Optimizing Dual Interdependent Products from a Single Crop

Karen W. Taylor and Francis M. Epplin

Karen W. Taylor is a graduate research assistant and Francis M. Epplin is Charles A. Breedlove professor, Department of Agricultural Economics. Project H-2574. Professional paper AEP-0702 of the Oklahoma Agricultural Experiment Station.

Contact author:
Francis M. Epplin
Department of Agricultural Economics
Oklahoma State University
Stillwater, OK 74078-6026

Phone: 405-744-6156
FAX: 405-744-8210
E-mail: f.epplin@okstate.edu

Optimizing Dual Interdependent Products from a Single Crop
Abstract

The objective of the research is to determine the optimal grazing termination date that maximizes expected net returns from dual-purpose winter wheat production. Preliminary results indicate that grazing should be terminated at or before first hollow stem to generate the highest expected net returns in a dual-purpose winter wheat production enterprise.

Introduction

Dual-purpose use of small grains is practiced in many countries throughout the world and is important to the agricultural economies of south-western Kansas, eastern New Mexico, western Oklahoma, south-eastern Colorado, and the Texas Panhandle. True et al. estimate that six million acres are seeded annually to winter wheat in Oklahoma, with two-thirds intended for dual-purpose. In a dual-purpose winter wheat system, the wheat is used as forage by grazing cattle as well as harvested for grain after the cattle are removed. In Southern Plains dual-purpose winter wheat enterprises, wheat is planted in early September and is available for grazing by livestock from mid November through the winter. Most winter wheat pastures are stocked with young steers or heifers that are purchased in the fall and sold at the end of the winter grazing season in the spring. After the cattle are removed, the wheat continues to grow and is harvested in June.

One of the most economically important decisions encountered by dual-purpose wheat producers is when to terminate grazing. Redmon et al. (1996) found that to maximize grain yields, grazing should be terminated at the development of the first hollow stem (FHS). FHS is the stage when the stems begin to elongate and become hollow just above the roots. The occurrence of FHS depends on several climatic factors including temperature, precipitation and wheat variety. If the livestock are removed prior to or at development of FHS, the wheat will

1

mature and produce a grain crop. However, if cattle are left on pastures too long (significantly after the development of FHS) the wheat plant is not able to recover from grazing and grain yields will decrease significantly.

The time to terminate grazing is not only driven by FHS, but also the prices and weight of cattle being at the date of removal from wheat pasture. Seasonal price patterns in the region may be influenced since many animals are marketed during the relatively narrow time period of FHS. Occurrence of FHS, prices of cattle, wheat yields, weight of cattle on sale day, and wheat prices all impact the optimal grazing termination date. This study is intended to determine the optimal time to terminate grazing, relative to FHS that maximizes the expected profits of both cattle and wheat returns. This research also determines the value of different levels of information in the occurrence and distribution of FHS. The results of the research will aid producers in deciding when to remove cattle from dual-purpose wheat pasture.

Previous research by Redmon et al. (1996) reported that if cattle are grazed even one week past FHS, grain yield will fall dramatically (as much as 1.25 bushels per day during the first three weeks after FHS). They found that grain yield loss was far too great to graze cattle past FHS, and recommended that producers closely monitor the occurrence of FHS. However, additional research by Fieser et al. concluded that in times of high cattle prices, it may be optimal to graze stockers past FHS and that the increase in the value of the cattle may offset the loss in value of wheat grain. Over the two years of their study grain yield did not decrease linearly with days grazed past FHS, indicating that there may be a "safety zone" of removing cattle without drastically reducing grain yields. Thus, indicating that the grain yield loss of grazing past FHS may not be as severe as previously reported. And, for the conditions of the Feiser et al. study,

under some relative price situations and some weather conditions, grazing past FHS may be warranted to maximize expected returns to the combined cattle and wheat grain operation.

Both studies found that grazing termination is a key management variable and that grazing past FHS decreases grain yields, but the rate of the grain yield decline differed across the two studies. There are some very important differences between these previous studies. Specifically, the functional form of the response functions used to evaluate grain yield and weight gain were different. Redmon et al. used a linear spline function to determine wheat yield response to FHS. Fieser et al. used a quadratic response function. Neither study estimated a cattle price response function or analyzed the distribution of the occurrence of FHS. Thus, there is a need to re-evaluate weight gain and grain yield in estimating how cattle and grain returns are affected by grazing past FHS.

In this paper, determining the optimal grazing termination date is found using expected profit maximization. Models are estimated to determine the distribution of FHS. Response functions for cattle prices, cattle gains, and wheat yields are derived. The random nature of the occurrence of FHS is captured in a plateau model used to estimate wheat yield response.

