Journal of Agricultural and Applied Economics, 42,1(February 2010):87–103

Optimal Grazing Termination Date for Dual-Purpose Winter Wheat Production

Karen W. Taylor, Francis M. Epplin, B. Wade Brorsen, Brian G. Fieser, and Gerald W. Horn

Dual-purpose winter wheat (fall-winter forage plus grain) production is an important economic enterprise in the southern Great Plains. Grazing termination to enable grain production is a critical decision. The objective is to determine the optimal grazing termination date for dual-purpose wheat. The value of knowing the occurrence of first hollow stem (FHS), a wheat growth threshold for grazing termination, is also determined. Results indicate that for most price situations grazing should be terminated at or before FHS. Marginal wheat returns from extended grazing were negative and the value of FHS information ranges from $1.50 to $10 per acre.

Key Words: dual-purpose, first hollow stem, plateau function, stocker cattle, value of information, wheat

JEL Classifications: Q12, Q16

In the Southern Plains of the United States, winter wheat may be produced as a dual-purpose crop in which the fall winter forage may be used to pasture livestock. If the livestock are removed in the late winter prior to the time when the wheat plants emerge from winter dormancy, the wheat will mature and produce a grain crop for harvest in June. The wheat may be planted in September and grazed by livestock from mid-November into the late winter. Most 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.

Precise estimates of the number of acres used to produce dual-purpose wheat in the region are not provided by the USDA. Pinchak et al. (1996) hypothesized that between 20–60% of the acres seeded to winter wheat in the Southern Plains are used as a dual-purpose crop. Statewide surveys have found that two-thirds of Oklahoma wheat acres are intended for dual-purpose use (True et al., 2001; Hossain et al., 2004). In a typical year 12 million acres are planted to winter wheat in New Mexico, Oklahoma, and Texas. It is likely that more than half, 6 million acres, are managed to produce dual-purpose wheat and provide fall-winter forage for 3 million stocker cattle (Brorsen et al. 1983; Coulibaly, Bernardo, and Horn, 1996; Epplin, Hossain, and Krenzer,

Karen W. Taylor is senior relationship manager, Farm Credit Canada, Abbotsford, BC. Francis M. Epplin is Charles A. Breedlove professor, B. Wade Brorsen is regents professor and Jean & Patsy Neustadt chair, Department of Agricultural Economics, Brian G. Fieser is a former research assistant, and Gerald W. Horn is professor, Department of Animal Science, Oklahoma State University.

This project was supported in part by the USDA Cooperative State Research, Education and Extension Service, Hatch grant number H-2574, and in part by USDA Cooperative State Research, Education and Extension Service special research grants including 2008-34198-19207. Journal paper AEJ-268 of the Oklahoma Agricultural Experiment Station.

2000; Fieser et al., 2006; Hossain, Epplin, and Krenzer, 2003; Kaitibie et al., 2003a; Ralston et al., 1990; Redmon et al., 1995; Rodríguez et al., 1990; Whitson et al., 1973; Zhang et al., 2008). Dual-purpose wheat is also an important crop in Argentina (Arzadún et al., 2006), Australia, Morocco, Pakistan, Syria, and Uruguay (Rodriguez et al., 1990).

Grazing termination date is critical to the economic success of dual-purpose winter wheat. If grazing is terminated too early, livestock weight gain will be less than what it could be. If grazing is terminated too late, wheat grain yield will be reduced. Prior research sought to determine optimal grazing termination date (Fieser et al., 2006; Horn, 2006; Redmon et al., 1995, 1996). Redmon et al. (1996) concluded that grazing should be terminated at the first hollow stem (FHS) growth stage of the winter wheat. However, more recent research reported by Fieser et al. (2006) concluded that in times of high cattle prices and low wheat prices, it would be economical to graze livestock past FHS.

FHS occurs when the stems of ungrazed plants begin to elongate and the stem above the roots, and below the developing head, becomes hollow. The wheat plant is said to be at FHS when the hollow stem portion of the plant is one half inch long. The occurrence of FHS depends on climatic factors including temperature and precipitation and on wheat variety. Redmon et al. (1996) found that when livestock are removed prior to, or at development of FHS, there is little or no loss of grain yield due to grazing. However, grain yield is reduced when cattle are left on wheat pasture after the development of FHS. If cattle graze past FHS, they will consume leaves of the wheat plant that produce photosynthate, a chemical product of photosynthesis required to grow the upper leaves of the plant and enable the head to grow and fill (Edwards et al., 2007).

