. One consequence is that many lightweight calves are transported to the region in the fall to graze on the lush winter wheat pastures (Brorsen, Bailey and Thomsen). Wheat pasture producers are faced with a number of important decisions. However, one of the most economically important decisions is the selection of the number of animals to stock on a given land area of wheat pasture. Among the many factors affecting wheat grazing system management are agricultural production risks that occur as a result of variability in weather, and the complex interactions and tradeoffs between the two products wheat and beef (Rodriguez et al.).

Stocking density describes the number of animals stocked per unit land area or total live weight per unit land area. Low stocking densities could lead to underutilization of large amounts of forage, while high stocking densities could result in low gain per animal or high-cost supplemental feeding. The economically optimal stocking density is one that strikes a balance between steer gain and grain yield, while taking into account their respective market prices. This study is a significant attempt to determine the optimal stocking density in dual-purpose wheat production based on available forage, and length of grazing period, as well as on the market prices of both products.

Objectives

The main objective of this study is to determine the stocking density that would maximize profit from dual-purpose winter wheat production. The effect of stocking density on wheat grain yield and average daily gain will be determined to aid in the formulation of the farmer's expected profit function. Plateau level average daily gains will be calculated together with their corresponding optimal forage allowances or grazing pressures for different related functional forms. Finally, the economically optimal stocking density will be determined from the farmer's expected profit function, based on the incidence of stochastic and nonstochastic plateaus.

II.2. Data Sources

Data on forage yield, wheat yield, steer weight, and steer grazing period were obtained from the Expanded Wheat Pasture Research facility located near Marshall, North Central Oklahoma. The soil type at Marshall is Kirkland silt loam (fine, mixed, thermic Udertic Paleustoll), which is typical of much of the wheatland in north central Oklahoma (Horn, et al.). Between 1988 and 2000 inclusive, average annual rainfall in Marshall was estimated at 84 centimeters. Data on prices and costs were obtained from USDA published series.

Stocking density experiments were conducted from the 1992/93 through the 1999/00 seasons. No data were available for the 1995/96 season. The wheat pastures were relatively large (7.3 or 9.7 hectares each), and therefore not replicated. In the 1992/1993 season, four different wheat varieties were grazed at four stocking densities that varied from 1.24 steers per hectare to 2.05 steers per hectare. In the 1993/94 season the same four wheat varieties were grazed at stocking densities that ranged from 1.04 steers per hectare to 2.05 steers per hectare. In subsequent seasons, wheat varieties and stocking densities were altered to account for variability in forage production. This underscores the importance of linking optimal stocking density with available forage at placement time. As a result, stocking densities as high as 2.87 steers per hectare were included in the studies. The average steer purchase weight and average steer placement weight in Marshall were 228 kg/steer and 230 kg/steer, respectively.

Initial standing crop measurements were made prior to placement. This involved clipping a ½ m^2 area of forage to the soil surface from each of 10 quadrats randomly selected from the pasture. This forage was dried to constant weight in a 100 ^{o}F oven and yields expressed as dry weight. Means of some important parameters are provided in table 1.

II.3. Analytical Framework

Many studies (Mader et al.; Rodriguez et al.; Horn et al.; Pinchak et al; Redmon et al., 1995b) have modeled animal response to grazing of dual-purpose winter wheat. Also, Schlegel et al. and Wachenheim et al. have modeled animal response to grazing in direct seeded alfalfa pastures. Determining an optimal stocking density has gained very little attention. Such a model could take into account total gain per steer, length of the grazing period, and initial standing crop.

A dual-purpose wheat production enterprise derives income from wheat grain and steer gain. However, the real determinants of wheat yield may be factors other than stocking density, such as the yield potential of the wheat variety. Several studies have presented reasonable grazing conditions under which grazing wheat has little or no effect on wheat grain yield (Christiansen, Svejcar and Phillips; Krenzer and Horn; Winter, Thompson and Musick; and Worrell, Undersander and Khalilian).

Hart et al.,1988b, studying rangeland stocking decisions, considered functional relationships among stocking density, livestock performance and profitability to define optimum management of different grazing systems in terms of the area and stocking density of each component. To adjust for grazing intensity differences arising from variation in forage production across years, some studies (Hart et al.,1988b; Volesky et al.; and Vallentine), standardized the grazing input to forage allowance or grazing pressure. Grazing pressure describes the relationship between the number of animal units or forage intake units and weight of dry matter forage per unit area at any one point in time while allowance is the amount of available forage per animal unit or animal unit day. Therefore, when properly defined, forage allowance is the inverse of grazing pressure. Grazing pressure is here defined based on the definitions of Hart et al., and Torell, Lyon and Godfrey, so that

$$(1)\ GP = \frac{t \times SD}{F},$$

where GP is grazing pressure in steer days per ton of forage, t is length of grazing period in days, SD is stocking density in steers per hectare, and F is quantity of forage produced in tons per hectare. One reason for expressing the grazing input as grazing pressure instead of stocking density for perennial species is to remove the effects of years on forage production (Hart et al., 1988a). However, it does not account for weight differences between stocker steers.

Some research has been undertaken on the effect of grazing pressure on average daily gain (Hart et al., 1988a; Hart et al., 1988b; Torrell, Lyon and Godfrey; and Volesky et al.), and the effect of forage allowance on average daily gain (Pinchak, et al.; Schlegel et al.; Redmon et al., 1995). These studies generally postulated a plateau function. The difference is that the response function occurs to the right of the plateau for grazing pressure, while the plateau follows the response function for forage allowance.

A plateau is observed at low grazing pressures followed by a decline in average daily gain at higher grazing pressures beyond the critical grazing pressure. As long as the critical grazing pressure is not exceeded, gain per steer per day will remain constant and high at low stocking densities. Consider the following univariate linear response plateau function

$$(2)\quad ADG = \frac{ENDWT - PLTWT}{t} = \begin{cases} \lambda_0 + \lambda_1 GP + \varepsilon, & \text{if GP > GP}_{\text{critical}} \\ ADG_{\max} + \varepsilon, & \text{otherwise} \end{cases}$$

where $ENDWT$ is ending weight (kg/steer), $PLTWT$ is placement weight (kg/steer), $GP_{critical}$ is the critical grazing pressure beyond which average daily gain decreases from the plateau level, and ADG_{max} is the maximum average daily gain represented by the plateau. Although apparently splined, the plateau function is assumed continuous, such that the term $ADG_{max} = \lambda_0 + \lambda_1 GP_{critical}$, describes the point of spline between the response function and its plateau. The slope of the response function, λ_1, is expected to be negative.

For forage allowance, the univariate linear response and plateau function may be represented as

$$ADG = \frac{ENDWT - PLTWT}{t} = \begin{cases} \alpha_0 + \alpha_1 FA + \varepsilon, & \text{if FA} < \text{FA}_{\text{critical}} \\ ADG_{\max} + \varepsilon, & \text{otherwise}, \end{cases}$$

(3)

$$\text{where } \text{ADG}_{\max} \sim \text{N}(\alpha_0 + \alpha_1 FA_{critical}, \sigma_v^2).$$

The definitions of *ADG*, *ENDWT*, *PLTWT* and *t* are the same as previously mentioned, and *FA* is forage allowance. As is the case for grazing pressure, continuity is imposed on the above functions, so that $ADG_{max} = \alpha_0 + \alpha_1 FA_{critical}$ describes the point of spline between the response function and the plateau. $FA_{critical}$ is the forage allowance that achieves the plateau and ADG_{max} is the maximum average daily gain represented by the plateau. The slope of the response function, α_1, is expected to be positive. For a given stocking density, average daily gain would increase as available forage increases, up to a plateau, beyond which the effect of additional forage is limited by natural and metabolic capabilities. Livestock consumption and gain are constrained by stomach capacity. A quadratic response plateau could be formulated by introducing a quadratic term into the response functions in (2) and (3).

In spite of the earlier works, the true form of the response function is not always known. A quadratic response plateau function has been postulated between forage allowance and average daily gain (Redmon, et al.; Pinchak et al.; Schlegel et al.) and a linear response plateau between grazing pressure and average daily gain (Hart, et al.(a); Hart et al.(b); Torell, Lyon and Godfrey). Additionally, Tembo, Brorsen and Epplin, and Berck and Helfand, raise the possibility of a stochastic response with a stochastic plateau function, given the plethora of noncontrollable factors such as weather and soil type that prevail each year. Accordingly, the model error, ε, is linearly decomposed into a pure random error, ε^*, with mean 0 and variance $\sigma^2_{\varepsilon^*}$, year random effects, u, with mean 0 and variance σ^2_u, and a random error term v associated with the stochastic plateau, with mean 0 and variance σ^2_v. Thus

$$(4)\quad \varepsilon = \varepsilon^* + u + v\,.$$

Unlike Berck and Helfand, the approach in Tembo, Brorsen, and Epplin is readily implemented with available software, and allows random effects to be estimated. If the error terms are assumed independent, then the variance of the total error is given as

$$(5)\quad \sigma^2_\varepsilon = \sigma^2_{\varepsilon^*} + \sigma^2_u + \sigma^2_v\,.$$

Because grazing pressure is the inverse of forage allowance, average daily gain was estimated as a function of forage allowance. The non-linear mixed procedure in SAS was used to estimate three models: stochastic and nonstochastic linear response plateau functions, and a nonstochastic quadratic response plateau function. In addition, a plain quadratic model with year random effect (*u*), and a model error (ε), was estimated using the SAS nonlinear mixed procedure.

The linear response plateau function is nested in the linear stochastic response plateau function. Consequently, the likelihood ratio test, which is invariant to nonlinear transformation, was used to discriminate between the two models. No other models were compared because there were no other nested models, and repeated attempts at estimating the more encompassing quadratic stochastic response plateau function, with and without the differentiability restrictions failed on convergence.

Table 2 shows estimates of parameters and variance components for four types of response functions. The linear-based response functions and the quadratic based response functions showed similar expected maximum gains per steer-day, as well as corresponding maximum forage allowances. The maximum forage allowances (or critical grazing pressures) were 0.0116 tons/steer-day (86 steer-days/ton), 0.0105 tons/steer-day (95 steer-days/ton), 0.0162 tons/steer-days (62 steer-days/ton) and 0.01665 tons/steer-day (60 steer-days/ton) for the linear plateau, the linear stochastic plateau, the quadratic plateau and the plain quadratic model. These generally corresponded to similar average daily gains that ranged from 1.17 to 1.20 kg/steer-day.

Likelihood ratio tests showed that the quadratic term in the plain quadratic model was significant, supporting earlier hypotheses on nonlinear relationships between average daily gain and forage allowance (Pinchak, et al.; Schlegel, et al.; and Redmon, et al., 1995). While the need to examine a quadratic-based stochastic model is borne out of this, the quadratic plateau models seemed generally poor, relative to the linear plateau models.

Subtracting -2 log likelihood values for the general linear stochastic plateau from that of the simple linear plateau yielded a chi-square value of 8.4, implying that the linear nonstochastic plateau function can be rejected at the 5% probability level ($\chi^2_{0.05} = 3.84$). The economically optimal stocking density was estimated based on the stochastic linear plateau, and compared to those from the nonstochastic linear plateau function and the quadratic models.

Profit Maximizing Stocking Density

In dual-purpose winter wheat production revenue is derived from both wheat grain and beef gain. To aid in formulating the farmer's profit function, the effects of stocking density on wheat grain yield was determined. Following the earlier mentioned findings of Christiansen, Svejcar and Phillips, Krenzer and Horn, Winter, Thompson and Musick, and Worrell, Undersander and Khalilian, linear and quadratic response functions with year random effects were formulated.

Wheat grain yield response to stocking density as well as to forage allowance was estimated using the SAS nonlinear mixed model, and the SAS mixed model, respectively. Results are presented in table 3. Likelihood ratio tests for the first model and Wald tests for the second model showed that stocking density and forage allowance do not have a significant effect on wheat grain yield. However results in table 4 show that stocking density has a significant effect on standing forage. Therefore, with respect to wheat grain yield, the risk neutral farmer is indifferent between the range of stocking densities that maximizes returns to the steer production enterprise. The expected profit function was formulated based on this assumption.

A static single-period economic model is postulated that allows stocking densities to be dependent upon forage availability, length of grazing period and variations in the cost/price structure of the grazing enterprise. This model employs the value of marginal product model of optimal input use as applied to a stocking density problem, and the concept of grazing pressure.

The formulated expected profit function derives revenue from expected total gain. At approximately 230 kg/steer, steer placement weight was marginally higher than steer purchase weights estimated at 228 kg/steer. It is therefore assumed that weight lost during transportation is regained in the receiving program, so that the difference between steer purchase weight and steer placement weight is negligible.

Grazing pressure in steer-days/ton of forage can also be expressed as a measure of stocking density in steer-days/ha, to account for expected forage production per unit hectare. This is achieved by multiplying the parameter estimate α_1 by the average initial standing forage value of 1.732 tons/ha. This allows total gain TG, to be expressed as

$$(6)\quad E(TG \mid GP) = E\left[(ADG \mid FA)\right] \times GP\,.$$

If ADG is expressed in kg/steer-day and GP is a measure of stocking density expressed in steer-days/ha, then total steer gain is expressed in kg/ha. The optimal grazing pressure is obtained by selecting the grazing pressure that maximizes expected net returns (\$/ha) to the steer production enterprise

$$(7)\quad E(\pi \mid GP) = p\Big[\ (E(TG \mid GP(\bar{t},\bar{F},SD)))\ \Big] - rGP(\bar{t},\bar{F},SD)$$

where p is the value of steer gain in \$ per kg, and r is the marginal cost of the steer grazing enterprise in \$ per steer-day. It is assumed that the length of the grazing period, $\bar{t}$ and the amount of available forage, $\bar{F}$, will be determined exogenously.