Theory

A general model is defined to maximize the expected profit from a dual-purpose winter wheat production system. The expected profit optimization equation can be expressed as:

$$(1) \qquad \underset{d}{\text{Max}}\ \text{E}(\pi) = \left\{ \text{E}[\text{P}_C(d,W(d))] \bullet \text{E}[W(d)] - C_C \right\} \bullet SD + \text{E}[P_Y] \bullet \text{E}[Y(d,FHS)] - C_Y,$$

where $\text{E}(\pi)$ represents expected profits (\$/acre), d is removal/selling time in days (where d, day of the year, equals to 1 represent January 1, and 90 for March 31), $\text{E}[P_C]$ is the expected sale price of cattle (\$/cwt), $\text{E}[W]$ is the expected weight of cattle on sale day (cwt/head), C_C represents the costs of purchasing the cattle and other costs incurred in addition to the cost of

3

pasture ($/head), *SD* is stocking density (head/acre), $E[P_Y]$ is the expected sale price of wheat ($/bushel), $E[Y]$ is the expected wheat yield (bushel/acre), *FHS* is the day of FHS, and C_Y represents the costs of producing wheat ($/acre). The expected price of cattle on sale day is a function of cattle weight and day of sale. Generally, heavier steers have a lower sale price per pound. Weight of the steers on sale day is a function of the number of days on pasture. The returns per head of cattle is multiplied by the stocking density to convert to a per acre basis. Previous research has determined that stocking density has no effect on grain yield, so stocking density is assumed to affect only cattle returns (Redmon et al., 1996; Katibie et al., 2003b).

Value of Information

The distribution of FHS is needed to determine expected profits when FHS date is not known. FHS usually occurs between mid February and mid March. The value of information is defined as follows:

(2) $Value\ of\ Information = E(\pi/\Omega, I_M) - E(\pi/\Omega, I_0)$,

where *Value of Information* represents the value of different levels of information, $E(\pi/\Omega, I_M)$ is the expected profit given the information set, Ω, I_M is the level of available information based on the model (*M*) of the distribution of FHS, and $E(\pi/\Omega, I_0)$ is the expected profit given the information set of I_0 which is equal to no information. The value of information of knowing the occurrence of FHS is found by subtracting the expected profits when FHS is unknown from the expected profits when FHS is known, for different levels of information sets.

Data

FHS occurrence data, prices of cattle and wheat, weight gains of cattle, and wheat yields were required. The distribution of FHS was found from Oklahoma State University wheat trials performed in Stillwater, OK and reported by Edwards et al. (2006a). The cattle price response

4

function was estimated from steer cash and futures prices, reported by the Livestock Market Information Center (USDA, 2005). The expected price of wheat was estimated at $2.89/bushel, which represents the five year average Oklahoma cash price received during June and July from 2000 to 2005 (USDA, 2006).

Data to estimate wheat grain yield response functions were obtained from two studies conducted at the Oklahoma State University Marshall Wheat Pasture Research unit (Fieser et al.; Redmon et al., 1996). Charts of grain yields from both experiments are included in figure 1. The assumed value of cattle weight gain was based upon an average reported by several studies. (Hossain et al.; Fieser et al.; Redmon et al., 1996; Kaitibie et al., 2003a).

Procedure

The occurrence of FHS is stochastic because it is affected by uncontrolled variables such as weather and precipitation, but a distribution of FHS can be estimated.

Distribution of FHS

Data gathered over an 8-year period was used to determine the FHS distribution (Edwards et al., 2006a). Eight models of FHS distribution were estimated, each with different levels of information. The first model is based on estimating FHS when only the year is known. This can be found by reading a time-sensitive newsletter distributed to farmers in the region which includes the date of FHS. The model can be written mathematically as:

$$(3) \qquad FHS_{it} = \alpha_0 + \sum_{t=1}^{T-1} \beta_t D_{it} + \varepsilon_{it},$$

where FHS_{it} is the date of FHS as a function of year, α_0 represents the intercept, β_t is the effect of year on FHS to be estimated ($t = 1,\ldots,T$-1), D_{it} is an indictor variable for year t (where t is over the range 1998 to 2005), and ε_{it} is an error term with $\varepsilon_{it} \overset{iid}{\sim} N(0,\sigma_{it}^2)$. The occurrence of FHS

5

may not only be estimated by year. The wheat variety also affects when the plant reaches FHS. The second model includes information on variety as well as year. The data include 52 different wheat varieties. The varieties were separated into four classifications relative to their occurrence of FHS (early, middle, late and unknown) (Edwards et al., 2006b). If the variety classification was not available, the variety was classified as unknown. The second model is defined as follows:

$$(4) \qquad FHS_{ijt} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \sum_{t=1}^{T-1} \beta_t D_{it} + \varepsilon_{ijt},$$

where FHS_{ijt} is the date of FHS as a function of variety and year, β_j is the effect of variety on FHS to be estimated ($j = 1,\ldots,J\text{-}1$), V_{ij} represents variety of wheat relative to timing of FHS (where j is equal to 1 for "early", j is equal to 2 for "middle", j is equal to 3 for "late", and j is equal to 4 for "unknown"), ε_{ijt} is an error term with $\varepsilon_{ijt} \overset{iid}{\sim} N(0, \sigma_{ijt}^2)$, and the other variables are as previously defined. Additional information may be available to determine FHS. The third model includes information on variety as well as the cumulative thermal units present at the time of FHS. Mathematically, the third model is shown as:

$$(5) \qquad FHS_{ij} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \beta_F FHSTU_i + \varepsilon_{ij},$$

where FHS_{ij} is the date of FHS as a function of variety and FHS thermal units, $FHSTU_i$ represents the cumulative thermal units present at FHS (cd), ε_{ij} is an error term with $\varepsilon_{ij} \overset{iid}{\sim} N(0, \sigma_{ij}^2)$, and other variables are as defined previously. The fourth model includes the highest level of information. It is based on knowing the variety and year, as well as the cumulative thermal units present at FHS. It can be shown mathematically as:

(6) $\quad FHS_{ijt} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \sum_{t=1}^{T-1} \beta_t D_{it} + \beta_F FHSTU_i + \varepsilon_{ijt},$

where FHS_{ijt} is the date of FHS as a function of variety, year and thermal units, ε_{ijt} is an error

term with $\varepsilon_{ijt} \overset{iid}{\sim} N(0, \sigma_{ijt}^2)$, and the other variables are as previously defined. Information about

FHS is often limited; therefore the fifth model assumes that the only information available is the

cumulative thermal units present at FHS. The fifth model can be shown mathematically as:

(7) $\quad FHS_i = \alpha_0 + \beta_F FHSTU_i + \varepsilon_i,$

where FHS_i is the date of FHS is a function of thermal units, ε_i is an error term with

$\varepsilon_i \overset{iid}{\sim} N(0, \sigma_i^2)$, and the other variables are as defined previously. The first five models were

estimated using analysis of variance models in SAS with the PROC MIXED command. The

Shapiro-Wilk test was performed to test for normality and confirms that the error terms are

normally distributed.

FHS may also be estimated with no information, perfect information, and an average

intercept. If there is no information available, the date of FHS can be found by using the actual

date of FHS over time and computing an average. Thus, the sixth model can be illustrated by the

following equation:

(8) $\quad \overline{FHS} = \left(\begin{array}{l} FHS_{t=1998} + FHS_{t=1999} + FHS_{t=2000} + FHS_{t=2001} + FHS_{t=2002} \\ + FHS_{t=2003} + FHS_{t=2004} + FHS_{t=2005} \end{array} \right) / 8,$

where $\overline{FHS}$ represents the average FHS during the study period from 1998 to 2005.

If perfect information is available, the model is expressed as:

(9) $\quad \hat{FHS}_{ijt} = FHS_{ijt},$

where FHS_{ijt} is based on perfect information of knowing the occurrence of FHS.

A random survey of 4,815 Oklahoma wheat producers (Hossain et al.) found that 58% of producers used calendar date to determine when to terminate grazing. By this measure over half of dual-purpose wheat producers remove their cattle according to calendar date. Only 31% reporting using date of FHS. Hossain et al. noted that two-thirds of dual-purpose wheat producers did not reveal a correct understanding of the term "FHS". Farmers were also asked their average grazing termination date. The state average was March 3 (ranging from February 29 to March 6). Thus, a model can be estimated basing the occurrence of FHS as the average surveyed calendar date when cattle were removed from pasture. However, information on FHS and stocker production practices are not always readily available, so the distribution of FHS may be estimated with only an intercept term. The eighth model is based on knowing an intercept and can be shown mathematically as:

(10) $\quad FHS_i = \alpha_0 + \varepsilon_i,$

where FHS_i is based only on the intercept (α_0) because no additional information is available and

an error term represented by ε_i where $\varepsilon_i \overset{iid}{\sim} N(0, \sigma_\varepsilon^2)$. To achieve a numerical value of this

intercept, the simple average is computed. Each of the eight models of FHS were estimated and were used to in the equations to find the optimal grazing termination date, depending on the varying levels of information.

Price Response Functions

Cattle price is a function of cattle weight and the day of sale. Cattle weight is a function of the number of grazing days. The longer steers are grazed, the higher their sale weight and heavier cattle tend to have a lower price per pound than lighter cattle. To estimate the cattle price response function, a quadratic functional form was defined in which the change in the basis

8

(cash – futures) price was estimated as a function of weight and selling date, accounting for a

random year effect. The cattle price equation follows:

$$(11) \quad Basis\% = \ln\left\{\frac{P_C(W(d),d,t)}{P_{CF}(t)}\right\} \times 100 = \gamma_0 + \gamma_1 W + \gamma_2 W^2 + \alpha d + \beta_1 Wd + \beta_2 Wd^2 + \varepsilon_{Wdt} + \mu_t,$$

where *Basis%* represents the basis change (percent), P_C is the cash price of steers as a function of

weight (W), removal date (d), and year (t) in \$/cwt, P_{CF} is the April futures price of steers

(\$/cwt), γ_0, γ_1, γ_2, α, β_1, and β_2 are the parameters to be estimated, ε_{Wdt} is a random error term

with $\varepsilon_{Wdt} \overset{iid}{\sim} N(0,\sigma_\varepsilon^2)$, and μ_t is a year random effect with $\mu_t \overset{iid}{\sim} N(0,\sigma_\mu^2)$. The expected price of

cattle may be estimated using:

$$(12) \quad E[P_C(W(d),d,t)] = \exp\left[\left\{\gamma_0 + \gamma_1 W + \gamma_2 W^2 + \alpha d + \beta_1 Wd + \beta_2 Wd^2\right\}/100 \times \ln(P_{CF})\right],$$

where the variables are as defined previously. The price function was estimated using maximum

likelihood estimation and the PROC MIXED command in SAS. The procedure included testing

for year random effects and heteroskedasticity. The futures price was estimated at \$81/cwt,

representing the average futures price from 1992 to 2006.