Maximizing returns from a dual-purpose wheat enterprise requires an understanding of the tradeoff between livestock weight gain and wheat grain yield. Grazing past FHS reduces wheat grain yield but increases livestock weight. Redmon et al. (1996) reported that grain yield fell dramatically (as much as 1.25 bushels per day) for each day that wheat was grazed past FHS (Redmon et al., 1996; Krenzer and Horn, 1997). By this measure, at historical prices, for normal livestock weight gain from wheat forage, grazing a single day past FHS would not be economical.

Fieser et al. (2006) found that grain yield declined nonlinearly with days grazed past FHS. They concluded that there is a "safety zone" during which cattle may be grazed past FHS without drastically reducing grain yields. The two studies (Redmon et al., 1996; Fieser et al., 2006) came to different conclusions for several reasons. First, there were differences in the design and execution of the field trials used to produce the data. Second, they used different functional forms. Third, Redmon et al. (1996) assumed an average daily steer weight gain of 2.4 pounds whereas Fieser et al. (2006) measured weight gains of over 3.0 pounds per day. Neither study estimated a cattle price response function or analyzed the distribution of the occurrence of FHS. Thus, there is a need to reevaluate weight gain and grain yield in estimating how cattle and grain returns are affected by grazing past FHS.

This study was motivated by the inconsistent findings of these prior studies. The objective of this research is to determine the optimal grazing termination date for dual-purpose winter wheat. This study also determines the value of knowing the occurrence of FHS. In the model developed here, expected return maximization is used to determine the optimal grazing termination date.

Theory

Fall-winter wheat pasture is assumed to be stocked with young steers. Producers are assumed to maximize net returns from dual-purpose winter wheat production that includes revenue earned from steer weight gain and revenue earned from wheat grain. The gain in revenue from grazing past FHS must be weighed against the loss in grain revenue. The expected profit optimization equation is:

$$
\begin{aligned}
\max_{d} \mathrm{E}(\pi) = \{&\mathrm{E}[\mathrm{P_C}(d, W(d))] \times \mathrm{E}[W(d)] \\
&- C_C\} \times SD + \mathrm{E}[P_Y] \\
&\times \mathrm{E}[Y(d, FHS)] - C_Y,
\end{aligned} \tag{1}
$$

where $\mathrm{E}(\pi)$ represents expected profits of a dual-purpose winter wheat enterprise ($/acre),

d is steer removal/sale date (where d is equal to 1 on January 1), E[P_C] is the expected sale price of steers (\$/cwt), E[W] is the expected weight of steers on sale day (cwt/head), C_C represents the costs of purchasing steers, bringing them to market and other costs incurred other than the cost of wheat 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 sale price of steers (P_C) depends on the sale weight (W), and since prices are seasonal, on the day (d) of the year that they are sold. Sale price is therefore modeled as a function of sale weight and sale date. Steer sale weight is a function of the number of grazing days. The stocking density parameter is used to convert steer value to an acre basis. Moderate stocking density is assumed to have no effect on grain yield, so stocking density is held constant and is assumed to affect only steer returns (Redmon et al., 1996; Kaitibie et al., 2003b).[1] The first order condition for the optimal grazing termination date is:

$$\frac{\partial \mathrm{E}(\pi)}{\partial d} = \frac{\partial\{\mathrm{E}[P_C(d,W(d)) \times \mathrm{E}(W(d)) \times SD\}}{\partial d} + \frac{\partial\{\mathrm{E}[P_Y] \times \mathrm{E}[Y(d,FHS)]\}}{\partial d} - 0, \tag{2}$$

where the variables are as previously defined. Equation (2) can be solved numerically to find d^*, the optimal grazing termination date. Steers are assumed to be sold at d^*.

Value of Information

The distribution of FHS is required to determine expected returns when FHS date is not known. The value of FHS information is defined as:

$$Value\ of\ Information = \mathrm{E}(\pi/\Omega,I_M) - \mathrm{E}(\pi/\Omega,I_1), \tag{3}$$

where E($\pi/\Omega,I_M$) is the expected profit given the information set (Ω and I_M), I_M is the level of available information based on the model of the distribution of FHS, M represents the number of models of different levels of information (M = 1,. . .,8), and E($\pi/\Omega,I_1$) is the expected profit given no information. Eight models of FHS were formulated based on information about year, variety, and growing conditions of the wheat plant.

