Integrated Crop and Livestock Risk Modeling

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Abstract

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This study was conducted to determine risk efficient production strategies for crop and livestock producers who have the opportunity to produce wheat as a dual-purpose forage and grain crop. Empirical data obtained from field trials were incorporated into an integrated crop and livestock production and marketing risk-programming model.

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Grazing winter wheat during its vegetative stage is a common practice in the Southern Plains. Pinchak et al. estimate that 30 to 80 percent of the twenty million acres seeded to wheat annually in the region are grazed. Wheat may be planted in the late summer and grazed throughout the fall and winter. If livestock are removed in the late winter, prior to the development of the first hollow stem, the wheat will mature and produce grain. The use of winter wheat as a dual-purpose forage and grain crop is important to the agricultural economies of southwestern Kansas, eastern New Mexico, western Oklahoma, southeastern Colorado, and the Texas Panhandle (Pinchak et al.).

For a given planting date, properly managed fall-winter grazing may not reduce grain yield. However, dual-purpose wheat producers encounter a tradeoff between fall/winter forage production and grain production. Wheat that is planted in early September in the Southern Plains is expected to yield more forage and support more livestock for grazing than wheat planted in late September. However, the expected grain yield from early-planted wheat is significantly less than the expected grain yield from later planted wheat. Epplin, Hossain, and Krenzer determined that a three week delay in planting from September 1 to September 21 was associated with 44% increase in expected grain yield. However, the same three-week delay resulted in a fall-winter forage yield of only 32% as much as September 1 planting.

Producers who have the opportunity to produce wheat for forage and grain or for grain only are confronted with several key decisions. First, they must decide whether to produce wheat for grain only and forgo the opportunity to graze or to produce dual-purpose wheat. Second, they must select a target planting date. If they plant relatively early they may expect more forage production but less grain production. Alternatively, later planting increases

expected grain yield but decreases expected forage yield. Third, they must select the type of animals to stock on the fall/winter wheat pasture and fourth, they must select a stocking density.

In general, the stocking density decision must be based upon expected forage production rather than actual forage production. Fall/winter forage production depends upon the weather. If the weather is favorable and if the wheat is seeded relatively early, fall/winter forage production will be sufficient to support a relatively high stocking density. However, if the weather is not favorable, fall/winter forage production will not support a high stocking density. If the weather is favorable and a low stocking density is selected, not all of the forage will be used. However, if the weather is not favorable and a high stocking density is selected, forage production will not be sufficient to support all the animals' targeted weight gain and either supplemental feed will be required or some animals will have to be liquidated prematurely.

Production of wheat for both forage and grain and grazing of wheat is a complicated and risky process involving the interaction of livestock production with wheat grain production. For a given planting date lower stocking densities are expected to result in relatively less livestock gain per acre variability than higher stocking densities (Honeycutt). Hence, livestock weight gain per acre is a function of initial weight, stocking density, and forage production. Expected forage yield and expected grain yield are both functions of planting date and weather. Other major sources of variability include livestock purchase price, wheat seed price, fertilizer price, supplemental feed and hay quantity and price, interest rate, wheat grain yield, and livestock and wheat sale prices. The objective of the research reported in this study is to determine risk efficient production strategies for wheat and livestock farmers in the Southern Plains.

The vast majority of agricultural risk modeling efforts reported in the literature address crop production and marketing strategies. A few studies have addressed livestock production.

The current study is unique in several respects. First, production and price risk from both crop and livestock activities are integrated into the model. Second, the model captures the variability of the tradeoff between the production of forage and grain for a dual-purpose crop.

Theory

Risk has historically been defined as a deviation of realized economic returns from those expected (Markowitz; Hey). One normally assumes a positive relationship between risk and expected income for most economic activities. There are many specifications of risk presented in the literature of decision theory. Curtis et al. identified three potential ones. These are the mean-variance (EV), the mean-absolute deviation (MAD), and absolute negative deviation (ANTD) measures of risk.