Cattle Gain and Wheat Yield Response Functions

　　　Expected cattle weight on sale day was modeled as:

$$(13) \quad E[W(d)] = W_P + ADG \times d,$$

where W is the weight of cattle on sale day (lb/head), W_P is the weight on January 1 (lb/head),

and *ADG* is the steer average daily gain (lb). Approximately 30% of dual-purpose wheat

producers purchase cattle in October or November with beginning weights for steers of 426 lb

(Hossain et al.). The assumed value of ADG was based upon an average reported by several

studies. The state-wide survey reported an ADG of 2.3 lb (Hossain et al.). Fieser et al. reported

an ADG of 3.53 lb in 2003 and 3.48 lb in 2005. Redmon et al. assumed an ADG of 2.43 lb in

their 1990-1995 study. Kaitibie et al. (2003a) reported an ADG of 2.59 lb. For the purposes of

this paper, an ADG of 2.74 lb is assumed. Thus, if steers were stocked on wheat pasture on

November 15, the expected January 1 weight would be 550 lb (i.e. 426 lb + 2.74 lb/head/day ×

45 day $\approx$ 550 lb/head).

The expected yield of wheat relative to cattle grazing past FHS is of particular interest.

In this study, a unique functional form is fitted to find the expected wheat grain yield. It nests

the linear spline form used by Redmon et al. (1996) and the quadratic form used by Fieser et al.

The yield of wheat is a function of the time the cattle are removed as well as the occurrence of

FHS. The expected wheat yield was estimated using the following plateau model with known

switching points:

$$(14) \quad Y(d,FHS) = \begin{cases} \overline{Y} + v_{d,FHS} + u_t & \text{if } d \leq FHS \\ \overline{Y} + \rho_1(d - FHS) + \rho_2(d - FHS)^2 + v_{d,FHS} + u_t & \text{if } d > FHS \end{cases},$$

where Y is grain yield (bushels/acre), d and FHS are as previously defined, $\overline{Y}$ is the maximum

grain yield which will differ by year as it is influenced by weather, precipitation, etc.

(bushels,/acre), ρ_1 and ρ_2 are the parameters to be estimated, $v_{d,FHS}$ is an error term where

$v_{d,FHS} \overset{iid}{\sim} N(0,\sigma_v^2)$, and u_t is a year random effect term with $u_t \overset{iid}{\sim} N(0,\sigma_u^2)$. In empirical

specification, independence is assumed between the two variance components, σ_u^2 and σ_v^2. The

estimates were determined using a nonlinear mixed model and maximum likelihood estimation.

To nest the linear spline form used by Redmon et al. (1996) and the quadratic form of

Fieser et al, it is necessary to estimate a wheat yield model with an unknown switching point.

The switching point is specified relative to the date of FHS. Estimated wheat yield may also be

determined using the following plateau model with unknown switching points:

$$(15) \quad Y(d, FHS) = \begin{cases} \bar{Y} + v_{d,FHS} + u_t & \text{if } d \leq FHS - \delta \\ \bar{Y} + \rho_1(d - FHS - \delta) + \rho_2(d - FHS - \delta)^2 + v_{d,FHS} + u_t & \text{if } d > FHS - \delta \end{cases},$$

where δ represents an unknown value (days), and all other variables are as previously defined.

This model was also estimated as a nonlinear mixed model with year random effects.

Wheat Yield Estimation

To estimate the wheat yield, the following integration is computed:

$$(16) \quad E[Y(d, FHS)] = \int_{-\infty}^{\infty} Y(d, FHS) f(FHS) dFHS,$$

where the integral is determined for each of the FHS distribution models. Because the

distribution of FHS is based on eight years of data, the following mathematical application must

be performed to find expected yield:

$$(17) \quad E[Y(d, FHS)] = \sum_{t=1}^{T} \int_{-\infty}^{\infty} \{(Y(d, FHS) f(\varepsilon) d\varepsilon)\}/T,$$

where T is the number of years. By inserting the estimated wheat yield response function (14),

the following equation is found:

$$(18) \quad E[Y(d, FHS)] = \sum_{t=1}^{T} \int_{-\infty}^{\infty} \{\min(\bar{Y}, \bar{Y} + \rho_1(d - FHS) + \rho_2(d - FHS)^2) f(\varepsilon) d\varepsilon\}/T$$

Based on the distribution assumption of FHS, the normal density function of ε is expressed as:

$$(19) \quad f(\varepsilon) = \frac{1}{\sqrt{2\pi\sigma_\varepsilon^2}} \exp\left(-\frac{\varepsilon^2}{2\sigma_\varepsilon^2}\right),$$

where $\varepsilon \overset{iid}{\sim} N(0, \sigma_\varepsilon^2)$ and the other variables are as defined previously. Total expected profits

were optimized to find a numerical solution for d, the optimal grazing termination date that

maximizes expected profits.