Data

Distribution of FHS data were obtained from Edwards, Carver, and Payton (2007). These data include the wheat variety, date of FHS, heading date, and the cumulative thermal units present at both the time of FHS and heading. Data were available from eight years (1998–2005) for 52 varieties at a location near Stillwater, Oklahoma. Temperature data used to compute growing degree days were collected from an on-site weather station. FHS occurred between February 10 and March 28 across the 52 varieties and eight years.

Steer cash and futures price data were obtained from the Livestock Market Information Center (USDA, 2005). Cash prices were

[1] The most common alternative to dual-purpose wheat in the region is wheat for grain-only. Based on surveys, Oklahoma producers indicate that typically they intend to mange two-thirds of their wheat acres for dual-purpose use (Hossain et al., 2004; True et al., 2001). This suggests that in the region the expected returns from dual-purpose wheat exceed the expected returns from grain-only wheat. However, wheat production practices (and production costs) are different depending on intended use. The optimal seeding rate, nitrogen fertilizer rate, and planting date are different for dual-purpose wheat (Epplin, Hossain, and Krenzer, 2000; Hossain, Epplin, and Krenzer, 2003). Small plot studies have found that the expected grain yield from the earlier planted dual-purpose wheat is approximately 90 percent of the expected grain yield from the later planted grain-only wheat. The value of grazing must be sufficient to offset the cost of the additional seed, additional nitrogen, and grain yield loss. Budget estimates provided by Taylor et al. (2007) are that the gross value of the grazing is about \$60 per acre; adjusting for the additional cost and grain yield loss would leave a net value of about \$20 per acre. The net value of grazing is very sensitive to the sale price of cattle. Epplin, Krenzer, and Horn (2001) reported that in 16 of 20 years evaluated, the net returns from dual-purpose wheat exceeded the net returns from grain-only wheat on average \$11 per acre. The difference in net returns of dual-purpose relative to grain-only ranged from a −\$7 to +\$35 per acre.

available in 50-pound increments from 1992 to 2006. Steer futures prices were based on the month of April. The expected price of wheat was taken from the five-year average Oklahoma cash price received during June and July from 2000 to 2005 (USDA, 2006).

Steer weight gain and wheat grain yield response data were obtained from the four-year study reported by Redmon et al. (1996) and the Fieser et al. (2006) two-year study. The mean wheat yield from both previous studies can be found in Figure 1. Both experiments were conducted at the Wheat Pasture Research Unit near Marshall, Oklahoma (Kaitibie et al., 2003b).

Procedure

The model requires a distribution of FHS dates, a cattle price response function, a cattle gain function, and a wheat grain yield function. The occurrence of FHS is stochastic because it is affected by weather, but a distribution of FHS can be estimated.

Distribution of FHS

The FHS data reported by Edwards, Carver, and Payton (2007) were used to estimate eight models of FHS distributions. Because collecting data on FHS could be expensive for some producers, we consider several models with less than perfect information. Currently producers in the region have several options regarding how to determine when to remove livestock from dual-purpose wheat. One option is to remove the cattle at the same calendar date each year. Based on survey results (Hossain et al., 2004) many producers use this method and based on tradition and experience remove cattle from wheat on or near a fixed date each year. The average calendar date for removal as reported by producers is March 3 which is close to the average date of FHS of March 6 reported by Edwards, Carver, and Payton (2007). Equation (4) is used to represent this calendar date strategy. It is referred to as a zero information system, which means that it assumes that the farmer follows a calendar date strategy and does not use the information provided by agronomists for the specific year and variety.

$$(4) \qquad FHS_i = \alpha_0 + \varepsilon_i,$$

where FHS_i is based only on the intercept, α_0, and an error term represented by ε_i where $\varepsilon_i \overset{iid}{\sim} N(0,\sigma_\varepsilon^2)$. The estimate of this intercept is