Total gain expresses steer gain per hectare for the length of the grazing season. It is obtained by multiplying ADG by grazing pressure, which is expressed in steer-days per hectare. Obtaining total gain in this manner introduces heteroscedasticity in the model when the response function is stochastic, such that variability in total gain increases as grazing pressure increases. Based on the plateau function in (3), total gain is expressed as[2]

$$(8)\quad TG = ADG \times GP = \begin{cases} \alpha_0 GP + \alpha_1 + \varepsilon \times GP, & \text{if FA} < \text{FA}_{\text{critical}} \\ ADG_{\max} \times GP + \varepsilon \times GP, & \text{otherwise}, \end{cases}$$

$$\text{where } \text{FA}_{\text{critical}} \sim \text{N}((\text{ADG}_{\text{m}} - \alpha_0)/\alpha_1, \sigma_v^2/\alpha_1^2),$$

where ADG_m is the mean average daily gain. $TG_{max} = ADG_{max} \times GP$ is the maximum total gain, and $FA^{-1} = GP$ when the determinants are expressed in identical units. Based on (8), the total gain function may be expanded by use of an indicator function, such that

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[2] Other variables such as ADG_{max}, $GP_{critical} = FA^{-1}_{critical}$ or TG_{max} can be used as spline criterion, rather than $FA_{critical}$. Since $FA_{critical}$ is normally distributed, it is easier to work with.

$$TG = \{(\alpha_0 GP + \alpha_1)(1 - I_{-\infty,GP^{-1}}(FA_{critical})) + ADG_{\max} GP\, I_{-\infty,GP^{-1}}(FA_{critical})\} + \varepsilon \times GP \tag{9}$$

where the indicator function is defined as

$$I_{-\infty,GP^{-1}}(FA_{critical}) = \begin{cases} 1, & \text{if } FA_{critical} \le GP^{-1} \\ 0, & \text{otherwise} \end{cases}. \tag{10}$$

Based on the assumption that the expected value of the error term is zero, expectations of the total gain function in (9) may be taken to obtain the following:

$$\begin{aligned} E(TG \mid GP) = (\alpha_0 GP + \alpha_1) E(1 - I_{-\infty,GP^{-1}}(FA_{critical})) \\ + E(ADG_{\max} GP\, I_{-\infty,GP^{-1}}(FA_{critical})) \end{aligned}, \tag{11}$$

where the expected value of the indicator function is defined as

$$E(I_{-\infty,GP^{-1}}(FA_{critical})) = \text{prob}(FA_{critical} \le GP^{-1}) = F(GP^{-1}). \tag{12}$$

$F(.)$ is the cumulative density function of $FA_{critical}$ evaluated at GP^{-1}. Because of the nonlinearity of the stochastic plateau functions the expectations must be maintained throughout the derivation. Based on the distributional assumption of $FA_{critical}$ in (8), the normal density function of $FA_{critical}$ is expressed as

$$(13)\quad f(FA_{critical}) = \frac{1}{(2\pi\sigma_v^2 / \alpha_1^2)^{\frac{1}{2}}} \exp\left(-\frac{(FA_{critical} - \mu_{FA})^2}{2\sigma_v^2 / \alpha_1^2} \right),$$

where the parameter μ_{FA} is the mean critical forage allowance in hectares of forage per steer-day associated with the plateau level *ADG*. Executing the expectations in (11) gives

$$(14)\quad \begin{aligned} E(TG \mid GP) &= (\alpha_0 GP + \alpha_1)(1 - F(GP^{-1})) \\ &\quad + \int_{-\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical}) GP\ f(FA_{critical}) dFA_{critical} \end{aligned}$$

where $F(GP^{-1})$ is the cumulative density function, defined as $\int_{-\infty}^{GP^{-1}} f(FA_{critical})$. For the normal probability density function, *F*(.) does not have a closed-form solution.

The expected profit function for the risk-neutral decision-maker is expressed as

$$(15)\quad E(\pi \mid GP) = pE(TG \mid GP) - rGP,$$

where *p* and *r* are the same as described in (7). By substituting (14) into (15) the risk neutral decision-maker will

$$(16)\quad \begin{aligned} \text{Max } E(\pi \mid GP) &= p\left[(\alpha_0 GP + \alpha_1)(1 - F(GP^{-1}))\right] \\ &\quad + p\left[\int_{-\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical}) GP\ f(FA_{critical}) d(FA_{critical}) \right] \\ &\quad - rGP. \end{aligned}$$

When the response function is a stochastic linear response plateau, (16) describes the profit-maximizing decision-maker's utility. To obtain the profit-maximizing level of grazing pressure, the first-order condition can be obtained by differentiating the above equation with respect to GP, so that

$$\begin{aligned}
\frac{\partial E(\pi \mid GP)}{\partial GP} &= p\left[\frac{\partial(\alpha_0 GP + \alpha_1)(1-(F(GP^{-1}))}{\partial GP}\right] \\
(17) \qquad &+ p\left[\frac{\partial}{\partial GP}\int_{-\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical})GP\ f(FA_{critical})dFA_{critical}\right] \\
&- r = 0.
\end{aligned}$$

The chain rule is used to evaluate the derivative in the first term, yielding

$$(18) \quad p\left[\frac{\partial(\alpha_0 GP + \alpha_1)(1-F(GP^{-1}))}{\partial GP}\right] = p(\alpha_0(1-F(GP^{-1}) + (\alpha_0 GP + \alpha_1)(fGP^{-1})GP^{-2}).$$

To evaluate the derivative of the integral in the second term requires an adaptation of the Liebnitz integral rule, following the definitions of Khuri, and the exposition of Tembo, Brorsen and Epplin. If a function $G:[a_2, b_2] \rightarrow \Re$ is differentiable and $G(x_2) = \int_{\eta(x_2)}^{\theta(x_2)} g(x_1, x_2)dx_1$, then the Liebnitz rule suggests that

$$(19) \quad \frac{\partial G}{\partial x_2} = \int_{\eta(x_2)}^{\theta(x_2)} \frac{\partial g(x_1, x_2)}{\partial x_2} dx_1 + \theta'(x_2)g(\theta(x_2), x_2) - \eta'(x_2)g(\eta(x_2), x_2),$$

where $g(.)$ is a continuous function of x_1 and x_2. If the upper and lower limits of the integral are continuous functions of x_2, then their respective derivatives are $\theta'(x_2)$ and $\eta'(x_2)$. Based on (17), G may be defined as

$$(20)\quad G(x) = \int_{\eta(x)}^{\theta(x)} (\alpha_0 + \alpha_1 FA_{critical}) GP\ f(FA_{critical}) dFA_{critical} \text{ ,}$$

where $\eta(x) = -\infty$ and $\theta(x) = GP^{-1}$. When the Liebnitz rule is applied to the second term in (17), it can be shown that

$$(21)\quad \begin{aligned} & p\left[\frac{\partial}{\partial GP} \int_{\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical}) GPf(FA_{critical}) dFA_{critical}\right] \\ & \qquad = p(-GP^{-2}(\alpha_0 GP + \alpha_1) f(GP^{-1})) \\ & \qquad + \text{p}(\int_{-\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical})\ f(FA_{critical})\ d(FA_{critical})). \end{aligned}$$

The second term in (18) and the first term in (21) cancel, so that

$$(22)\quad \begin{aligned} \frac{\partial E(\pi \mid GP)}{\partial GP} = & \ p\left[\alpha_0 (1 - F(GP^{-1})) + \int_{-\infty}^{GP^{-1}} (\alpha_0 + \alpha_1 FA_{critical}) f(FA_{critical}) d(FA_{critical})\right] \\ & - r = 0. \end{aligned}$$

Because the cumulative density function does not have a closed-form solution, (22) cannot be solved analytically. A grid search procedure was used to obtain the grazing pressure that maximizes the risk-neutral decision-maker's expected profit.

The parameter values for α_0 and α_1 in the linear stochastic plateau are given in table 2 as 0.4812 and 66.47, respectively. The value of α_1 is further adjusted to account for forage allowance in hectares per steer-day, rather than tons per steer-day, by multiplying by the average initial standing crop of 1732 kg/ha and dividing by 1000 kg/ton. This gives a value of 115.13 for α_1.

The steer sale price and steer carrying costs were estimated for the 1999/2000 wheat-growing season, based on data obtained from Marshall and the USDA. The average steer sale price for steers in the Marshall trials was estimated at \$75 per 45.5 kg wt, while the purchase price was \$86 per 45.5 kg wt. If the initial steer weight was 228 kg, for an average ADG of 0.99 kg/steer-day and a grazing period of 120 days, the value of gain was estimated as \$1.20 per kg, using the following equation

$$(23) \qquad \mathrm{VG} = \frac{[\text{Sale Price} \times (\text{Initial wt} + \text{grazing period} * \text{ADG})] - (\text{Initial wt} * \text{Pur. Price})}{\text{grazing period} * \text{ADG}},$$

where *VG* is value of gain (\$/kg).

Steer production costs were adapted from cost data obtained from the Expanded Wheat Pasture Research facility near Marshall, Oklahoma. The steer carrying costs include order buyer fees (\$4.97/steer), shipping to pasture (\$9.95/steer), receiving program (\$9.53/steer), hay during inclement weather (\$1.44/steer), high calcium mineral mixture (\$0.76/steer) and veterinary and medicine (\$9.00/steer). It also covers shipping to market and sales commission (\$14.90/steer), machinery costs (\$10.00/steer) and labor (\$7.50/steer). Interest on operating capital was estimated based on a 9.50 % interest rate

(Fed Bank prime loan rate), resulting in \$13.37 per steer for a 228 kg steer purchased at \$428 per steer, and grazed for approximately 120 days. The marginal variable cost, *r*, was estimated at \$0.67 per steer-day.

Substituting for *p*, α_0, α_1 and *r* in (22), and using a grid search procedure in MAPLE, yields an economically optimal grazing pressure of 178 steer-days per hectare. Based on a 120-day grazing period, this grazing pressure translates into a stocking density of 1.48 steers per hectare or 0.60 steers per acre. Figure 1 shows the movement of expected profit as grazing pressure increases.

For the nonstochastic linear plateau function, the problem involves comparing the value of marginal product to the marginal cost of the steer grazing enterprise. If the value of marginal product exceeds the marginal factor cost, then the economically optimal $GP = GP_{max}$. At p=\$1.20 and r=\$0.67, the value of marginal product (of \$0.72) obtained by multiplying the price by the marginal physical product of total gain (\$1.20*0.6002), exceeds the marginal cost of steer grazing (\$0.67), therefore the economically optimal grazing pressure is 149 steer-days per hectare. For a 120-day grazing period, this is equivalent to 1.24 steers per hectare or 0.50 steers per acre.

The solution steps for the plain quadratic function are the same as those for the quadratic nonstochastic plateau. Multiplying the quadratic average daily gain response function by grazing pressure in steer-days per hectare, produces a total gain function whose marginal product when set equal to the cost-price ratio yields a profit maximizing grazing pressure

$$(24)\quad GP = \left[\frac{\alpha_2}{\frac{r}{p} - \alpha_0} \right]^{\frac{1}{2}},$$

which implies infinite stocking density if the cost-price ratio is less than α_0. The cost-price ratio is 0.5883 while the value of α_0 is 0.4550 for the quadratic nonstochastic plateau, and 0.4581 for the plain quadratic plateau. The values of α_2 are adjusted to reflect forage production per hectare by multiplying by the average initial standing forage of 1.732 tons/ha. This gives optimal grazing pressures of 217 steer-days per hectare and 216 steer-days per hectare for the quadratic nonstochastic plateau and the plain quadratic plateau, respectively. Based on a 120-day grazing period, the two quadratic functional forms yield an optimal stocking density of approximately 1.80 steers per hectare (0.73 steers per acre). Table 5 shows optimal grazing pressures and stocking densities by response function.

Note that to derive the optimal stocking density (steers per hectare), the optimal stocking density in steer-days per hectare is divided by the number of days in the grazing period. Therefore at placement time, the farmer must exogenously determine the amount of available forage, and assume knowledge of the length of the grazing period. Following Redmon et al., knowledge of timing of the development of first hollow stem in ungrazed wheat is important in maximizing net returns to the wheat grain-stocker cattle enterprise.

Additional analyses were carried out to determine how changes in the cost-price structure affect optimal stocking density for the stochastic linear plateau function. The marginal steer production costs were increased to \$1.01, and then to \$1.40. At r=\$1.01 the optimal grazing pressure declined to 162 steer-days per hectare. When r was further increased to \$1.40, the optimal grazing pressure declined to 144 steer-days per hectare. The results suggest that the incidence of uncertainty leads to higher grazing pressure, but this depends on the cost-price structure of the grazing enterprise.

Table 6 summarizes changes in grazing pressure with changes in initial standing forage and value of gain. As expected, optimal grazing pressure, and therefore stocking density, increased with increase in initial standing forage, as well as increase in expected value of gain.