Profit Maximizing Grazing Termination Date

Given the expected price response function (12), the expected weight function (13), and

the expected yield function (14), the complete profit function can be found as:

(20)

$$\underset{d}{\text{Max}}\ E(\pi) = \left[\exp\left(\ln(P_{CF}) \times \left\{\gamma_0 + \gamma_1 W + \gamma_2 W^2 + \alpha d + \beta_1 Wd + \beta_2 Wd\right\}/100\right) \times \left\{W_P + ADG \times d\right\} - C_C\right] \times SD$$

$$+ P_Y\left[\sum_{t=1}^{8} \int_{-\infty}^{\infty} \left\{\min\left(\overline{Y}, \overline{Y} + \rho_1(d - FHS) + \rho_2(d - FHS)^2\right)f(\varepsilon)d\varepsilon\right\}/8\right] - C_Y$$

Assumptions are required to achieve a numerical solution. P_{CF} is assumed to be equal to

$81/cwt, which represents the mean April futures price of steer cattle from 1992 to the present.

W_P is set equal to 550 lb., ADG are set equal to 2.74 lb, P_Y is set equal to $2.89, and the stocking

density is set equal to 0.64 steer/acre. The optimal removal/selling date (d^*) is found by

differentiating the expected profit function with respect to d and finding an optimum level of d^*.

The expected profit model is optimized for each of the eight FHS distribution models. The

estimated profit model can be expressed as:

(21)

$$\underset{d}{\text{Max}}\ E(\pi) = \begin{bmatrix} \exp\left(\ln(81) \times \left\{49.33 - 9.54W + 0.43W^2 + 0.3d - 0.04Wd + 0.000025Wd\right\}/100\right) \\ \times \left\{550 + 2.74d\right\} - C_C \end{bmatrix} \times 0.64$$

$$+ 2.89\left[\sum_{t=1}^{8} \int_{-\infty}^{\infty} \left\{\min\left(30.32, 30.32 - 0.55(d - FHS_M) + 0.002(d - FHS_M)^2\right)f(\varepsilon_M)d\varepsilon_M\right\}/8\right] - C_Y$$

where W is the selling weight, d is the optimal grazing termination date, FHS_M is the estimated

date of FHS for the eight models ($M = 1,…,8$), and ε_M is the error associated with the model.

The optimal grazing removal date, *d,* and the value of information was found for each of the

eight models of FHS.

Results

Given eight years of FHS data about year, variety, thermal units, and surveys, eight models of FHS were estimated that used different levels of information (table 1). The fourth model based on the highest level of information (including year, variety, and thermal units at FHS) produced the best fit ($R^2 = 0.99$).

The results of the steer price response function are shown in table 3. The estimates possess the expected signs and can be used to determine the expected price. The weight of cattle on removal/selling date was estimated to be:

$$(22) \quad E[W(d)] = 5.50 + .0264d ,$$

assuming that the steers weigh 550 lb on January 1 with an ADG of 2.6 lb.

The results for the expected yield plateau function when FHS is known are reported in table 4. The results indicate that every day cattle are grazed past FHS, grain yields fall by approximately half of a bushel per day. Furthermore, the rate of grain yield loss decreases at a decreasing rate as grazing continues. Estimation also found that the empirical mean value of removal date (d) during the 1990 to 1994 and 2003 and 2005 study periods was 73 (March 13) and the mean value of FHS (*FHS*) was 69 (March 9).

A plateau model of wheat yield was also estimated with an unknown switching point. The estimated value of δ was 0.22 days. However, it was not significantly different than zero. This means that the spline point of wheat yield (i.e. the point when wheat yields begin to significantly decrease) is, in fact, at occurrence of FHS.

Based upon the stocking rate and ADG assumptions and estimated functions the optimal time to remove cattle from dual-purpose wheat pasture is at or before occurrence of FHS. In an

average year, the value of the additional weight gain from grazing past FHS is not sufficient to overcome the value of the grain lost.

A numerical solution for grazing termination date, $d*$, has not been reported in this study, but results will be forthcoming. A numerical solution can be found by solving the first order condition of the expected profit function, or an analytical solution will be determined using a grid search. Preliminary results show that the estimated wheat yield function illustrates that by grazing cattle past FHS, grain yields decrease 0.55 bushels/acre/day initially and continue to decrease, at a decreasing rate, eventually approaching zero. The value of 0.55 bushel/acre of wheat loss incurred by an additional day of grazing is $1.59/acre/day. The additional returns generated from extended grazing are $1.37/acre/day. Thus, the additional cattle gains do not compensate the grain yield loss from extended grazing. Furthermore, the wheat yield function found using the combined Fieser et al. and Redmon et al. data appears very linear, with a clear spline point occurring at FHS. The plateau functional form estimated for this study may be used to re-estimate both Fieser et al. and Redmon et al.'s findings. Using our functional form, wheat yield loss in Fieser et al.'s study is significantly smaller than that reported when the data are combined, approximately 0.02 bushels/acre/day with grain yields declining at an increasing rate. The spline point is smoother. On the other, when our functional form is applied to Redmond et al.'s data set, the grain yield loss is very large, showing a decline in grain yield of 1.67 bushels/acre/day of extended grazing past FHS, declining at a declining rate, with a clear spline point at FHS. Thus, our findings present a compromise in not only the functional form of determining wheat yield, but also in the grain yield loss that occurs by grazing steers past FHS. Further research is planned.

References

Carver, B.F., E.L. Smith, R.M. Hunger, A.R. Klatt, J.T. Edwards, D.R. Porter, J. Verchot-Lubicz, P.Rayas-Duarte, G.H. Bias, B.C. Martin, E.G. Krenzer, and B.W. Seabourn. 2006. "Registration of 'Endurance' Wheat." *Crop Science* 46:1816-1818.