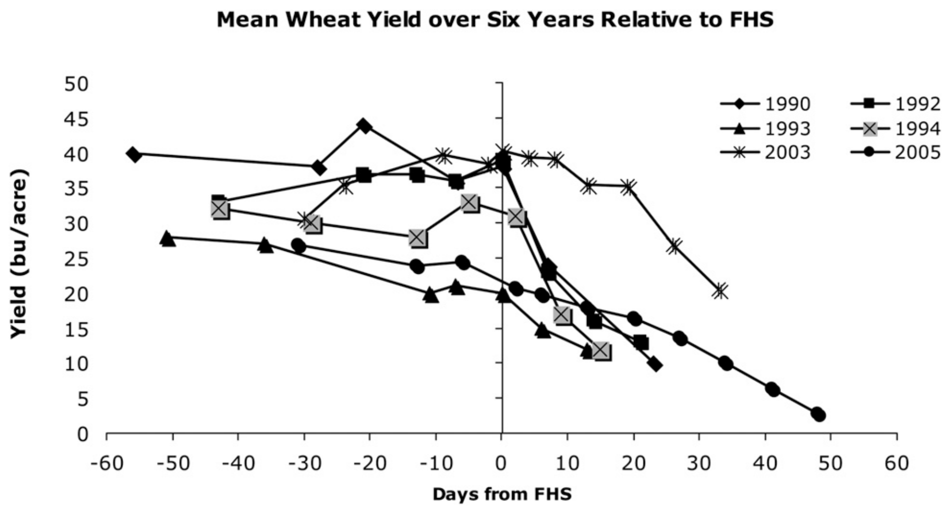

Figure 1. Mean Wheat Yields Relative to First Hollow Stem (FHS) (Wheat yields relative to FHS and date of grazing termination for six production seasons at the Wheat Pasture Research Unit, Marshall, OK. Wheat yields in years 1990–1994 are based on Redmon et al. [1996] and wheat yields in 2003 and 2005 are based on Fieser et al. [2006].)

the average date of FHS across the eight years for which data were available.

Since the weather is different across years, producers that follow a calendar date strategy forgo additional livestock weight gain and value in years when the animals are removed prior to FHS, and suffer a reduction in wheat yield and value in years when steers are removed after FHS. Over the period from 1998 to 2005, Edwards, Carver, and Payton (2007) found that FHS occurred between February 10 and March 28, depending on year and variety. Following a calendar date, the "no information" strategy, could be costly.

A second option that has become available to producers in the last decade is to consider information provided by state agronomy extension wheat production specialist. Because of the importance of FHS, beginning in February, agronomists monitor the occurrence of FHS at several locations across the region and provide frequent updates via web sites, e-mail, and newsletters. This information is also disseminated via mass media – radio and newspapers. Producers can then use the information regarding the growth of wheat plants in the region to make decisions regarding their fields. The purpose of Equation (5) is to determine the value of this regional information that is provided to producers during the growing season each year. In this context, "year" refers to the current year. The information will be less than "perfect" because conditions for a particular field may differ from those of the field or plots used by the agronomists to obtain the regional information. The second model is based on estimating FHS when only the year is known.

$$(5) \qquad FHS_{it} = \alpha_0 + \sum_{t=1}^{T-1} \beta_t D_{it} + \varepsilon_{it},$$

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 indicator variable for year t (where t is over the range 1998–2005), and ε_{it} is an error term with $\varepsilon_{it} \overset{iid}{\sim} N(0,\sigma^2_{it})$.

Wheat variety also affects date of FHS. The 52 varieties were separated into four classifications relative to their occurrence of FHS (i.e. early, middle, late and unknown) (Edwards et al., 2006). Historical FHS data were not available for 14 of the 52 varieties. These 14 were classified as unknown. The third model is defined as:

$$(6) \qquad FHS_{ij} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \varepsilon_{ij},$$

where FHS_{ij} is the date of FHS as a function of variety, β_j is the effect of variety on FHS to be estimated ($j = 1,\ldots,J - 1$), V_{ij} represents an indicator variable for the variety 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_{ij} is an error term with $\varepsilon_{ij} \overset{iid}{\sim} N(0,\sigma^2_{ij})$, and the other variables are as previously defined.

The fourth model is based on the combined knowledge of variety and year:

$$(7) \qquad FHS_{ijt} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \sum_{t=1}^{T-1} \beta_t D_{it} + \varepsilon_{ijt},$$

where FHS_{ijt} is the date of FHS as a function of variety and year, ε_{ijt} is an error term with $\varepsilon_{ijt} \overset{iid}{\sim} N(0,\sigma^2_{ijt})$, and the other variables are as defined previously.