II.4. Summary and Conclusions

Farmers in Oklahoma generally cultivate much of their wheat crop as dual-purpose wheat. The purpose of this study is to enable the farmer make the choice of stocking density that would maximize expected economic profits, based on standing wheat crop at placement time, and *a priori* knowledge of the length of the grazing period. The response of average daily gain to the standardized grazing input, forage allowance, was evaluated with stochastic and nonstochastic linear, as well as a quadratic nonstochastic response plateau. To aid in formulating a profit function, the effect of stocking density on wheat grain yield was also evaluated.

Stocking density does not affect wheat grain yield if the appropriate agronomic practices are followed. Therefore the rational farmer's stocking decision is to select the stocking density that maximizes profits from the steer production enterprise, while ensuring that wheat grazing begins after proper root formation and ceases prior to the development of first hollow stem.

Based on a stochastic linear plateau the economically optimal grazing pressure was estimated at 178 steer-days per hectare, yielding a stocking density of 1.48 steers per hectare (0.60 steers per acre), based on a 120-day grazing period. This grazing pressure was higher than when the plateau was not stochastic. Uncertainty leads to higher stocking densities, depending on the cost-price structure of the steer grazing enterprise. The higher stocking density in the stochastic plateau is essentially a result of the producer making sure that there are enough cattle to eat all of the forage available.

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Table 1. Means for Average Daily Gain, Forage Allowance, Grazing Pressure and Stocking Density at the Expanded Wheat Pasture Research facility near Marshall, Oklahoma, 1992-2000.

Item	Unit of measure	Mean
Average daily gain[a]	kg/steer-day	0.9900
Forage allowance	tons/steer-day[b]	0.0086
Grazing pressure	steer-days/ton	116.75
Stocking density	steer-days/ha	190.00
Stocking density	steers/ha	1.6000

[a] This is the average daily gain of steers stocked on wheat pasture with an average placement weight of 230 kg/steer an average of 120 grazing days.

[b] A ton is 1,000 kg.

Table 2. Average Daily Gain Response to Forage Allowance for Different Functional Forms, Marshall, Oklahoma 1992-2000

		Estimates and standard errors by type of response function[a]			
Regressor/Error Component	Symbol	Linear plateau	Linear stochastic plateau	Quadratic plateau [b]	Plain quadratic [c]
Intercept	α_0	0.6002 (0.1019)	0.4812 (0.1038)	0.4550 (0.1330)	0.4581 (0.1152)
Forage allowance (tons/steer-day)	α_1	49.32 (9.68)	66.47 (9.59)	91.05 (22.69)	89.54 (16.82)
Forage allowance squared	α_2			-2818.00 (1024.00)	-2688.59 (675.00)
Expected maximum gain (kg/steer-day)	ADG_{max}	1.1740 (0.0734)	1.1798 (0.0997)	1.1905 (0.0764)	1.2036 (0.0745)
Forage allowance at maximum gain (tons/steer-day)	$FA_{critical}$	0.0116 (0.0010)	0.0105 (0.0011)	0.0162 (0.0021)	0.01665 (0.0013)
Variance of year random effects	σ_u^2	0.0321 (0.0181)	0.0384 (0.0214)	0.0322 (0.0181)	0.0324 (0.0182)
Variance of error term	$\sigma_{\varepsilon^*}^2$	0.0160 (0.0026)	0.0123 (0.0021)	0.0161 (0.0027)	0.0158 (0.0026)
Variance of plateau level gain	σ_v^2		0.0022 (0.0163)		
-2 Log Likelihood		-83.9	-92.3	-83.2	-84.6

[a] The dependent variable is average daily gain (kg) of steers with an initial weight of 230 kg; standard errors are in parentheses.

[b] Differentiability is imposed so the linear stochastic plateau is not a special case.

[c] Differentiability was imposed to estimate optimal forage allowance and its corresponding average daily gain.

Table 3. Wheat Grain Yield Response to Stocking Density and Forage Allowance, Marshall, Oklahoma 1992-2000

		Estimates and standard errors for stocking density as independent variable [1]		Estimates and t-values for forage allowance as independent variable [2]	
Regressors	Symbol	Simple linear	Simple quadratic	Simple linear	Simple quadratic
Intercept	α_0	2222.80 (281.79)	2549.23 (573.48)	1833.17** (6.61)	1428.31** (3.60)
Stocking density	α_{1SD}	-148.55 (97.18)	-562.39 (641.01)		
Forage allowance	α_{1FA}			16135.00 (1.28)	95143.00 (1.67)
Stocking density squared	α_{2SD}		117.99 (180.53)		
Forage allowance squared	α_{2FA}				-3255569.00 (-1.42)
Year random error	σ_u^2	370788 (245713)	370791 (254871)	408683	408670
Model error	σ_ε^2	185081 (31203)	185093 (31331)	184068	181520

[1] Likelihood ratio tests show that neither the linear term, nor the quadratic term has a significant effect on yield (-2 Log Likelihood values for the general model = 1230.6, and for the restricted models when $\alpha_1=0$ is 1231.4, and when $\alpha_2=0$ is 1231.1). The models were estimated by SAS NLMIXED procedure.

[2] Statistical significance at 1 % and 5 % are respectively denoted by ** and *. The models were estimated by SAS MIXED procedure.

Table 4. Average Standing Forage Response to Stocking Density, Marshall, Oklahoma, 1992-2000.

		Estimates and standard errors by type of response function	
Regressor	Symbol	Simple linear	Simple quadratic
Intercept	α_0	2831.53^{**} (13.31)	3681.23^{**} (8.28)
Stocking density	α_1	-641.78^{**} (-8.20)	-1717.97^{**} (-3.42)
Stocking density	α_2		306.83^{*} (2.17)
Year random error	σ_u^2	196391	191611
Model error	σ_ε^2	120407	114842

Note: t-statistics are provided in parentheses; ** and * denote significance at 1% and 5 %, respectively.

Table 5. Optimal Stocking Density by type of Response Function.

		Response function			
Item	Unit	Linear plateau	Linear stochastic plateau	Quadratic plateau	Plain quadratic
Grazing pressure	Steer-days per hectare	149	178	217	216
Stocking density	Steers per hectare	1.24	1.48	1.81	1.80
Stocking density	Steers per acre	0.50	0.60	0.73	0.73

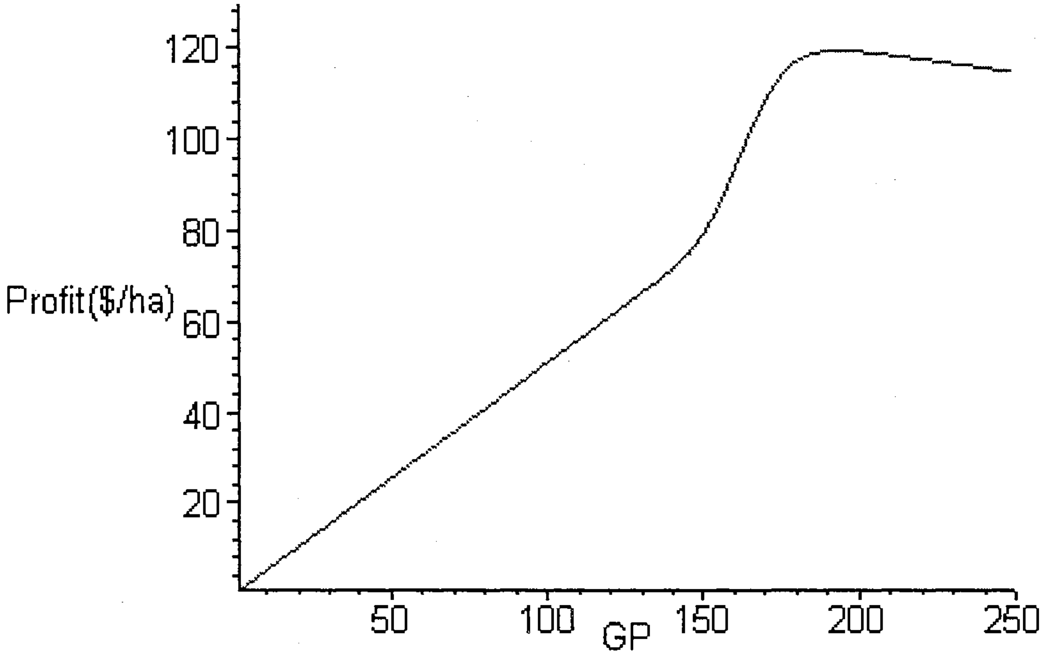
Note: Stocking density is based on 120-day grazing period.

Table 6. Effects of Changes in Forage Availability and Value of Gain on Optimal Stocking Density (steers per hectare) for the Stochastic Linear Plateau Function.

	Initial standing forage (kg/hectare)		
Value of gain ($/kg)	1200	1732	2000
1.00	0.98	1.43	1.65
1.20	1.03	1.48	1.72
1.35	1.10	1.58	1.83

Note: Optimal stocking density is based on a 120-day grazing period. The marginal cost of steer grazing is assumed constant at $0.67 per steer-day.

Figure 1. Expected Profit Function



CHAPTER III

III. ESTIMATED COSTS AND RETURNS TO MANAGEMENT STRATEGIES IN A STOCKING DENSITY EXPERIMENT

ESTIMATED COSTS AND RETURNS TO MANAGEMENT STRATEGIES IN A STOCKING DENSITY EXPERIMENT

ABSTRACT

Winter wheat is used as dual-purpose (forage and grain) crop in the Southern Plains of the United States. A research facility designed to test wheat and wheat stocker production strategies, was established near Marshall, Oklahoma in 1989. The purpose of this paper is to provide a description of some of the studies, summarize some of the results, and to determine the economic consequences of alternative stocking densities.

ESTIMATED COSTS AND RETURNS TO MANAGEMENT STRATEGIES IN A STOCKING DENSITY EXPERIMENT [1]

III.1. Introduction

In the southern plains, grazing winter wheat is a common practice that ultimately produces both meat and grain. Animal gain as well as wheat grain yield depends on the weather, stocking density, phase of vegetative growth at which grazing is terminated and wheat variety.

Pinchak et al.(1996) estimate that up to 80 percent of the 20 million acres annually seeded to wheat in the southern plains is grazed in fall through winter. In Oklahoma, about 7 million acres were seeded to wheat in 1995, two thirds of which the producers intended to use for forage and grain (True et al., 2001). The same study showed an average fall/winter grazing stocking density of 0.37 steers per acre. The farmer's choice of stocking density may not have a basis in economic or risk optima.

Tweeten (1982) hypothesized that approximately 1.5 million stocker cattle graze winter wheat in Oklahoma. True et al., (2001) estimated that the total number of stocker steers and stocker heifers on Oklahoma pastures in the fall/winter 1995-96 season was 868 thousand. Although a higher stocking density may lead to an increase in per acre return, grazing if not properly managed may decrease grain yield. This makes timing of grazing extremely important. If winter wheat is grazed and the animals removed prior to

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the emergence of first hollow stem, the crop's grain production potential will remain relatively unaffected. The importance of the timing of removal is underscored by Redmon et al., (1996) who suggest that net return from wheat as well as total net return from cattle plus wheat will continue to decline as cattle continue to graze beyond the first hollow stem stage of growth.

Beef cattle have emerged as the most important agricultural product in the state of Oklahoma, generating an estimated $ 1.2 billion in revenue in 1998 (OASS, 1999). Very low stocking densities may lead to vast amounts of forage remaining unutilized. On the other hand very high stocking densities may lead to overgrazing, probably resulting in reduced grain yield. Hence the need arises to determine an optimal stocking density. Also, little work has been done to determine comprehensive strategies that would optimize returns to a farm family's resources devoted to the production of winter wheat and livestock grazing on wheat pasture (True, et al., 2001).

Grazing experiments have been conducted at Oklahoma State University's Expanded Wheat Pasture Research Center in Marshall, North-Central Oklahoma, since the 1989-90 wheat production season. These trials have included a myriad of important wheat production practices. These experiments have produced data that may be used to determine the economics of wheat pasture production and use. The costs of these practices, and ultimately, the net returns to the fixed production resources are equally important, but unknown at this time.

The Marshall research facility has been instrumental in a number of important research studies that have addressed issues associated with stocking steers on dual-purpose wheat pasture. This includes the following studies: bloat prevention (Anderson and Horn, 1987), stocker steer supplementation strategies (Coulibaly, Bernardo, and Horn, 1996; Horn et al.,1995a; Paisley and Horn, 1996; Paisley and Horn, 1998; Paisley, Ackerman and Horn, 1997; Paisley, 1998), use of ionophores (Andrae et al., 1995), wheat planting date (Epplin, Hossain, and Krenzer, 2000; Horn et al., 1998; Horn et al., 1999), grazing termination (Krenzer et al., 1995; Redmon et al., 1996), wheat variety selection (Horn et al., 1994; Horn et al., 1995b), development of a management decision aid (Epplin, Horn, and Krenzer, 1999a; Epplin, Horn, and Krenzer, 1999b; Epplin, Horn, and Krenzer, 1999c), and several other issues (Horn et al., 1995c; Redmon et al., 1995).

Several important issues that have not been resolved in the aforementioned studies involve stocking density. Specifically, wheat fall-winter forage yield response to stocking density, wheat grain yield response to stocking density, and stocker steer weight gain response to stocking density have not been determined. Stocking density is a very important management decision. If too few animals are stocked on the wheat forage, the excess forage will be lost. If too many animals are stocked on the wheat forage, weight gain will be limited and in the extreme case, animals may lose weight.