Epplin, Francis M., Gerald W. Horn, and Eugene G. Krenzer Jr. 1999. "Wheat and Wheat-Stocker Production Planner." Oklahoma State University Agriculture Experiment Station, Division of Agricultural Sciences and Natural Resources. Bull. No. P-974.

Epplin, F. M., I. Hossain, and E.G. Krenzer Jr. 2000. "Winter Wheat Fall-Winter Forage Yield and Grain Yield Response to Planting Date in a Dual-Purpose System." *Agricultural Systems* 63:161-173.

Epplin, Francis M., Eugene G. Krenzer Jr., and Gerald Horn. 2001. "Net Returns from Dual-Purpose Wheat and Grain-Only Wheat." *Journal of the ASFMRA* 65:8-14.

Edwards, Jeffrey T., Brett F. Carver, and Mark E. Payton. 2006a. "Relationship of First Hollow Stem and Heading Date in Winter Wheat." Oklahoma 2005 Winter Wheat Variety Trial Results.

Edwards, Jeff, Bob Hunger, Brett Carver, and Tom Royer. 2006b. "Wheat Variety Comparison Chart." Oklahoma State University, Department of Plant and Soil Sciences. Production Technology Report Vol. 18, No. 6.

Fieser, B.G., G.W. Horn, J.T. Edwards, and E.G. Krenzer, Jr. 2006. "Timing of Grazing Termination in Dual-Purpose Winter Wheat Enterprises." *The Professional Animal Scientist* 22:210-216.

Horn, G. W., M. D. Cravey, F. T. McCollum, C. A. Strasia, E.G. Krenzer Jr., and P. L. Claypool. 1995. "Influence of High-Starch vs. High-Fiber Energy Supplements on Performance of Stocker Cattle Grazing Wheat Pasture and Subsequent Feedlot Performance." *Journal of Animal Science* 73:45-54.

Horn, G.W., P.A. Beck, J.G. Andrae, and S.I. Paisley. 2005. "Designing Supplements for Stocker Cattle Grazing Wheat Pasture." *Journal of Animal Science* 83 E. Suppl.:E69-E78.

Horn, Gerald W. 2006. "Growing Cattle on Winter Wheat Pasture: Management and Herd Health Considerations." *Veterinary Clinics Food Animal Practice* 22:335-356.

Hossain, Ishrat, Francis M. Epplin, Gerald W. Horn, and Eugene G. Krenzer Jr. 2004. "Wheat Production and Management Practices Used by Oklahoma Grain and Livestock Producers." Oklahoma State University Agricultural Experiment Station. Bull. No. B-818.

Kaitibie, Simeon, Francis M. Epplin, B. Wade Brorsen, Gerald W. Horn, Eugene G. Krenzer Jr., and Steven I. Paisley. 2003a. "Optimal Stocking Density for Dual-Purpose Winter Wheat Production." *Journal of Agricultural and Applied Economics* 35 (1):29-38.

Kaitibie, Simeon, Francis M. Epplin, Gerald W. Horn, Eugeune G. Krenzer Jr., and Steven I. Paisley. 2003b. "Dual-Purpose Winter Wheat and Stocker Steer Grazing Experiments at the Wheat Pasture Research Unit, Marshall, Oklahoma." Oklahoma State University Agricultural Experiment Station. Bull. No. B-816.

Krenzer, Gene and Gerald Horn. 1997. "Economic Impact of Grazing Termination in a Wheat Grain-Stocker Cattle Enterprise." Oklahoma State University Agricultural Experiment Station. Bull. No. PT 97-5 Vol.9, No. 5.

Paisley, S. I., G. W. Horn, J. N. Carter, and C. J. Ackerman. 1998. "Alternated Day Feeding of a Monensin-Containing Energy Supplement on Weight Gains of Steers Grazing Winter Wheat Pasture." Department of Animal Science, Research Report, Oklahoma State University.

Peel, Derrel S. 2003. "Beef Cattle Growing and Backgrounding Programs." *The Veterinary Clinics Food Animal Practice* 19:365-385.

Redmon, Larry A., Gerald W. Horn, Eugene G. Krenzer Jr., and David J. Bernardo. 1995. "A Review of Livestock Grazing and Wheat Grain Yield: Boom or Bust?" *Agronomy Journal* 88:94-97.

Redmon, Larry A., Eugene G. Krenzer Jr., Daniel J. Bernardo, and Gerald W. Horn. 1996. "Effect of Wheat Morphological Stage at Grazing Termination on Economic Return." *Agronomy Journal* 88:94-97.

Tembo, G., B.W. Brorsen, and F.M. Epplin. 2001. "Stochastic Linear-Response Plateau Functions." Unpublished manuscipt, Oklahoma State University.

True, R., F. Epplin, E. Krenzer, Jr., and D. Bernardo. 2001. "A Survey on Wheat Production and Wheat Forage Use Practices in Oklahoma." Oklahoma State University Agricultural Experiment Station. Bull. No. B-815.

U. S. Department of Agriculture. 1992-2005. Market News Information Service, Livestock, Grain & Hay. Oklahoma Market Report. Oklahoma City, Oklahoma. http://www.oda.state.ok.us/mktdev-reportshome.htm. Archived price data available from the Livestock Marketing Information Center, http://www.lmic.info/.