Cumulative thermal units are a weather indicator in which larger values represent higher temperatures and more favorable wheat growing conditions resulting in an earlier FHS date.

The fifth model assumes that the only information available is cumulative thermal units:

$$(8) \qquad FHS_i = \alpha_0 + \beta_F FHSTU_i + \varepsilon_i,$$

where FHS_i is the date of FHS as a function of thermal units, $FHSTU_i$ represents the cumulative thermal units present on the day of FHS in units of cd, and ε_i is an error term with $\varepsilon_i \overset{iid}{\sim} N(0,\sigma^2_i)$.[2] The Oklahoma Mesonet provides real time growing degree days (a measure of thermal units) data online and has the potential to offer prediction of FHS.

Model six includes variety and cumulative thermal units present at FHS:

[2] cd stems from the Latin word Candela for "candle". It is a unit measurement of the intensity of light. An ordinary wax candle generates approximately one candela. More specifically, one candela (cd) is the monochromatic radiation of 540THz with a radiant intensity of 1/683 watt per steradian in the same direction.

$$(9)\qquad FHS_{ij} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \beta_F FHSTU_i + \varepsilon_{ij},$$

where FHS_{ij} is the date of FHS as a function of variety and FHS thermal units, ε_{ij} is an error term with $\varepsilon_{ij} \overset{iid}{\sim} N(0,\sigma^2_{ij})$, and other variables are as defined previously.

Model seven includes the most information: variety, year, and cumulative thermal units present at FHS:

$$(10)\qquad \begin{aligned} FHS_{ijt} = \alpha_0 + \sum_{j=1}^{J-1} \beta_j V_{ij} + \sum_{t=1}^{T-1} \beta_t D_{it} \\ + \beta_F FHSTU_i + \varepsilon_{ijt}, \end{aligned}$$

where FHS_{ijt} is the date of FHS as a function of variety, year and thermal units, ε_{ijt} is an error term with $\varepsilon_{ijt} \overset{iid}{\sim} N(0,\sigma^2_{ijt})$, and the other variables are as previously defined.

Model eight is based on knowing the occurrence of FHS with perfect information:

$$(11)\qquad FHS_{it} = \overline{FHS}_{it},$$

where FHS_{it} is the date of FHS and is equal to the average FHS. In this case, certainty is assumed and FHS date can be estimated as the annual mean FHS across the 52 varieties and eight years.

Models 2 through 7 were estimated with the SAS PROC MIXED command (SAS Institute, 2009). The Shapiro-Wilk test was performed to test for normality and confirmed that the error terms are normally distributed. The Breusch-Pagan test was conducted to test for heteroskedasticity. It tests whether the estimated variance of the residuals from each regression are dependent on FHS. Heteroskedasticity was corrected by weighting each of the years equally. Thus, in determining the expected date of FHS, the estimated mean FHS for each year is determined and the eight years are given equal weighting. Each of the eight models of FHS were estimated, corrected for heteroskedasticity, and used in the equations to find the optimal grazing termination date, depending on the varying levels of information.

Price Response

Since many steers are removed from wheat pastures and sold during the relatively narrow FHS time period, seasonal price patterns in the region may be influenced. This temporary surge in sales should affect cash price and not futures prices and thus should be reflected in the basis. The change in the steer price basis (cash – futures) price was estimated as a function of weight and selling date, accounting for a random year effect:

$$(12)\qquad \begin{aligned} Basis\%_{Wdt} &= \ln\left\{\frac{P_C(W(d),d,t)}{P_F(t)}\right\} \times 100 \\ &= \gamma_0 + \gamma_1 + \gamma_2 W^2 + \alpha d \\ &\quad + \beta_1 Wd + \beta_2 Wd^2 + \varepsilon_{Wdt} + \mu_t, \end{aligned}$$

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_F is the April futures price of steers (\$/cwt), γ_0, γ_1, γ_2, α, β_1, and β_2 are parameters to be estimated, ε_{Wdt} is a random error term with $\varepsilon_{Wdt} \overset{iid}{\sim} N(0,\sigma^2_\varepsilon)$, and μ_t is a year random effect with $\mu_t \overset{iid}{\sim} N(0,\sigma^2_\mu)$. The expected steer price may be calculated using:

$$(13)\qquad \begin{aligned} \mathrm{E}[P_C(W(d),d,t)] = \exp\big(\{\gamma_0 + \gamma_1 W + \gamma_2 W^2 \\ + \alpha d + \beta_1 Wd + \beta_2 Wd^2 \\ + \sigma^2_\varepsilon/2\}/100\big) \times P_F, \end{aligned}$$

where the variables are as defined previously.