The stocking density decision is also complicated by the variability of weather in the region. Over the time period from 1988 to 2000, at the Marshall facility, annual precipitation ranged from 25.5 inches in 1990 to 42 inches in 1999. In the very important wheat forage production month of October, rainfall ranged from 0.5 inch in 1995 to 7.7 inches in 1998. The Palmer Drought Severity Index (PDSI) provides another measure of weather variability. Based upon the PDSI September of 1992 was “severely wet” whereas September of 1998 was a time of “severe drought”.

Objectives

The grazing experiments at Oklahoma State University's expanded wheat pasture research center in Marshall, North-Central Oklahoma were designed, in part, to determine steer weight gain and wheat grain yield response to stocking density for dual-purpose wheat. The objectives of this paper are to:

1. Describe how wheat and stocker steers were managed on the 16 pastures at the Marshall facility from 1989 to 2000.
2. Report the wheat fall-winter forage yield, wheat grain yield, and stocker steer weight gain for the 16 pastures.
3. Prepare a base dual-purpose wheat returns and cost budget.
4. Prepare a base returns and cost budget for fall-winter wheat pasture stocker steers.
5. Determine the returns and costs for each of the alternative wheat varieties by year, by stocking density.
6. Determine wheat fall-winter forage yield response to stocking density.
7. Determine wheat grain yield response to stocking density.
8. Determine steer weight gain response to stocking density.
9. The ultimate objective is to determine the economically optimal stocking density.

III.2. Procedure

First the steer and wheat production enterprises conducted at the Marshall, Oklahoma research facility are documented and described. Then enterprise budgets are used to determine returns to land and management, for each pasture in each year. These total costs and returns were based on a dual-enterprise structure, steer production and wheat production, as illustrated by the following multi-product expected net returns function:

$$E[\pi] = \sum_{i}^{n} p_i E[y_i(x_1, \ldots, x_m)] - \sum_{j}^{m} r_j x_j - FC, \tag{1}$$

where y_i is the level of the ith output, with its corresponding price per unit p_i, x_j is the level of the jth input with per unit cost r_j, and FC represents the fixed costs. In analyzing the Marshall experiment, the dual-enterprise is assumed to be owner-operated. The total returns were then compared across stocking density and season to determine whether there are any obvious changes in net returns that were due to changes in stocking density or season.

It was assumed that the type of cattle used in the trials was consistent across pastures and seasons. Therefore average returns were calculated and compared across seasons and across stocking density. Returns were determined for each stocking density for each variety for each season. The process of aggregation (of forage yield, grain yield and net returns) would be aided by mixed linear regression procedures designed to determine the effect of wheat variety on grain yield, forage yield, steer weight gain and net returns, using maximum likelihood estimates. The postulated linear relationships are generally supported in the literature (Paisley, 1998; Horn et al., 1994). The linear functions were compared to quadratic functions. In addition to stocking density, the independent variables included dummy variables for seasons (year) and varieties.

The SAS MIXED procedure dropped three instead of two dummy variables to prevent the problem of singular matrices. This was undesirable, hence a new restriction was imposed such that all wheat varieties grown in one or two seasons were aggregated into a group called 'Fields'. Therefore 'Fields' in the regression analyses includes the following wheat varieties: Karl, Longhorn, Scout 66, 2163 and 2174. These classifications were only used in the regression procedures.

The Marshall Research Facility

The Marshall research facility is located northwest of the intersection of state highways 74 and 51 in northwest Logan County in central Oklahoma. The predominant soil type in Marshall and much of north-central Oklahoma is Kirkland silt loam (fine, mixed, thermic Udertic Paleustoll). The 440-acre facility includes 16 pastures, the sizes of which are either 18 or 24 acres (table 1). Each of these pastures constituted a unique treatment - one of several wheat varieties grazed at a given stocking density. It was practically impossible to replicate the experiment because of the relatively large sizes of the experimental units.

Weather plays an important role in dual-purpose wheat production; data on rainfall precipitation and drought were reported to illustrate changes in weather. Table 2 contains monthly rainfall precipitation for the years 1988 through June 2000 for Marshall, Oklahoma. This period covers the years for which the experiment was conducted. Dual-purpose wheat is usually planted in September, and harvested in June. Steers graze on fall-winter wheat pasture from November through February. Total rainfall was highest in 1999, and lowest in 1990. Except for 1994 and 2000, on average the month of September showed moderate to high rainfall. Drought-like conditions were evident for the months of December, January and February in the 1994/95 growing season, although this period was preceded by a couple of months of high rainfall. This probably accounts for the extremely low grain yields obtained for that season. From 1988 through 2000 average annual rainfall was approximately 33 inches.

Table 3 contains monthly data for the Palmer Drought Severity Index (PDSI) for Central Oklahoma. The PDSI is published by the National Oceanic and Atmospheric Administration (NOAA). It has values that generally range from -6 to +6, with negative values used to denote dry periods and positive values, wet periods. PDSI values ranging from 0.5 to - 0.5 generally imply "normal"; - 0.5 to -1.0 is incipient drought; - 1.0 to - 2.0 is mild drought; - 2.0 to - 3.0 imply moderate drought; and - 3.0 to - 4.0 imply severe drought. Similar ranges of positive values are used in describing wet periods.

The data in table 3 confirm the presence of incipient drought in much of 1994 including the months of September and October. The PDSI shows there was incipient to severe drought for almost all of the 1995-96 growing season. No experimental data were collected for the 1995/96 growing season.

III.3. Results and Discussion

The results include descriptive analyses of the wheat enterprise and the stocker steer enterprise, as well as econometric analyses of the effects of stocking density, wheat variety and season on average standing crop, wheat grain yield and steer weight gain. Ultimately the budgets were developed and used to estimate net returns to land and management, and to determine the effects of stocking density, wheat variety and season on these net returns.

The Wheat Enterprise

This section concerns the economics of growing wheat as a dual-purpose crop. In dual-purpose production where wheat is grazed and harvested for grain, an estimate of the returns to the fixed production resources will aid in determining differences in determining expected returns across differing stocking densities.

Table 4 shows the field operations that were carried out for the wheat production enterprise while table 5 shows the prices and quantities of some of the inputs used in the wheat production enterprise. Tillage was done by use of an offset disk in June, a chisel and offset disk in July, and a field cultivator in August and September. During the first field cultivation in August, anhydrous ammonia (82-0-0) was applied preplant typically at the rate of 170 lbs per acre. Nitrogen application level was based upon a targeted yield goal of 3000 lbs of fall-winter forage, and 50 bushels of grain per acre. In subsequent seasons, the amount of anhydrous ammonia applied varied from 189 lbs per acre in 1989, to 98 lbs per acre in 1991, to 168 lbs per acre in 2000. In September (usually the first week) wheat is drilled into furrows at a rate of 120 lbs per acre. At the same time diammonium phosphate (18-46-0) was placed in the furrows at the rate of 50 lbs per acre to meet the phosphorus requirements.

The herbicide Finesse was applied at 0.4 oz per acre every other year at a cost of $13.00 per ounce. Lime requirements were met by applying two tons per acre ECCE lime in the summer of 1992. By the summer of 1994, the initial pH of 4.7-4.9 had stabilized at pH 5.7.

The wheat pastures were grazed from November to February and combine-harvested in June. As shown in table 5, the winter wheat seed price is the August Oklahoma City wheat price received, multiplied by two. This assumption was used due to the absence of more precise wheat seed price data. Even though the US average is higher in many cases, the rationale is that most farmers may save seed from the previous season's wheat harvest.

Although the experiments at Marshall commenced in 1989, the stocking density experiments began in earnest in 1992. Four semi-dwarf hard red winter wheat varieties Karl, 2163, 2180 and AgSeCo 7853 were grazed in the first two seasons, 1992/93 and 1993/94. In the following seasons, except for 1995/96, Karl and 2163 were replaced with Longhorn and Scout 66. In 1997/98 growing season and subsequent growing seasons, Tonkawa replaced all varieties, except for the 1999/00 season when 2174 was also included.

In 1992, Karl was the most popular variety in Oklahoma, although it is susceptible to acid soil conditions and leaf rust. Varieties 2163 and AgSeCo 7853 were new wheat varieties. 2163 is acid-tolerant and less susceptible to leaf rust than Karl, while AgSeCo 7853 shows moderate to high tolerance to soil acidity and leaf rust. 2180 is early maturing and shows moderate to high resistance to soil acidity and leaf rust. Scout 66 is a tall late maturing wheat variety, which is highly susceptible to both soil acidity and leaf rust. Tonkawa is resistant to leaf rust, but susceptible to soil acidity. The wheat varieties used in this experiment were generally tolerant to soil-borne mosaic virus. By the year 2000, many of these wheat varieties had lost their initial appeal to farmers, such that in 2000 the top wheat variety by percentage of Oklahoma seeded acres was Jagger at 38.1 percent.

Stocking density is determined by availability of forage and prevailing climatic conditions. When varieties are being evaluated, potentially large year-to-year or environmental effects make it imperative to conduct the experiments over several years (Epplin et. al., 1996). Several studies (eg Bruckner and Raymer, 1990) suggest that varietal differences in forage production may exist. After the first season of the stocking density experiment, stocking densities were varied depending on the amount of forage available at the time of placement, and sometimes, during grazing. Standing wheat crop was measured per acre per pasture, three times in the 1992/93 season, and four times in the subsequent years, except for 1999/00 when the measurement was done three times. The results, together with the average standing crop, are reported in table 6. The initial standing crop measurements were made prior to placement. The results indicate that average standing crop was highest for the 1994/95 season and lowest for the 1992/93 season.

Table 7 contains wheat grain yields from the dual-purpose forage plus grain experiments, as well as the corresponding county averages from all wheat harvested in the county (includes grain only and dual-purpose wheat). To enable comparison with county averages, wheat yields were averaged across seasons and compared to the Logan County average for each season. In general, Logan County average yields compared favorably with experimental yields. For three of the seven seasons, the county average was higher than the experiment average. Wheat yields were very low in 1995. On the other hand, the latter seasons: 1997/98, 1998/99 and 1999/00 registered consistently high county and experiment yields.

Because wheat was predominantly harvested in June, June wheat prices are reported. As reported in table 8 the highest June wheat price of $5.48 per bushel was recorded for 1996. That coincided with the drought period when inventories and production were low. Otherwise the nominal June wheat prices did not appear to follow any trend. However, it is evident that after the high of 1996, wheat prices declined.

Table 9 includes a standard enterprise budget developed for the purpose of estimating net returns to fixed production resources. For the wheat enterprise, gross receipts are obtained from the sale of wheat grain. The value of the fall-winter forage is not included in the budget. Oklahoma City market wheat prices are used for obtaining production values. The operating capital costs included wheat seed, diammonium phosphate and anhydrous ammonia in quantities and unit costs as reflected in table 5, and elsewhere as has been described. The operating costs were adjusted to reflect the 10-month period between seeding in September and grain harvest in June.

The Stocker Steer Enterprise

This is an attempt to estimate costs and returns to the stocker steer component of dual-purpose wheat, where wheat is grazed and harvested for grain. This provides information on the economics of grazing wheat, as opposed to growing wheat for grain alone when compared to the costs and returns from the wheat enterprise.

Steers used in the Marshall experiments were predominantly crosses; data on their origin are only available for four seasons (table 10). Table 11 shows the total number of steers purchased, average purchase weights and receiving dates. For the purpose of budgeting, the purchase prices are based on Oklahoma City prices. In table 12 October purchase prices for Oklahoma City market medium/large frame No. 1 steers are listed. After the steers have been purchased they are transported to the Marshall facility where they are put in a receiving program. The receiving program lasted from four days in the 1993/94 season to 22 days in the 1998/99 season.

In the receiving program steer calves were vaccinated with modified live virus strains of IBR, BVD and BRSV plus a *Leptospira pomona* bacterin within 24 hours of arrival. They were also given an intranasal IBR/PI3 vaccine and a Pastuerella haemolytica bacterin-toxoid "One-shot". The combination of IBR, BVD, BRSV, and PI3 was administered twice at $0.90 per head. Ivomec-F was administered once at $0.50 per hundred pounds of body weight, to treat internal and external parasites.

During the receiving program, the calves were fed free choice bermudagrass hay, amounting to an intake of about 8 lbs/steer/day, and 2 lbs/steer/day of a soybean meal-based, high protein supplement that contained vitamin E, Deccox and Selenium. The budgeted quantities of bermudagrass hay and the soybean meal varied with the length of the receiving program while the prices were fixed at $0.03 per pound and $0.09 per pound, respectively. The steers were implanted with Synovex-S® immediately before placing them on wheat pasture. The five-way clostridia and Synovex-S were administered once during the receiving program, at $0.25 and $0.70 per head, respectively. The receiving program activities are specified in the steer production enterprise budget (table 13).

Following the receiving program steers were weighed and placed on pastures. The recorded placement weights are shown in table 15. The steers were provided free-choice access to a high calcium commercial mineral mixture, but received no other supplemental feed except for limited amounts of alfalfa hay when snow covered the wheat fields. For the purpose of this analysis it was assumed that there were two days of inclement weather in a typical season, so that the steers received 12 lb of alfalfa hay per day for two days, at a fixed cost of $0.06 per lb. Steers were only removed from the pastures for periodic weighing. For our purpose it was assumed that at the end of the grazing period steers were shipped to the market for sale. The Oklahoma City market March sale prices for medium/large frame No. 1 steers are reported in table 14.