U. S. Department of Agriculture. 2006. Oklahoma Agricultural Statistics. Archived price data available in the annual bulletin, http://www.nass.usda.gov/ok/bulletin06/ok_annual_bulletin_2006.pdf/.
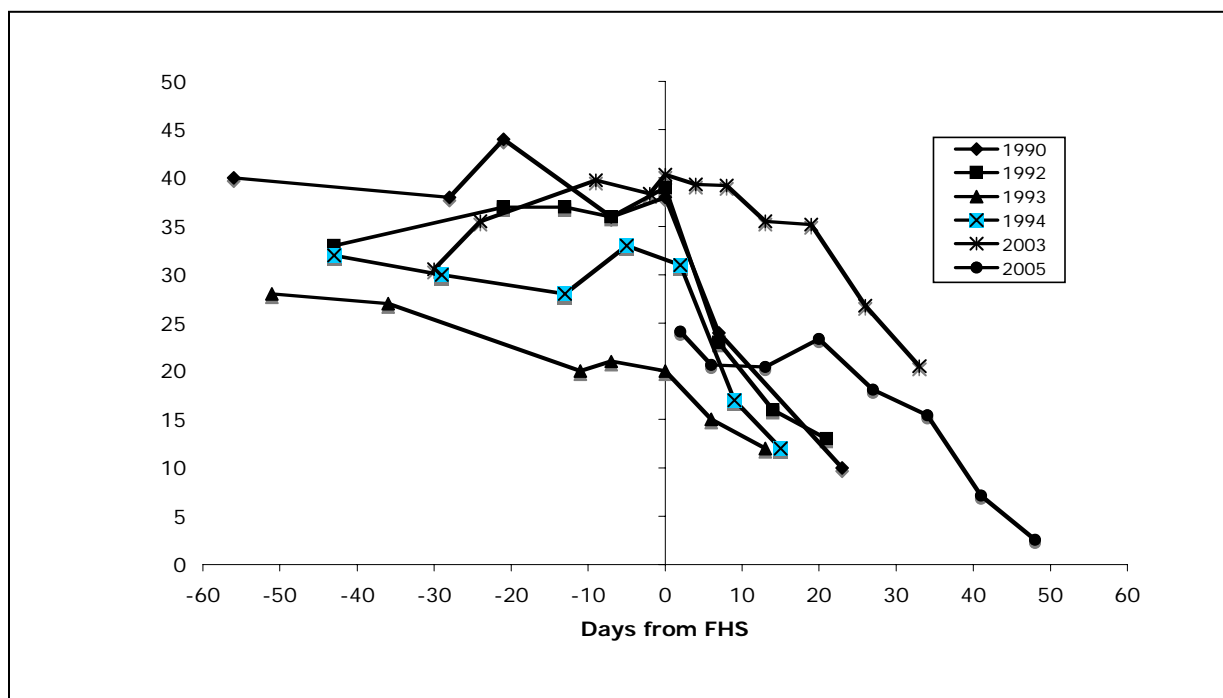
Figure 1. Mean wheat yields (bu/acre) of Redmon et al. and Fieser et al.'s studies relative to first hollow stem (FHS)

Table 1. Estimates of the Distribution of First Hollow Stem (FHS) using Five Models of Regression (Models 1 – 5)

Statistic	Definition	Estimates[a]				
		Model 1 $f(FHS/\text{Year})$	Model 2 $f(FHS/\text{Variety, Year})$	Model 3 $f(FHS/\text{Variety, FHSTU})$	Model 4 $f(FHS/\text{Variety, Year, FHSTU})$	Model 5 $f(FHS/FHSTU)$
α_0	Intercept	54.57* (1.56)	57.59* (1.14)	46.34* (2.85)	23.97* (0.59)	38.64* (2.49)
$\beta_{t=1998}$	1998	1.16 (2.99)	0.61 (2.15)	-	3.35* (1.00)	-
$\beta_{t=1999}$	1999	7.27* (1.90)	6.70* (1.25)		-7.71* (0.42)	-
$\beta_{t=2000}$	2000	8.18* (1.92)	7.28* (1.24)	-	-5.33* (0.48)	-
$\beta_{t=2001}$	2001	23.98* (1.60)	22.97* (1.17)	-	16.32* (0.26)	-
$\beta_{t=2002}$	2002	25.37* (1.88)	24.41* (1.24)	-	7.71* (0.38)	-
$\beta_{t=2003}$	2003	17.63* (1.71)	16.34* (1.12)	-	17.24* (0.32)	-
$\beta_{t=2004}$	2004	8.52* (2.05)	7.71* (1.33)	-	6.90* (0.23)	-
$\beta_{t=2005}$	2005	-	-	-	-	-
$\beta_{j=1}$	"Early" Variety	-	-5.87* (0.63)	-7.07* (1.47)	-0.47* (0.21)	-
$\beta_{j=2}$	"Middle" Variety	-	-1.93* (0.75)	-6.03* (2.40)	-0.03 (0.26)	-
$\beta_{j=3}$	"Late" Variety	-	1.66* (0.67)	3.66* (1.50)	-0.25 (0.20)	-
$\beta_{j=4}$	"Unknown" Variety	-	-	-	-	-
β_F	FHS Thermal Units	-	-	0.08* (0.007)	0.11* (0.002)	0.08* (0.007)