The EV and MAD specifications measure risk by summing the deviations of actual returns from average returns in previous states of the world (Curtis et al.). A principal difference between these risk measures is that the non-linear EV measure places significantly greater weight on large deviations. A producer facing risk (as defined by EV or MAD) is assumed to maximize the expected utility generated from all activities entered. Utility is defined to be a function of both income and some dispersion function representing risk. When choosing among alternatives, marketing activity or portfolio of strategies, activity A would dominate activity B if and only if:

$$E(\pi_a) \geq E(\pi_b); \text{and } R_a \leq R_b, \qquad (1)$$

with at least one strict inequality. $E(\pi_i)$ and R_i are expected income and a measure of dispersion, respectively. Where the precise risk preferences represented by derived utility functions are known, the expected utility for each action choice may be calculated, and action choices ordered according to the expected utility index (Cochran, Robison, and Lodwick). This

unique and complete ordering procedure derives from the von Neumann-Morgenstern expected utility hypothesis.

Many have considered the inclusion of positive deviations in risk calculations as potentially inappropriate. Curtis et al. contend that it does not make sense to consider actual returns in which income is greater than expected as risky. Markowitz suggested the semivariance (SV) specification as a theoretical correction for some of the flaws in the EV risk measure. Risk was redefined as the summation of squared deviations below the mean income. The SV approach also asserts that a producer is risk averse to returns below expected income and risk neutral if returns are above those expected.

Summing the absolute value of the deviations below a uniform target (ANTD) provides a linear risk measure similar to the non-linear semivariance measure. An additional attribute of risk measured as ANTD is that it does not require the use of mean income as the base from which deviations are calculated. Use of the average return as the risk reference point may not be preferred because average returns can (and usually do) vary across activities (Curtis et al.). Watts, Held, and Helmers pointed out that measuring risk as absolute negative deviations from a target level of income standardizes the risk reference point across all activities considered, which allows for increased discrimination among the alternative portfolios. Thus, this risk measure should identify a smaller set of preferred alternatives, which reduces the complexity of the decision process. Tauer presents proof that portfolios developed using ANTD as a risk criterion are a subset of the second-degree stochastic dominance set.

Target MOTAD (minimization of total absolute deviations) is employed to determine risk-efficient (as measured by ANTD) portfolios of production strategies for wheat and wheat stocker producers (Tauer). Target MOTAD efficient frontiers are developed by parametrically

varying deviations from levels associated with the linear programming (LP) solution to zero. Risk-efficient frontiers can be developed for various fixed targets allowing for differences across firms in returns required for long-run survival. For each target, risk-efficient frontiers can be developed for optimal solutions over a range of expected deviations. A frontier of optimal production strategies is derived to generalize the portfolio selection process. The specific production portfolio employed by a producer will depend on the nature of the individual's income and risk preferences.

Solutions to Target MOTAD are efficient according to second-degree stochastic dominance (Tauer; McCamley and Kliebensten). However, no attempt has been made to determine which of the solutions are consistent with which ranges of the Arrow-Pratt measures of risk aversion. The Target MOTAD model has two parameters relating to risk which must be specified. These, in turn, are parameterized to yield different risk solutions (McCarl and Spreen).

Given the complexity of the current problem, it is necessary to use a flexible mathematical programming procedure such as Target MOTAD. The literature is virtually silent on application of risk programming models to problems that involve interdependent crop and livestock activities.

Procedures and Data

Grazing trials are relatively expensive. Experiment station studies have been conducted to evaluate various production alternatives. However, no single experiment has been conducted to determine the expected livestock weight gain and expected wheat grain yield from alternative planting dates and alternative stocking densities. Livestock weight gain may be estimated based upon quantity and quality of the forage for animals of various types and sizes for alternative

stocking densities. Krenzer et al. suggest that typical 450 pound steers could be expected to gain an average of two pounds per day for the typical fall/winter wheat grazing season if 24 pounds of wheat forage dry matter per day were available.

Wheat fall/winter forage and grain yield data were obtained from experiment station trials conducted at the north central research station near Lahoma, Oklahoma. A series of field experiments were conducted over six growing seasons beginning in 1991-92. Treatments varied from season-to-season. However, planting date treatments ranging from late August to late October were included in each of the six seasons. Each treatment was replicated four times in a randomized complete block design. To simulate grazing, the plots were mechanically clipped and the forage removed once in the fall and once in the spring prior to development of the first hollow stem. Forage yield was based upon the combined dry matter yield of the two clippings. All plots were fertilized to ensure that soil fertility would not be the first-limiting yield factor.