As stated earlier, table 13 shows the steer enterprise budget. Gross receipts were obtained from steer sales using Oklahoma City market prices. An average death loss of 2% was assumed in the budget[3]. The operating costs include the cost of steer calves, order buyer fees, cost of shipping to pasture, receiving program costs, machinery fuel and repairs, and machinery fixed costs. Steer costs were estimated using Oklahoma City market prices for medium/large frame No. 1 steers. For this analysis order buyer fees and shipping fees were fixed at $1 and $2 per cwt, respectively.

A high calcium mineral mixture was available free choice. For budgeting purposes it was assumed that during a grazing season each steer would consume 8.40 lbs at a cost of $0.09 per pound. Veterinary and medicine costs (excluding vaccine costs) were estimated at $9.00 per head. After grazing steers were shipped to the market. The costs of marketing plus sales commission were estimated at $2.00 per cwt. The interest

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[3] During the course of the experiments the death loss was essentially zero. However, for the purpose of budgeting, a death loss of 2% was used.

on operating capital was based on market interest rates. The cost of operating capital was adjusted to reflect the value over the five-month period in which the steer production enterprise was effectively undertaken. The estimated returns to the stocker steer enterprise are expressed in dollars per head. These values can be converted into dollars per acre by multiplying by stocking density.

Table 15 shows the average stocking densities, initial placement and final weights of the stocker steers, average daily gain and weight gain per steer. In the 1989/90 season and the 1991/92 season, one stocking density each, 0.50 and 0.51 steers per acre respectively, was used. In the 1992/93 and 1993/94 seasons, various stocking densities that ranged from 0.42 to 0.83 steers per acre were used. In subsequent years, stocking densities were adjusted as attempts were made to characterize forage and grain production responses for a wide array of stocking densities. The intent was to ensure that identical grazing pressures were established for all wheat varieties based on available forage alone.

Average steer purchase weights per year, but not per pasture, were available for some years (excluding 1989/90 and 1994/95). These weights are reported in table 11. To obtain steer purchase weights for each pasture, steer placement weights per pasture were adjusted by the difference between the average steer purchase weight per year and the average steer placement weight per year. The average weight difference of 11.5 lbs was used to adjust placement weights in years for which purchase weights were not available.

Steer placement weight across all seasons was 510 lbs. The highest weights (574 lbs) were observed in the 1998/99 season, and the lowest (462 lbs) in the 1989/90 season. The average daily gain (ADG) after placement on wheat, across all seasons was

2.22 lbs. Steers in the 1997/98 season had the highest ADG at 2.65 lbs while the lowest ADG, 1.41 was for steers in the 1992/93 season. On average, steers were removed from pastures at 759 lbs, after 112 grazing days. The highest steer sale weights were not necessarily achieved with the longest grazing periods. For instance in the 1997/98 season wheat pastures were grazed for 118 days to achieve a steer sale weight of 855 lbs, while in 1996/97 season pastures were grazed for 128 days to achieve a sale weight of 743 lbs.

The grazing dates and number of grazing days are shown in table 16. Grazing generally commenced in the month of November and ended in March. The average number of grazing days varied from 85 in 1991/92 to a high of 134 for the scout 66 variety in 1994/95. A chronological summary of some production activities is presented in table 17. It shows an average placement date of November 12 and an average removal date of March 5. Prior to placement, is the receiving program, which lasts an average of 15 days, from October 28 to November 12. In most seasons the wheat was planted in the first week of September.

Machinery Cost in Dual Purpose Wheat Production

This section will cover cost of machinery operations and labor costs for both the wheat production enterprise and steer production enterprise. Kletke's Farm Machinery Complement Selection (MACHSEL) program was used to determine machinery costs for the wheat production enterprise. The size of the dual-purpose wheat pasture enterprise may affect its cost structure. Indeed, Ahearn, Whittaker and El-Osta (1993) showed that costs of producing wheat decline with increase in the size of the enterprise. But Olson and Lohano (1997) suggest that such costs may level off and even begin to rise after achieving economies of size. USDA's 1997 Census of Agriculture estimates average farm size in Oklahoma at 448 acres.

Table 18 shows machinery costs for the wheat production enterprise. Machinery fixed costs used in the enterprise budgets value depreciation, taxes and insurance, as well as interest on machinery and equipment. The costs were based on market interest rates on capital, and a fixed wage rate of $6.00 per hour.

The wheat crop was assumed to be custom harvested at $13.00 per acre and $0.13 per bushel for every bushel above 20 bushels per acre. Labor was assumed fixed at 0.774 hours at a wage rate of $6.00 per acre. Machinery fuel, lube and repair costs for the wheat production enterprise were also estimated using Kletke's MACHSEL program.

Determining machinery fixed costs for the steer production enterprise entailed making assumptions that were then cross-checked with extension specialists for validity. It is assumed that 1.25 hours of labor are used per head, at a fixed wage rate of $6.00. Machinery fuel and repairs are estimated at $10.00 per head. Fixed production costs are estimated based on an interest cost of machinery and equipment of $2.50 per steer, and $5.50 for depreciation, taxes and insurance.

Econometric and economic analyses

The linear model in table 19 shows that increasing stocking density results in a statistically significant decrease in average standing forage. Several wheat varieties and growing seasons were statistically significant intercept shifters. For instance, average standing crop was significantly lower for Tonkawa, and in the year 1993.

The parameter estimates in table 20 showed that stocking density does not have a significant effect on wheat grain yield. Other studies (Christiansen, Svejcar and Phillips, 1989; and Krenzer and Horn, 1997) have arrived at the same conclusion under reasonable grazing conditions. The Wald-F test could not support a quadratic model. Wheat varieties AgSeCo 7853 and Tonkawa, as well as the year 1995 served as statistically significant intercept shifters. The average wheat yield would be higher for the two varieties but lower in the year 1995.

In table 21 the effects of wheat variety, season and stocking density on weight gain per steer are presented in a linear model and in a quadratic model. Increased stocking density has a significant decreasing effect on weight gain per steer in the linear model, but not in the quadratic model. There were no significant intercept shifters among the wheat varieties. However in 1993, the average weight gain per steer was significantly lower. The quadratic term is not statistically significant.

The returns from the wheat and steer production enterprises were aggregated across varieties by season and stocking density to determine how the magnitude of returns to land and management varied across seasons and stocking density. Table 22 includes the returns to land and management calculated by pasture, and where possible, averaged across pastures with identical stocking densities each season. The use of different stocking densities between varieties within seasons for 1994/95 and 1996/97 and single varieties in subsequent years (except for 2000) made it impossible to compute average net returns across varieties for seasons other than 1992/93 and 1993/94.

More uniform data were available for 1992/93 and 1993/94 than for subsequent seasons. In the first two seasons of the stocking density experiment, sixteen pastures each were cultivated. There were four varieties and four stocking densities. In the first season, the pastures of wheat varieties Karl, 2163, 2180 and AgSeco 7853 were each stocked at 0.50, 0.61, 0.72 and 0.83 steers per acre. A computation of the average net returns by stocking density across pastures showed that the highest returns (-$7.92/acre) were realized when the stocking density was 0.50 steers per acre, while the lowest returns (-$51.79/acre) were realized when the stocking density was 0.83 steers per acre. Net returns increased as stocking density was reduced.

In the 1993/94 season the stocking densities were the same as those for the prior season, except for the lowest stocking density, which was changed from 0.50 to 0.42 steers per acre. The same varieties were used in the wheat pastures. The highest net returns ($0.63/acre) were observed when stocking density was 0.61 steers per acre and the lowest net returns (-$9.45/acre) were realized when the stocking density was 0.83 steers per acre. Net returns increased as stocking density decreased, until a stocking density of 0.61 steers per acre, beyond which net returns declined.

In 1994/95 and 1996/97 wheat varieties Karl and 2163 were replaced with Longhorn and Scout 66. Four different stocking densities were used for each variety. Therefore for these seasons, the average returns in the table represent returns from only one pasture. Ignoring the effect of variety in the 1994/95 season, it was shown that the highest net returns (-$14.19/acre) were achieved when the stocking density was 0.93 steers per acre. In the same season the lowest net returns (-$72.06/acre) were achieved when the stocking density was 0.43 steers per acre. The general increase and decline in net returns with decrease in stocking density does not follow the same pattern as in the first two seasons.

In the 1996/97 season the results suggested an entirely different pattern. At stocking density 0.38 steers per acre, the highest net returns of $59.84 per acre were realized. The lowest net returns (-$48.92/acre) were realized when the stocking density was 0.44 steers per acre. The top three net returns for the 1996/97 season were obtained from pastures seeded with AgSeCo 7853, whereas the lowest two net returns were obtained from pastures seeded with variety 2180.

In the 1997/98 season the only wheat variety cultivated was Tonkawa, and it was grazed at four different stocking densities: 0.34, 0.42, 0.56, and 0.83 steers per acre. The highest net returns ($4.79/acre) were achieved when the stocking density was 0.42 steers per acre. The lowest net returns (-$9.79/acre) occurred when the stocking density was 0.56 steers per acre.

The stocking densities in 1998/99 were 0.38, 0.47, 0.62 and 0.89 steers per acre, and Tonkawa was the only variety. The highest net returns ($34.06/acre) were achieved at a stocking density of 0.47 steers per acre, and the lowest net returns (-$11.37/acre) occurred at a stocking density of 0.38 steers per acre. As in the second season, net returns increased as stocking density decreased, until the maximum was achieved at 0.47 steers per acre, beyond which there was a decline in net returns.

In the 1999/2000 season, two varieties, Tonkawa and 2174, were cultivated in the wheat pastures. The lowest net returns (-$2.06/acre) resulted from the 2174 pasture with stocking density 0.46 steers per acre, while the highest net returns ($105.40/acre) were realized from the Tonkawa pasture with stocking density 1.06 steers per acre. The next highest net returns ($93.38/acre) were obtained at stocking density 1.16 steers per acre.

It must be noted that wheat variety had a significant effect on weight gain per steer and on forage yield as measured by average standing forage per acre, but not on wheat grain yield per acre. The most obvious effect is that associated with seasonal variability in all of the dependent variables. That stocking density has no effect on wheat grain yield is probably due to the fact that grazing was not allowed beyond the development of first hollow stem. The difficulty of predicting movement of net returns in relation to stocking density may be explained by variability in prices and other non-controllable factors.

III.4. Summary and Conclusions

The opportunity to grow wheat for grain and forage for livestock is important for many farmers in the Southern Plains. The stocking density experiments conducted at the Marshall, Oklahoma research facility was initiated to generate data to investigate ways of helping the farmer make that decision. A comprehensive look at the procedures and practices employed by researchers at Marshall, and an estimation of the costs and returns from those dual-purpose wheat production experiments will be useful to the farmers. Comparing these returns among pastures stocked at different stocking densities and over several growing seasons will determine which stocking densities are more likely to generate higher returns.

Increasing stocking density leads to significant decreases in average standing crop and weight gain per steer. As more steers are grazed per unit land, the amount of available forage per unit animal will decrease, leading to lower intake and a lower steer gain. There was no effect of stocking density on wheat grain yield. The termination of grazing prior to the development of first hollow stem was apparently well managed in the experiment. This further confirms that yield potential remains relatively unaffected if grazing is terminated prior to the development of first hollow stem.

In the first season, decreasing stocking density led to a consistent increase in net returns. However, the difference between net returns for stocking densities 0.50 and 0.61 appeared marginal. Data from the 1993/94 season showed that returns were maximum when the stocking density was 0.61 steers per acre, and minimum when stocking density was 0.83 steers per acre. When stocking density was further decreased below 0.61 steers per acre net returns declined. In the next two seasons results were not so clear. For instance in 1996/97, net returns were highest where stocking density was lowest at 0.38 steers per acre. The pattern in 1998/99 was similar to that in the second season, save for maximum returns being achieved at 0.47 steers per acre. The implication is that the highest or lowest stocking densities do not necessarily yield the highest net returns for the dual-purpose wheat production enterprise. Workman (1986) suggests that the economic optimum for a typical set of price relationships exists at a stocking density intermediate between the highest weight gain per animal, and the maximum weight gain per unit area of pasture. Maximum profits exist somewhere between the two.

Except for about three seasons, discerning a true pattern of movement between stocking density and net returns was difficult. This problem was partly created by the lack of uniformity in the choice of stocking density over the years, and even within seasons. This in turn occurred because of the researchers' desire to make changes in stocking density in response to perceived changes in forage production. Hence a measure that takes into account grazing days, forage production and stocking density may create more uniformity than stocking density alone.