18

Table 1. Continued

| Statistic | Definition | Estimates[a] | | | | |
		Model 1 $f(FHS/\text{Year})$	Model 2 $f(FHS/\text{Variety, Year})$	Model 3 $f(FHS/\text{Variety, } FHSTU)$	Model 4 $f(FHS/\text{Variety, Year, } FHSTU)$	Model 5 $f(FHS/FHSTU)$
σ^2	Variance of Error				1.30* (0.19)	
R^2		0.71	0.86	0.46	0.99	0.42
Adj. R^2		0.70	0.86	0.45	0.99	0.41

[a] Asymptotic standard errors are shown in parentheses.
* Represents significance at the 5% level.
FHSTU represents cumulative thermal units (cd) present after January 1 at the wheat growing location in Stillwater, Oklahoma.
Note: The parameter estimates were estimated using an analysis of variance (ANOVA) model and PROC MIXED in SAS. Normality tests were performed to test if the errors were randomly distributed. The Shapiro-Wilk test confirms that all the errors are normally distributed.

Table 2. Estimates of the Distribution of First Hollow Stem (FHS) using Five Models of Regression (Models 6 – 8)

| Statistic | Definition | Estimates | | |
		Model 6 $f(FHS/\overline{FHS}$ No Information)	Model 7 $f(FHS/\hat{FHS}$ Perfect Information)	Model 8 $f(FHS/\alpha_0$ No Information)
FHS	Estimated date of First Hollow Stem	March 6 $\overline{FHS} = 66$	March 3 $\hat{FHS} = 63$	March 6 $\alpha_0 = 66$

Table 3. Steer Price Response as a Function of Weight (*W*) and Removal/Selling Date (*d*)

Statistic	Definition	Estimates[a]
γ_0	Intercept	49.33*
		(4.02)
γ_1	Weight	-9.54*
		(1.00)
γ_2	Weight Squared	0.43*
		(0.06)
α	Removal Date	0.30*
		(0.02)
β_1	Weight × Removal Date	-0.04*
		(0.002)
β_2	Weight × Removal Date Squared	2.5E-5*
		(9.7E-6)
σ_μ^2	Variance of year random effect	2.80*
		(1.08)
σ_ε^2	Variance of error term	8.38*
		(0.29)
-2LL	-2 Log Likelihood	
R^2	Measure of Fit	0.76
Adj. R^2	Adjusted Measure of Fit	0.76
Basis %	$49.33 - 9.54W + 0.43W^2 + 0.30d - 0.04Wd + 0.000025Wd^2$	

[a] Asymptotic standard errors are in parentheses.
* Represents significance at the 5% level.
Note: The parameter estimates were estimated using PROC MIXED in SAS with year random effects and corrected for heteroskedasticity.

Table 4. Plateau Model of Wheat Yield as a Function of First Hollow Stem (*FHS*) and Removal Date (*d*) with Known Switching Point

Statistic	Definition	Estimates[a]
ρ_1	Parameter Estimate of $(d\text{-}FHS)$	-0.55* (0.12)
ρ_2	Parameter Estimate of $(d\text{-}FHS)^2$	0.002 (0.003)
$\overline{Y}$	Expected Wheat Yield Plateau	30.32* (2.51)
σ^2_u	Variance of year random effect	33.66 (20.74)
σ^2_v	Variance of error term	30.70* (4.21)
-2LL	-2 Log Likelihood	717.8
FHS	Average FHS Date	March 10[b]
$\overline{d}$	Average Removal Date	March 14[b]
$Y(d,FHS)$	$\begin{cases} 30.32 & \text{if } d \leq FHS \\ 30.32 - 0.55(d - FHS) + 0.002(d - FHS)^2 & \text{if } d > FHS \end{cases}$	

[a] Asymptotic standard errors are in parentheses.
[b] Based on data from Fieser et al. and Redmon et al.
* Represents significance at the 5% level.
Note: The parameter estimates were estimated using PROC NLMIXED in SAS with year random effects and corrected for heteroskedasticity.

Table 5. Plateau Model of Wheat Yield as a Function of First Hollow Stem (*FHS*) and Removal Date (*d*) with Unknown Switching Point

Statistic	Definition	Estimates[a]
ρ_1	Parameter Estimate of (*d-FHS*)	-0.56* (0.15)
ρ_2	Parameter Estimate of (*d-FHS*)^2	0.002 (0.003)
$\overline{Y}$	Expected Wheat Yield Plateau	30.28* (2.55)
δ	Delta in days	0.22 (2.89)
σ^2_δ	Variance of delta	8.34
σ^2_u	Variance of year random effect	33.67 (20.75)
σ^2_v	Variance of error term	30.70* (4.21)
-2LL	-2 Log Likelihood	717.8
Y(*d,FHS*)	$\begin{cases} 30.28 & \text{if } d \le FHS + \delta \\ 30.28 - 0.56(d - FHS) + 0.002(d - FHS)^2 & \text{if } d > FHS + \delta \end{cases}$	

[a] Asymptotic standard errors are in parentheses.
* Represents significance at the 5% level.
Note: The parameter estimates were estimated using PROC NLMIXED in SAS with year random effects and corrected for heteroskedasticity.