Nine alternative production plans were considered. These alternatives comprised of one grain-only activity and eight variants of the forage-and-grain production activity. Wheat planting date and livestock stocking density are the key attributes used to distinguish these production alternatives. Table 1 presents the specific production strategies considered.

Activity annual gross margins were computed for each production strategy for the six years in which the fall/winter forage and grain yield data were available. Historical wheat sell price (June), steer (November) purchase price, and steer (March) sell price were obtained from Oklahoma Agricultural Statistics (Oklahoma Department of Agriculture). Bank prime rates on short-term business loans reported by USDA were used to represent interest rates. Fertilizer prices were obtained from the USDA National Agricultural Statistics Service (NASS). The 750

acre average farm size in the state (U. S. Department of Commerce) was used as the land upper bound in the optimization process.

It is assumed that the representative farm purchases 450 pound steers to stock on the fall/winter wheat forage in November and sells them after the grazing season in March. The assumption posited by Krenzer et al. that typical 450 pound steers could be expected to gain an average of two pounds per day for the typical fall/winter wheat grazing season if 24 pounds of wheat forage dry matter per day were available was used. Two possible growing season lengths were considered. These are 110 days (long season) and 105 days (short season). The 110-day and 105-day growing seasons correspond to the September 1 and September 15 wheat-planting dates, respectively.

If wheat forage is sufficient, the steer is expected to gain 220 pounds if the season is 110 days long and 210 if the season is 105 days long. In both cases, this corresponds to an average daily gain (ADG) of 2 pounds. The clipped forage data show that in most seasons forage production would be sufficient from early planted wheat to support the range of stocking densities considered. However, forage production was inadequate to support some alternatives in some years. This was true for the whole of 1994 and some heavy stocking densities in other years. In such cases, unless some kind of supplemental feeding is implemented, the animal would have an ADG < 2. The decision-maker has several options if confronted with insufficient forage production. The animal may be sold when the available forage becomes inadequate or, alternatively, the producer may provide supplemental feed. In the current study, it was assumed that for those states of nature with inadequate forage production (to support the stocking density), the decision-maker would provide supplemental feed sufficient to achieve a rate of gain of one pound per day. The number of days of supplemental feeding was calculated by taking the

difference between the season total and the number of days the available wheat forage would last, assuming *ADG* = 2. The quantity of supplemental feed required was estimated by using National Research Council data and equations. It was further assumed that the supplement would be composed primarily of hay and wheat middlings.

The cost of supplemental feed was included in the gross margin computations for all situations in which the quantity of wheat forage was insufficient. Historical price series for hay were obtained from Oklahoma Agricultural Statistics. Prices of wheat middlings were obtained from Grain and Feed Market News published by the USDA. The gross margins used in the Target MOTAD model are presented in table 2.

As can be seen in table 2, there is a wide variation in the level of gross margins across years and strategies. It is clear, though, that 1994 and 1997 were two extreme years. All strategies but one (grain-only) had negative gross margins in 1994, indicating that it was a very bad year. This corresponds to costly supplemental feeding due to extremely low wheat forage production. As the table indicates, the grain-only strategy seems to be more rewarding during bad years than strategies with steers. In years of high forage production, such as 1997, activities with relatively high stocking densities are more rewarding.

Results

Risk-efficient frontiers of wheat and wheat-stocker steer production portfolios associated with target income levels of $13,000 and $17,000 were derived using a microcomputer-based linear programming system. Only two production strategies were found to be in the Target MOTAD efficient set. These are grain-only production and forage and grain production planted on September 1 and stocked at a rate of 1.5 acres per steer. The grain-only activity was in the basis in all the solutions.

In all cases, more than 81 percent of total available land area is allocated to the grain-only activity when the targeted income is $17,000. When the targeted income is $13,000, more than 91 percent of the land area is allocated to the grain-only strategy. The remainder of the land is allocated to forage and grain production with September 1 as wheat planting date and 1.5-acre-per-steer stocking density. For both target levels, the proportion of available land allocated to grain-only increases with increase in the risk parameter. Tables 3 and 4 include a summary of these findings.