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Table 1. Acreage for Dual-Purpose Wheat Production Pastures at Marshall, Oklahoma, 1988-2000

Pasture No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Size (acres)	24	18	18	18	24	18	18	18	24	18	18	18	18	18	18	24

Table 2. Monthly Precipitation (inches) at Marshall, Oklahoma, 1988 – 2000

Year	January	February	March	April	May	June	July	August	September	October	November	December	Total rainfall
1988	1.17	0.00	3.96	6.58	0.37	2.30	2.58	0.65	6.03	1.23	2.43	0.57	27.87
1989	1.08	1.24	3.35	0.30	3.77	8.95	1.36	2.90	3.25	3.46	0.00	0.16	29.82
1990	1.52	3.25	2.42	3.55	5.39	1.05	1.84	1.19	2.18	0.98	1.50	0.65	25.52
1991	0.52	M[a]	1.10	1.03	4.16	1.20	2.65	1.69	6.80	2.12	2.40	3.86	27.53
1992	0.69	0.71	1.51	1.67	1.75	8.05	3.08	10.15	2.47	0.69	5.64	2.35	38.76
1993	2.17	1.32	1.79	5.84	9.36	3.57	1.74	2.13	3.61	0.46	2.39	1.41	35.79
1994	0.22	0.73	0.90	10.58	2.76	1.00	3.56	2.98	1.52	3.17	4.92	0.72	33.06
1995	0.67	0.00	3.33	3.16	5.64	7.68	3.06	6.52	3.47	0.50	0.12	1.76	35.91
1996	0.00	0.12	1.27	0.95	0.81	4.59	5.85	6.43	3.46	1.61	2.99	0.45	28.53
1997	0.26	4.44	0.00	5.54	3.37	3.33	2.76	4.12	3.70	2.48	0.79	2.52	33.31
1998	1.47	0.63	6.00	3.43	2.60	0.30	3.86	0.34	3.70	7.73	5.01	1.29	36.36
1999	1.12	0.34	2.97	6.50	4.41	9.35	1.43	2.30	5.53	3.60	0.19	4.32	42.03
2000	0.71	2.52	4.60	3.51	3.83	6.31	5.37	0.01	0.01	4.81	1.79	0.99	34.46
Monthly average	0.89	1.28	2.55	4.05	3.71	4.44	3.01	3.19	3.52	2.53	2.32	1.62	

Source: Oklahoma MESONET data available at www.mesonet.ou.edu/mesonetdata/mcd2 ; [a] Implies missing data

Table 3. Palmer Drought Severity Index (PDSI) for Central Oklahoma, 1988 – 2000[a]

Year	January	February	March	April	May	June	July	August	September	October	November	December
1988	3.68	3.09	3.85	4.05	-1.05	-1.76	-2.02	-2.55	0.55	0.39	0.63	0.65
1989	0.76	1.37	1.34	-1.02	-0.05	1.38	1.58	2.68	3.11	2.81	1.97	1.44
1990	1.63	2.62	4.29	5.04	4.73	-0.95	-1.39	-1.52	-1.25	-1.52	-1.52	-1.43
1991	-1.38	-2.12	-2.50	-2.65	-2.42	-2.3	-2.19	-2.24	1.01	1.23	1.52	3.17
1992	2.90	2.35	1.86	2.08	1.92	2.97	3.41	4.61	4.38	3.47	4.89	5.65
1993	5.70	6.09	5.65	5.72	6.12	-0.21	-0.68	-0.98	0.90	0.38	0.26	0.50
1994	0.09	0.37	0.68	1.17	-0.23	-1.03	-1.06	-0.88	-0.86	-0.91	1.29	1.20
1995	1.35	0.79	1.23	1.56	2.4	3.22	3.11	3.09	3.30	-0.49	-1.08	-0.84
1996	-1.19	-1.85	-1.94	-2.20	-3.2	-3.39	1.05	2.27	2.66	2.31	3.29	2.70
1997	2.21	3.06	2.11	2.75	2.21	2.04	2.26	2.78	2.32	2.32	1.90	2.69
1998	3.58	3.14	4.17	4.16	-0.75	-1.59	-2.68	-3.57	-3.75	1.27	1.82	2.05
1999	2.19	1.68	2.19	3.08	2.71	3.54	-0.11	-0.78	-0.46	-0.66	-1.42	-0.71
2000	-0.83	-1.00	-0.63	-0.69	-0.76	1.04	1.48	-0.75	-1.49	1.47	2.12	2.60

[a] The index generally ranges from -6 to +6, with negative values denoting dry spells and positive values denoting wet spells. PDSI values 0 to -0.5 = normal; -0.5 to -1.0 = incipient drought; -1.0 to -2.0 = mild drought; -2.0 to -3.0 = moderate drought; -3.0 to -4.0 = severe drought. Similar adjectives are attached to positive values of wet spells.
Source: NOAA; available at ftp://ftp.ncdc.noaa.gov/pub/data/cirs/0102.pdsi

Table 4. Field Operations Budgeted for Wheat Production Enterprise

Month	Field Operation
June	Offset Disk
July	Chisel
July	Offset Disk
August	Field Cultivation; Apply Anhydrous Ammonia (82-0-0)
September	Field Cultivation
September	Drill; Seed and Apply Diammonium Phosphate (18-46-0)
June	Combine Grain

Table 5. Prices and Quantities of Winter Wheat Seed, Diammonium Phosphate, and Anhydrous Ammonia applied to the Marshall fields, 1988-2000

Season	Winter wheat seed		Diammonium Phosphate (18-46-0)		Anhydrous Ammonia (82-0-0)	
	Price[a] ($/bu)	Quantity (bu/acre)	Price ($/ton)	Quantity (lb/acre)	Price ($/ton)	Quantity (lb/acre)
1988	6.84	2	237	50	185	0
1989	7.50	2	243	50	205	189
1990	4.94	2	210	50	167	174
1991	5.20	2	221	50	224	98
1992	5.66	2	216	50	173	177
1993	5.58	2	190	50	179	201
1994	6.54	2	217	50	223	146
1995	8.64	2	254	50	298	140
1996	9.08	2	278	0	267	0
1997	6.78	2	250	50	266	162
1998	4.44	2	247	50	222	119
1999	4.64	2	247	50	194	165
2000	4.62	2	227	50	195	168

[a] August Oklahoma City market price received, multiplied by 2

Source: Prices obtained from National Agricultural Statistics Service of the USDA

Table 6. Standing Wheat Forage Dry Matter per Acre of Pasture, Marshall, Oklahoma, 1992/93-2000

Year	Variety	Pasture	Stand crop (lb/acre)	Stand crop (lb/acre)	Stand crop (lb/acre)	Stand crop (lb/acre)	Average stand crop (lb/acre)
1992/93			11/13/92	1/28/93	3/9/93		
	Karl	1	1440	1511	627		1193
	Karl	13	1266	878	268		804
	Karl	4	1410	597	270		759
	Karl	11	1408	655	170		744
	AgSeCo7853	5	1526	1121	650		1099
	AgSeCo7853	2	1325	781	468		858
	AgSeCo7853	15	1562	355	107		675
	AgSeCo7853	8	1381	563	226		723
	2163	9	1952	1778	1766		1832
	2163	7	1593	1307	581		1160
	2163	12	1784	884	319		996
	2163	3	1701	588	215		835
	2180	16	977	1604	1110		1230
	2180	10	1310	1392	905		1202
	2180	14	1204	715	296		738
	2180	6	1135	726	194		685
1993/94							
			10/28/93	12/14/93	2/1/94	3/18/94	
	Karl	16	1619	2497	2896	2576	2397
	Karl	6	1405	1883	1883	1397	1642
	Karl	14	1491	2092	1639	1044	1567
	Karl	2	1240	1766	1652	1166	1456
	AgSeCo 7853	9	1495	2487	2563	2297	2211
	AgSeCo 7853	3	1183	1763	1604	1058	1402
	AgSeCo 7853	7	1334	1964	1547	1124	1492
	AgSeCo 7853	12	1370	1883	1189	828	1318
	2163	5	1151	2065	2428	2251	1974
	2163	15	1497	2487	2625	2106	2179
	2163	8	1458	2195	2360	1433	1862
	2163	10	1644	1972	1855	1233	1676
	2180	1	1375	1880	2503	1757	1879
	2180	11	1473	2216	2185	1608	1871
	2180	13	1424	2075	1542	1082	1531
	2180	4	1041	1595	1202	663	1125
1994/95							
			11/22/94	12/12/94	1/19/95	2/25/95	
	Scout 66	9	2233	2736	3289	3289	2887
	Scout 66	6	2063	2484	2512	2512	2393
	Scout 66	13	2329	2518	2385	2385	2404
	Scout 66	2	2115	1541	988	988	1408
	Longhorn	1	2271	2509	2840	2840	2615
	Longhorn	12	2224	2796	3042	3042	2776
	Longhorn	7	2205	2508	2068	2068	2212

Table 6. Standing Wheat Forage Dry Matter per Acre of Pasture, Marshall, Oklahoma, 1992/93-2000 (continued)

Year	Variety	Pasture	Stand crop (lb/acre)	Stand crop (lb/acre)	Stand crop (lb/acre)	Stand crop (lb/acre)	Average stand crop (lb/acre)
	Longhorn	14	2097	2508	1606	1606	1954
	2180	5	2135	2865	2960	2793	2688
	2180	10	2160	2572	3363	2880	2744
	2180	15	2209	2554	2575	1947	2321
	2180	3	1820	1651	1152	1003	1407
	AgSeCo 7853	1	1375	1880	2503	1757	1879
	AgSeCo 7853	11	1473	2216	2185	1608	1871
	AgSeCo 7853	13	1424	2075	1542	1082	1531
	AgSeCo 7853	4	1041	1595	1202	663	1125
1996/97							
			10/23/96	12/5/96	1/20/97	2/14/97	
	Scout 66	5	1856	2179	2352	2194	2145
	Scout 66	13	1810	2526	2726	2024	2272
	Scout 66	8	1706	2333	1531	1232	1701
	Scout 66	4	1665	1559	1017	558	1200
	Longhorn	16	1633	2760	2947	2544	2471
	Longhorn	12	1999	2836	2531	2200	2392
	Longhorn	2	1544	2066	1852	1809	1818
	Longhorn	7	1667	2183	1028	580	1365
	2180	9	1793	2835	3007	2425	2515
	2180	3	1501	2137	1914	1896	1862
	2180	11	2095	2485	2158	1359	2024
	2180	14	1886	2713	1768	1037	1851
	AgSeCo 7853	1	1876	2219	2147	1792	2009
	AgSeCo 7853	6	1542	2285	1483	1640	1738
	AgSeCo 7853	15	1732	2211	1929	1575	1862
	AgSeCo 7853	10	2090	1823	1483	979	1594
1997/98							
			10/24/97	12/12/97	1/20/98	2/17/98	
	Tonkawa	15	1478	3285	2996	2599	2590
	Tonkawa	1	1340	3088	2482	1937	2212
	Tonkawa	3	1245	2733	1526	1017	1630
	Tonkawa	16	1535	2996	1079	504	1529
1998/99							
			11/6/98	12/17/98	1/20/99	2/26/99	
	Tonkawa	1	718	1857	1973	1680	1557
	Tonkawa	3	701	1629	1281	993	1151
	Tonkawa	15	904	1641	1278	633	1114
	Tonkawa	16	936	2372	2514	2194	2004
1999/00							
			11/29/99	1/13/00	3/1/00		
	Tonkawa	1	1188	1359	1868		1472
	2174	18	1574	1863	2235		1891
	2174	17	1520	2094	2408		2007
	Tonkawa	4	951	820	1206		992

Table 6. Standing Wheat Forage Dry Matter per Acre of Pasture, Marshall, Oklahoma, 1992/93-2000 (continued)

Year	Variety	Pasture	Stand crop (lb/acre)	Stand crop (lb/acre)	Stand crop (lb/acre)	Average stand crop (lb/acre)
	Tonkawa	6	1129	288	277	565
	Tonkawa	10	1289	1458	1190	1312
	Tonkawa	8	1202	476	368	682
	Tonkawa	16	979	890	1057	975
	2174	12	1806	595	316	905

Table 7. Wheat Grain Yield from Dual-Purpose Forage plus Grain Experiments at Marshall, Oklahoma, by Variety and Stocking Density, 1993-2000 (bu/acre)

Season	Stocking Density (hd/acre)	Variety								Average Across all Varieties	Logan County Average[a]
		Karl	2163	2180	AgSeco-7853	Longhorn	Scout 66	Tonkawa	2174		
1992/93	0.50	32.10	29.80	26.80	25.30						
	0.61	18.10	34.90	27.90	28.80						
	0.72	24.70	17.90	26.50	18.20						
	0.83	15.30	17.80	19.10	20.10					23.96	20.00
1993/94	0.42	28.60	29.80	30.00	25.70						
	0.61	29.70	32.30	25.40	21.20						
	0.72	25.60	20.70	21.00	24.40						
	0.83	25.40	23.90	19.70	20.70					25.26	30.70
1994/95	0.36				15.50						
	0.39			21.80							
	0.40					13.40					
	0.43						7.70				
	0.44				21.00						
	0.53						13.90				
	0.57			18.00							
	0.59					17.80					
	0.65				19.50						
	0.72					13.20					
	0.76			19.10							
	0.78						12.80				
	0.91			19.90							
	0.92						11.7				
	0.93				21.70						
	1.14					13.10				16.26	18.50
1996/97	0.38				44.60						
	0.39						26.00				
	0.42				37.80						
	0.44			10.10							
	0.46			13.40		29.80					
	0.53						23.50				
	0.60					28.00					
	0.63						25.40				
	0.64					32.80					
	0.65				32.50						
	0.70			19.50							
	0.78						19.30				
	0.91				35.30						
	0.94					22.70					
	1.09			13.70						25.90	36.00
1997/98	0.34							44.50			
	0.42							43.90			
	0.56							43.30			
	0.83							47.30		44.75	38.00
1998/99	0.38							32.19			
	0.47							43.43			
	0.62							39.90			
	0.89							34.95		37.62	33.50
1999/00	0.42							42.13			
	0.43								30.57		
	0.46								21.05		
	0.56							40.20			
	0.63							26.07			
	0.56							45.24			
	1.06							40.16			
	1.16							31.12			
	1.16								43.71	35.59	34.50

[a] Logan County average yield obtained from the National Agricultural Statistics Service of the USDA

Table 8. Oklahoma City June Wheat Prices ($/bu), 1988-2000

Season	Price
1988	3.35
1989	3.87
1990	2.91
1991	2.50
1992	3.27
1993	2.54
1994	3.07
1995	3.88
1996	5.48
1997	3.28
1998	2.62
1999	2.31
2000	2.39

Source: National Agricultural Statistics Service of the USDA

Table 9. Enterprise Budget for Dual-Purpose Winter Wheat[a]

Item	Unit	Price	Quantity	Value
Gross receipts:				
Wheat grain	bu/acre	2.39	43.71	104.47
Operating costs:				
Wheat seed	bu	4.64	2.00	9.28
Diammonium phosphate (18-46-0)	lb	0.25	50.00	12.50
Anhydrous ammonia (82-0-0)	lb	0.19	170.00	32.30
Herbicide (Finesse)	oz	13.00	0.20	2.60
Custom harvest	ac	13.00	1.00	13.00
Custom harvest (> 20 bu/acre)	bu	0.13	23.71	3.08
Interest on operating capital	$	0.08	53.52	4.28
Labor	hr	6.00	0.774	4.64
Machinery fuel, lub., and repairs	$			7.54
Total operating costs, $/acre				89.22
Fixed costs for wheat production:				
Machinery and equipment – interest				9.92
Machinery and equipment – depr., taxes and insurance				16.04
Total fixed costs				25.96
Total costs, $/acre				115.18
Return to land and management, $/acre [b]				-10.71

[a] Shaded areas represent variables whose values may change between seasons and/or pastures.