Summary and Conclusions

It has been estimated that 30 to 80 percent of the twenty million acres seeded to winter wheat annually in the Southern Plains are grazed. Wheat may be planted in the late summer and grazed throughout the fall and winter. If livestock are removed in the late winter, prior to the development of the first hollow stem, the wheat will mature and produce grain.

Production of wheat for both forage and grain and grazing of wheat is a risky production activity. Livestock weight gain is a function of stocking density, forage production, and weather. Typically 400-500 pound calves are purchased in the fall, pastured on the wheat throughout the late fall and winter, and sold in late winter (late February-early March). Stocking density decisions (the number of calves to purchase) must be made early in the season before the quantity of fall-winter forage production is known. Hence, farmers are faced with several key risky decisions including the proportion of wheat seeded for grain only, target planting dates that influence grain yield and forage yield, and how many calves to purchase and stock on the dual-purpose wheat. If the wheat is planted early and if the weather is favorable for fall-winter forage production, a high stocking density can be supported with no supplemental feed required. However, if animals are purchased in anticipation of a high stocking density and if the weather is

not favorable, the production of forage will be insufficient to support feed requirements necessitating either the purchase of supplemental feed or the premature sale of animals.

Wheat forage and grain yield data were obtained from experiment station trials conducted over six growing seasons. Wheat planting dates in the trials ranged from late August to late October. To simulate grazing, the plots were mechanically clipped and forage removed once in the fall and once in the spring prior to the critical growth stage at which livestock must be removed to enable the plant to produce wheat grain.

A representative farm target MOTAD model was constructed. Grain yield, forage yield, livestock weight gain, grain price, livestock purchase price, livestock sale price, fertilizer price, seed price, supplemental feed quantity, and feed prices were included as stochastic variables. Thus, the model was designed to identify risk efficient combinations of crop and livestock production activities. The grain-only strategy dominates most alternatives, taking up no less than 80 percent of the average available land area in all the solutions. The second and only other strategy that entered the basis was 1.5-acre-per-steer with September 1 as the wheat planting date.

However, caution needs to be exercised against generalizing when interpreting the results of dynamic risk analyses of this specific application. The use of this model over a series of years might involve moving it through time.

Table 1. Attributes of the alternative production strategies*

		Stocking densities for dual-purpose activies (ac/str)			
Planting date	Grain-only	1.0	1.5	2.0	3.0
October 10	✓				
September 1		✓	✓	✓	✓
September 15		✓	✓	✓	✓

*the symbol ✓ indicates what is applicable

Table 2. Activity gross margins

Planting Date	Stategy/ stocking Density (ac/str)	Gross Margins 1992	1993	1994	1995	1996	1997
Oct 10	Grain only	105	12	51	46	79	122
Sept 1	3.0	67	35	-52	19	15	104
	2.0	76	52	-67	25	21	126
	1.5	85	68	-82	30	27	149
	1.0	103	58	-112	33	19	190
Sept 15	3.0	95	35	-32	37	48	147
	2.0	103	23	-46	33	51	169
	1.5	111	10	-62	14	32	169
	1.0	126	-15	-91	-25	-4	161

Table 3. Risk-efficient production strategies for $17,000 Target MOTAD model

Expected Deviation Below Target	Expected Return ($)	Selected production strategies (acres) Grain-Only	Sept 1 plans (ac/str) 1.0	1.5	2.0	3.0	Sept 15 plans (ac/str) 1.0	1.5	2.0	3.0
0	48,589	607		143						
300	49,329	639		111						
600	50,068	671		79						
900	50,807	704		46						
1,200	51,546	736		14						
1,400	51,875	750								

Table 4. Risk-efficient production strategies for $13,000 Target MOTAD model

Expected Deviation Below Target	Expected Return ($)	Selected production strategies (acres) Grain-Only	Sept 1 plans (ac/str) 1.0	1.5	2.0	3.0	Sept 15 plans (ac/str) 1.0	1.5	2.0	3.0
0	50,232	679		71						
300	50,971	711		39						
600	51,711	743		7						
700	51,875	750								

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