[b] The value of the fall-winter forage is not included.

Table 10. Origin and Description of Stocker Steers Pastured at the Marshall, Oklahoma Wheat Pasture Research Facility, 1992-1997

Season	Origin of steers	Breed description
1992/93	Near Harlem and Chinook, Montana	Predominantly Angus or Angus X Hereford
1993/94	Near Elk Mountain, Wyoming	British X Continental or Beefmaster Crossbred steers
1994/95	Ranch near Paris, Texas	1. Simmental (Fleckvieh) sired calves from F1 Hereford X Brahman dams 2. Simmental, Limousin or Brangus-sired calves from Brangus or black white-faced dams dams
1996/97		Crossbred calves from Brangus and Bradford cows, with calves sired by Limousin, Brangus, Beefmaster and Hereford bulls

Source: Paisley, S.I., 1998

Table 11. Steer Purchase Weights and Receiving Dates

Year	No of Steers	Pay weight (lbs)	Receiving date
1989/90	[a]	[a]	[a]
1990/91	207	483	11/15/1990
1991/92	210	467	11/05/1991
1992/93	210	488	11/02/1992
1993/94	210	501	10/28/1993
1994/95	[a]	[a]	10/03 – 10/05/1994
1995/96	180	529	10/30/1995
1996/97	190	478	10/10/1996
1997/98	175	535	10/10/1997
1998/99	185	546	10/20/1998
1999/00	190	497	10/20/1999
2000/01	175	545	12/06/2000

[a] Data not available.

Table 12. Oklahoma City October Purchase Price for Medium/Large Frame No 1 Steers, 1989-1999

Year	Base price ($/cwt)	Weight class (lb)
1989	100.71	400-500
1990	104.25	400-500
1991	95.00	500-600
1992	93.23	450-500
1993	98.85	500-550
	100.30	450-500
1994	78.55	550-600
	81.83	500-550
1995	62.50	550-600
	64.33	500-550
	66.33	450-500
1996	65.88	450-500
1997	84.85	550-600
	89.81	500-550
	94.01	450-500
1998	72.63	550-600
1999	86.01	500-550

Source: National Agricultural Statistics Service of the USDA

Table 13. Stocker Steer Enterprise Budget for Dual-Purpose Winter Wheat Pasture

Item	Unit	Price	Quantity	Value
Gross receipts:				
Steers (based on death loss of 2%)	cwt/hd	86.17	7.03	593.66
Operating costs:				
Steer calves	cwt	86.01	4.92	423.17
Order buyer fee	cwt	1.00	4.92	4.92
Shipping to pasture	cwt	2.00	4.92	9.84
Receiving program (21 days)				
Five-way clostridia (backleg)	head	0.25	1.00	0.25
IBR, BVD, BRSV, PI3 (shipping fever)	head	0.90	2.00	1.80
Synovex-S (implant)	head	0.70	1.00	0.70
Ivomec-F (parasites)	cc	0.50	5.11	2.56
Hay (8 lb/str/day)	lb	0.06	128.00	7.68
Soybean meal based supplement (2lb/str/day)	lb	0.09	32.00	2.88
Hay during inclement weather (assume 2 bad days)	lb	0.06	24.00	1.44
High calcium mineral mixture	lb	0.09	8.40	0.76
Veterinary and medicine	head	9.00	1.00	9.00
Shipping to market and sales commission	cwt	2.00	7.03	14.06
Interest on operating capital	$	0.08	206.04	16.48
Labor	Hour	6.00	1.25	7.50
Machinery fuel, lub., and repairs	$			10.00
Total operating costs, $/head				513.04
Fixed costs for steer production:				
Machinery and equipment – Interest				2.50
Machinery and equipment – Depr., taxes and insurance				5.50
Total fixed costs, $/head				8.00
Total costs, $/head				521.04
Return to land and management, $/head				72.62
Return to land and management, $/acre [a]				84.24

[a] Adjusted based on the stocking density in steers per acre; shaded areas represent variables whose values may change between seasons and/or pastures. The cost of standing wheat forage is not accounted for in this budget.

Table 14. Oklahoma City March Sale Price for Medium/Large Frame No 1 Steers, 1990-2000

Year	Base price ($/cwt)	Weight class (lb)
1990	82.18	700-800
1991	96.38	600-700
1992	80.16	700-750
1993	86.53	700-750
	88.95	650-700
	92.03	600-650
	97.98	550-600
	103.02	500-550
1994	79.66	800-850
	81.31	750-800
1995	63.97	900-950
	65.53	850-900
	66.88	800-850
	68.84	750-800
1996	55.22	800-850
	55.78	750-800
	56.34	700-750
	57.33	650-700
1997	69.14	750-800
	69.88	700-750
	72.16	650-700
1998	69.28	900-950
	70.87	850-900
	73.07	800-850
	73.95	750-800
1999	67.22	850-900
	68.98	800-850
2000	80.53	800-850
	83.84	750-800
	86.17	700-750
	98.68	600-650

Source: National Agricultural Statistics Service of the USDA

Table 15. Initial Steer Weight, Average Daily Gain, Steer Sale Weight, Weight Gain per Steer and Days on Wheat for Forage plus Grain Experiment at Marshall, Oklahoma, 1989-2000

			Initial Weight of Steer On Pasture [a]		Average Daily Gain		Steer Sale Weight		Weight Gain per Steer	
Season	Wheat Variety	Stocking Density (strs/acre)	Lb/steer	Lb/steer/ Season	Lb/steer	Lb/steer/ Season	Lb/steer	Lb/steer/ season	Lb/steer	Lb/steer/ Season
1989/90	2157	0.50	462	462	2.13	2.13	708	708	246	246
1990/91	2157	0.50	469		2.00		682		213	
		0.61	471		2.07		691		220	
		0.72	471	470	1.76	1.94	660	678	189	207
1991/92	2157	0.51	535	535	2.18	2.18	719	719	184	184
1992/93	**Karl**	0.50	480		1.80		682		202	
		0.61	482		1.64		666		184	
		0.72	473		0.96		580		107	
		0.83	485		1.10		608		123	
	2163	0.50	484		2.20		730		246	
		0.61	485		1.92		700		215	
		0.72	490		1.39		646		156	
		0.83	478		0.50		534		56	
	2180	0.50	489		2.18		733		244	
		0.61	482		1.90		694		212	
		0.72	486		1.45		649		163	
		0.83	487		0.95		594		107	
	AgSeCo 7853	0.50	480		1.69		669		189	
		0.61	465		1.14		593		128	
		0.72	481		0.68		557		76	
		0.83	478	482	0.99	1.41	589	639	111	157
1993/94	**Karl**	0.42	497		2.32		805		308	
		0.61	499		2.28		802		303	
		0.72	503		2.44		828		325	
		0.83	491		2.24		789		298	
	2163	0.42	511		2.39		829		318	
		0.61	498		2.38		814		316	
		0.72	512		2.44		836		324	
		0.83	504		2.41		824		320	
	2180	0.42	489		2.58		832		343	
		0.61	497		2.45		823		326	
		0.72	506		2.30		812		306	
		0.83	500		2.02		769		269	
	AgSeCo 7853	0.42	509		2.42		830		321	
		0.61	487		2.32		795		308	
		0.72	511		2.28		814		303	
		0.83	500	501	2.14	2.34	784	812	284	311
1994/95	2180	0.39	547		2.39		824		277	
		0.57	560		2.92		899		339	

Table 15. Initial Steer Weight, Average Daily Gain, Steer Sale Weight, Weight Gain per Steer and Days on Wheat for Forage plus Grain Experiment at Marshall, Oklahoma, 1989-2000 (continued)

Season	Wheat Variety	Stocking Density (hd/acre)	Initial Weight of Steer On Pasture [a]		Average Daily Gain		Steer Sale Weight		Weight Gain per Steer	
			Lb/steer	Lb/steer/ Season	Lb/steer	Lb/steer/ Season	Lb/steer	Lb/steer/ season	Lb/steer	Lb/steer/ Season
		0.76	545		2.55		840		295	
		0.91	556		2.30		823		267	
	AgSeCo 7853	0.36	554		2.53		870		316	
		0.44	527		2.43		830		303	
		0.65	543		2.54		860		317	
		0.93	556		1.95		799		243	
	Longhorn	0.40	568		2.76		913		345	
		0.59	550		2.46		857		307	
		0.72	546		2.62		873		327	
		1.14	537		2.04		792		255	
	Scout 66	0.43	547		2.43		874		327	
		0.53	524		2.71		888		364	
		0.78	551		2.51		887		336	
		0.92	547	547	1.96	2.44	809	852	262	305
1996/97	2180	0.46	467		2.26		743		276	
		0.44	470		2.40		763		293	
		0.70	468		2.20		736		268	
		1.09	465		2.03		713		248	
	AgSeCo 7853	0.38	464		2.34		778		314	
		0.42	467		2.10		749		282	
		0.65	469		2.22		766		297	
		0.91	468		1.74		701		233	
	Longhorn	0.46	468		2.36		756		288	
		0.60	463		2.34		749		286	
		0.64	465		2.31		747		282	
		0.94	466		2.09		721		255	
	Scout 66	0.39	467		2.21		763		296	
		0.53	474		2.19		767		293	
		0.63	467		2.14		754		287	
		0.78	465	467	1.61	2.16	681	743	216	276
1997/98	Tonkawa	0.34	594		2.86		931		337	
		0.42	558		2.87		897		339	
		0.56	543		2.48		836		293	
		0.83	474	542	2.37	2.65	754	855	280	312
1998/99	Tonkawa	0.38	575		2.23		821		246	
		0.47	564		2.89		882		318	
		0.62	581		2.26		830		249	
		0.89	577	574	2.18	2.39	816	837	239	263
1999/00	Tonkawa	0.42	516		3.07		793		277	

Table 15. Initial Steer Weight, Average Daily Gain, Steer Sale Weight, Weight Gain per Steer and Days on Wheat for Forage plus Grain Experiment at Marshall, Oklahoma, 1989-2000 (continued)

Season	Wheat Variety	Stocking Density (hd/acre)	Initial Weight of Steer On Pasture [a]		Average Daily Gain		Steer Sale Weight		Weight Gain per Steer	
			Lb/steer	Lb/steer/ season	Lb/steer	Lb/steer/ season	Lb/steer	Lb/steer/ season	Lb/steer	Lb/steer/ Season
	2174	0.43	521		3.24		813		292	
	2174	0.46	521		3.06		796		275	
		0.56	516		2.60		750		234	
		0.63	524		2.87		782		258	
		0.56	527		2.95		792		265	
		1.06	505		1.56		645		140	
		1.16	506		1.52		643		137	
	2174	1.16	511	516	2.13	2.56	703	746	192	230
Average across all seasons				510		2.22		759		249

[a] This is the average weight of the steers when they were moved from the receiving program to the wheat pastures.

Table 16. Starting Date, Pull-off Date and Days on Wheat for Forage plus Grain Experiment at Marshall, Oklahoma, 1989-2000

Season	Wheat Variety	Stocking Density (hd/acre)	Starting Date	Pull-off Date	Days on Wheat	Average # of Days/ Season
1989/90	2157	0.50	11/17/89	3/12/90	115	115
1990/91	2157	0.50	11/21/90	3/8/91	107	
		0.61	11/21/90	3/8/91	107	
		0.72	11/21/90	3/8/91	107	107
1991/92	2157	0.51	12/5/91	2/28/92	85	85
1992/93	Karl	0.50	11/18/92	3/10/93	112	
		0.61	11/18/92	3/10/93	112	
		0.72	11/18/92	3/10/93	112	
		0.83	11/18/92	3/10/93	112	
	2163	0.50	11/18/92	3/10/93	112	
		0.61	11/18/92	3/10/93	112	
		0.72	11/18/92	3/10/93	112	
		0.83	11/18/92	3/10/93	112	
	2180	0.50	11/18/92	3/10/93	112	
		0.61	11/18/92	3/10/93	112	
		0.72	11/18/92	3/10/93	112	
		0.83	11/18/92	3/10/93	112	
	AgSeCo 7853	0.50	11/18/92	3/10/93	112	
		0.61	11/18/92	3/10/93	112	
		0.72	11/18/92	3/10/93	112	
		0.83	11/18/92	3/10/93	112	112
1993/94	Karl	0.42	11/02/93	3/15/94	133	
		0.61	11/02/93	3/15/94	133	
		0.72	11/02/93	3/15/94	133	
		0.83	11/02/93	3/15/94	133	
	2163	0.42	11/02/93	3/15/94	133	
		0.61	11/02/93	3/15/94	133	
		0.72	11/02/93	3/15/94	133	
		0.83	11/02/93	3/15/94	133	
	2180	0.42	11/02/93	3/15/94	133	
		0.61	11/02/93	3/15/94	133	
		0.72	11/02/93	3/15/94	133	
		0.83	11/02/93	3/15/94	133	
	AgSeCo 7853	0.42	11/02/93	3/15/94	133	
		0.61	11/02/93	3/15/94	133	
		0.72	11/02/93	3/15/94	133	
		0.83	11/02/93	3/15/94	133	133
1994/95	2180	0.39	11/01/94	2/25/95	116	
		0.57	11/01/94	2/25/95	116	
		0.76	11/01/94	2/25/95	116	
		0.91	11/01/94	2/25/95	116	
	AgSeCo 7853	0.36	11/01/94	3/6/95	125	
		0.44	11/01/94	3/6/95	125	
		0.65	11/01/94	3/6/95	125	
		0.93	11/01/94	3/6/95	125	
	Longhorn	0.40	11/01/94	3/6/95	125	
		0.59	11/01/94	3/6/95	125	
		0.72	11/01/94	3/6/95	125	
		1.14	11/01/94	3/6/95	125	
	Scout 66	0.43	11/01/94	3/15/95	134	
		0.53	11/01/94	3/15/95	134	
		0.78	11/01/94	3/15/95	134	
		0.92	11/01/94	3/15/95	134	125
1996/97	2180	0.46	10/25/96	2/24/97	122	
		0.44	10/25/96	2/24/97	122	
		0.70	10/25/96	2/24/97	122	
		1.09	10/25/96	2/24/97	122	
	AgSeCo 7853	0.38	10/25/96	3/8/97	134	
		0.42	10/25/96	3/8/97	134	
		0.65	10/25/96	3/8/97	134	
		0.91	10/25/96	3/8/97	134	
	Longhorn	0.46	10/25/96	2/24/97	122	

Table 16. Starting Date, Pull-off Date and Days on Wheat for Forage plus Grain Experiment at Marshall, Oklahoma, 1989-2000 (continued)

Season	Wheat Variety	Stocking Density (hd/acre)	Starting Date	Pull-off Date	Days on Wheat	Average # of Days/ Season
		0.60	10/25/96	2/24/97	122	
		0.64	10/25/96	2/24/97	122	
		0.94	10/25/96	2/24/97	122	
	Scout 66	0.39	10/25/96	3/8/97	134	
		0.53	10/25/96	3/8/97	134	
		0.63	10/25/96	3/8/97	134	
		0.78	10/25/96	3/8/97	134	128
1997/98	Tonkawa	0.34	10/25/97	2/20/98	118	
		0.42	10/25/97	2/20/98	118	
		0.56	10/25/97	2/20/98	118	
		0.83	10/25/97	2/20/98	118	118
1998/99	Tonkawa	0.38	11/12/98	3/2/99	110	
		0.47	11/12/98	3/2/99	110	
		0.62	11/12/98	3/2/99	110	
		0.89	11/12/98	3/2/99	110	110
1999/00	Tonkawa	0.42	11/30/99	2/28/00	90	
	2174	0.43	11/30/99	2/28/00	90	
	2174	0.46	11/30/99	2/28/00	90	
		0.56	11/30/99	2/28/00	90	
		0.63	11/30/99	2/28/00	90	
		0.56	11/30/99	2/28/00	90	
		1.06	11/30/99	2/28/00	90	
		1.16	11/30/99	2/28/00	90	
	2174	1.16	11/30/99	2/28/00	90	90
Average across all seasons						112

Table 17. Average Dates of Wheat Planting, and Arrival, Placement on Wheat Pasture, and Removal from Wheat Pasture for Steers used at the Marshall Wheat Pasture Facility, 1989-2000

Date	Activity
September 1-7	Wheat Planted
October 28	Purchased steers arrive on farm
October 28 - November 12	Receiving program
November 12	Placement on wheat
March 5	Removal from wheat

Table 18. Machinery Costs for Wheat Production Enterprise

Season	Diesel Fuel April Price ($/gal)	Quantity (gal)	Fixed cost[1] ($/acre)	Variable cost ($/acre)	Total labor hours	Wage rate	Interest Rate	Total cost with all labor ($/acre)
1988	0.72	5.20	27.61	7.96	0.774	6.00	9.32	40.21
1989	0.76	5.20	29.54	8.20	0.774	6.00	10.87	42.38
1990	0.74	5.20	28.47	8.08	0.774	6.00	10.01	41.19
1991	0.75	5.20	26.54	8.14	0.774	6.00	8.46	39.32
1992	0.73	5.20	23.80	8.02	0.774	6.00	6.25	36.46
1993	0.77	5.20	23.49	8.25	0.774	6.00	6.00	36.38
1994	0.69	5.20	24.91	7.78	0.774	6.00	7.14	37.33
1995	0.70	5.20	27.00	7.84	0.774	6.00	8.83	39.48
1996	0.86	5.20	26.31	8.79	0.774	6.00	8.27	39.74
1997	0.79	5.20	26.52	8.37	0.774	6.00	8.44	39.53
1998	0.68	5.20	26.41	7.72	0.774	6.00	8.35	38.77
1999	0.65	5.20	25.96	7.54	0.774	6.00	7.99	38.14
2000	1.00	5.20	27.84	9.63	0.774	6.00	9.50	42.11

Source: Kletke's Farm Machinery Complement Selection (MACHSEL) spreadsheet; Diesel Fuel Price obtained from the National Agricultural Statistics Service of the USDA

[1] Machinery fixed costs include depreciation, taxes, and insurance as well as interest on machinery and equipment.

Table 19. Effects of Variety, Season and Stocking Density on Average Standing Crop, Marshall, Oklahoma, 1992-2000 [a]

Regressors	Coefficients [b]	
	Linear function	Quadratic function
Intercept [c]	2836.15**	3493.91**
	(13.94)	(9.37)
Stocking density	-1410.31**	-3514.98**
	(-8.86)	(-3.43)
Stocking density squared		1481.11*
		(2.08)
Variety dummy variables		
AGSECO 7853	-119.09	-123.16
	(-1.18)	(-1.25)
Tonkawa	-617.64**	-579.68**
	(-3.25)	(-3.14)
Fields [d]	-203.79*	-198.29*
	(-2.35)	(-2.34)
Year dummy variables [e]		
1993	-769.34**	-707.10**
	(-4.46)	(-4.24)
1994	-68.78	-22.43
	(-0.40)	(-0.14)
1995	349.19	355.98
	(2.03)	(2.17)
1997	100.37	114.08
	(0.58)	(0.69)
1998	465.56*	423.36
	(2.20)	(2.08)
1999	61.61	39.43
	(0.29)	(0.19)
2000	-138.61	-203.32
	(-0.78)	(-1.18)

[a] Average standing forage is the average of three or four standing forage measurements taken during the cropping season, in pounds per acre.

[b] t-statistics are provided in parentheses. ** denotes significance at 1 % and * denotes significance at 5 %.

[c] The intercept includes values for variety 2180.

[d] The name "Fields" includes wheat varieties Karl, Longhorn, Scout 66, 2163 and 2174, all of which were grown for at most two seasons.

[e] Year effects were estimated as random variable in linear mixed model.

Table 20. Effects of Variety, Season and Stocking Density on Wheat Grain Yield, Marshall, Oklahoma, 1992-2000 [a]

Regressors	Coefficients [b]	
	Linear function	Quadratic function
Intercept [c]	25.78^{**}	32.91^{**}
	(8.08)	(4.29)
Stocking density	-5.49	-27.74
	(-1.60)	(-1.26)
Stocking density squared		15.66
		(1.02)
Variety dummy variables		
AGSECO 7853	4.82^{*}	4.78^{*}
	(2.21)	(2.21)
Tonkawa	15.41^{**}	15.39^{**}
	(4.86)	(4.89)
Fields [d]	2.17	2.20
	(1.16)	(1.18)
Year dummy variables [e]		
1993	-0.39	0.03
	(-0.19)	(0.02)
1994	0.62	0.90
	(0.30)	(0.44)
1995	-6.93^{*}	-6.99^{**}
	(-3.34)	(-3.40)
1997	1.07	1.06
	(0.52)	(0.52)
1998	3.76	3.61
	(1.37)	(1.33)
1999	-0.19	-0.20
	(-0.07)	(-0.08)
2000	2.07	1.59
	(0.91)	(0.69)

[a] The dependent variable is wheat grain yield in bushels per acre.

[b] t-statistics are provided in parentheses. ** denotes significance at 1 % and * denotes significance at 5 %.

[c] The intercept includes values for variety 2180.

[d] The name "Fields" includes wheat varieties Karl, Longhorn, Scout 66, 2163 and 2174, all of which were grown for at most two seasons.

[e] Year effects were estimated as random variable in linear mixed model.

Table 21. Effects of Variety, Season and Stocking Density on Weight Gain per Steer, Marshall, Oklahoma, 1992-2000 [a]

Regressors	Coefficients [b]	
	Linear function	Quadratic function
Intercept [c]	366.63**	326.28**
	(14.75)	(8.11)
Stocking density	-135.94**	-5.33
	(-8.71)	(-0.05)
Stocking density squared		-91.88
		(-1.29)
Variety dummy variables		
AGSECO 7853	-18.09	-17.84
	(-1.83)	(-1.83)
Tonkawa	-18.58	-22.03
	(-0.94)	(-1.11)
Fields [d]	1.61	1.20
	(0.19)	(0.14)
Year dummy variables [e]		
1993	-119.32**	-123.74**
	(-5.30)	(-5.33)
1994	34.93	31.61
	(1.55)	(1.37)
1995	42.25	41.39
	(1.88)	(1.80)
1997	-12.78	-14.12
	(-0.57)	(-0.61)
1998	41.49	44.85
	(1.59)	(1.69)
1999	21.70	23.84
	(0.84)	(0.90)
2000	-8.27	-3.82
	(-0.36)	(-0.16)

[a] The dependent variable is weight gain per steer, in pounds.

[b] t-statistics are provided in parentheses. ** denotes significance at 1 % and * denotes significance at 5 %.

[c] The intercept includes values for variety 2180.

[d] The name "Fields" includes wheat varieties Karl, Longhorn, Scout 66, 2163 and 2174, all of which were grown for at most two seasons.

[e] Year effects were estimated as random variable in linear mixed model.

Table 22. Returns to Land and Management for Dual-Purpose Wheat Production in Marshall, Oklahoma, 1993-2000 ($/acre) [a]

Season	Stocking Density (hd/acre)	Wheat pasture								Average Across all Pastures
		Karl	2163	2180	AgSeco-7853	Longhorn	Scout 66	Tonkawa	2174	
1992/93	0.50	-2.48	1.82	-6.73	-24.28					-7.92
	0.61	-40.40	16.34	-1.57	-10.07					-8.93
	0.72	-29.36	-40.87	-15.24	-66.48					-37.99
	0.83	-67.99	-62.19	-41.51	-35.47					-51.79
1993/94	0.42	-7.76	0.37	8.55	-10.49					-2.33
	0.61	0.72	14.58	-0.88	-11.89					0.63
	0.72	9.34	-7.49	-15.22	-7.90					-5.32
	0.83	5.75	7.58	-31.89	-19.24					-9.45
1994/95	0.36				-40.18					-40.18
	0.39			-26.53						-26.53
	0.40					-46.48				-46.48
	0.43						-72.06			-72.06
	0.44				-19.80					-19.80
	0.53						-30.01			-30.01
	0.57			-15.45						-15.45
	0.59					-36.40				-36.40
	0.65				-23.79					-23.79
	0.72					-42.80				-42.80
	0.76			-25.32						-25.32
	0.78						-25.16			-25.16
	0.91			-21.35						-21.35
	0.92						-70.83			-70.83
	0.93				-14.17					-14.17
	1.14					-51.03				-51.03
1996/97	0.38				59.84					59.84
	0.39						-1.98			-1.98
	0.42				36.74					36.74
	0.44			-48.92						-48.92
	0.46			-38.48		15.37				-11.56
	0.53						4.22			4.22
	0.60					27.40				27.40
	0.63						18.51			18.51
	0.64					45.07				45.07
	0.65				47.73					47.73
	0.70			2.76						2.76
	0.78						-5.04			-5.04
	0.91				52.17					52.17
	0.94					28.14				28.14
	1.09			7.95						7.95
1997/98	0.34							-6.39		-6.39
	0.42							4.79		4.79
	0.56							-9.79		-9.79
	0.83							1.35		1.35
1998/99	0.38							-11.37		-11.37
	0.47							34.06		34.06
	0.62							20.01		20.01
	0.89							19.74		19.74
1999/00	0.42							41.34		41.34
	0.43								10.10	10.10
	0.46								-2.06	-2.06
	0.56							45.66		45.66
	0.63							22.42		22.42
	0.56							60.62		60.62
	1.06							105.40		105.40
	1.16							93.38		93.38
	1.16								82.41	82.41

[a] The returns from both wheat forage (steer production) and wheat grain are included.

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