The price function was estimated using the maximum likelihood procedure available in the SAS PROC MIXED command assuming year random effects. The steer cash price was found from weekly prices reported at the Oklahoma City auction market from 1992 to 2006. The cash prices represent weight ranges in 50-pound increments between 600–1000 pounds from the first week in January to the last week in April (i.e. the time frame that the cattle would be sold). The futures price is based on April futures prices from the period 1992–2006. Over 1,870 observations were used to estimate the steer price response function. The natural log transformation defined in Equation (13) was used to correct for heteroskedasticity. The expected price of wheat was assumed to be \$2.89 per bushel, the five-year average Oklahoma cash price received during June and July from 2000 to 2005 (USDA, 2006).

Steer Gain and Wheat Yield Response Functions

The expected steer weight on sale day was estimated as:

$$\text{(14)} \quad \mathrm{E}[W(d)] = W_P + ADG \times d,$$

where W is steer weight on sale day (cwt/head), W_P is steer weight on January 1 (cwt/head), and ADG is steer average daily gain (cwt/head). Approximately 30% of dual-purpose winter wheat producers purchase steers in October or November. The grazing season usually begins in mid-November. When stocked on wheat the average initial weight for these steers is 426 pounds (Hossain et al., 2004). A January 1 steer weight of 550 pounds was assumed. This was based on a November 15 expected weight of 426 pounds and an expected ADG of 2.75 pounds (i.e. 426 pounds + 2.75 pounds × 45 day ≈ 550 pounds).

The assumed ADG was based on a number of studies. A survey of producers reported an average ADG of 2.3 pounds (Hossain et al., 2004). Fieser et al. (2006) reported an ADG of 3.5 pounds in 2003 and 3.3 pounds in 2005. Redmon et al. (1996) reported an ADG of 2.43 pounds. Kaitibie et al. (2003a) reported an expected ADG of 2.59 pounds. In this study results are computed and reported for ADG levels of 2.5, 2.75, 3.0 and 3.5 pounds.

Fieser et al. (2006) used a quadratic function to estimate wheat grain yield (Figure 2a), while Redmon et al. (1996) used a spline function (Figure 2b). For the current study, wheat grain yield is estimated as a function of the time the steers are removed from the dual-purpose wheat relative to FHS as well as the occurrence of FHS. Two functions were estimated: one with a known and a second with an unknown switching point. The following model has a known switching point at FHS:

$$\text{(15)} \quad Y(d_{it},FHS_{it}) = \begin{cases} \overline{Y} + \nu_{it} + u_t & \text{if } d_{it} \leq FHS_{it} \\ \overline{Y} + \rho_1(d_{it} - FHS_{it}) + \rho_2(d_{it} - FHS_{it})^2 \\ \quad + \nu_{it} + u_t & \text{if } d_{it} > FHS_{it} \end{cases},$$

where Y is the grain yield (bushels/acre), d_{it} is the grazing termination date for observation i in year t, FHS_{it} is the date of FHS, $\overline{Y}$is the maximum wheat yield (bushels per acre) which will differ by year as it is influenced by weather and other factors, ρ_1 and ρ_2 are the parameters to be estimated, ν_{it} is an error term where $\nu_{it} \overset{iid}{\sim} N(0,\sigma_\nu^2)$, and u_t is a year random effect term with $u_t \overset{iid}{\sim} N(0,\sigma_u^2)$. Independence is assumed between the two variance components, $\sigma^2{}_u$ and $\sigma^2{}_\nu$.

Data from the two-year Fieser et al. (2006) study and Redmon et al. (1996) four-year study were used to fit the function. Since the data points from the two sources were based on different numbers of replications the variances were weighted to avoid heteroskedasticity (Dickens, 1990). The weighted variance is $\mathrm{var}(\nu_{it}) = \sigma_u^2 + \sigma_\nu^2/N_t$, where N_t is the number of replications in year t.

The model with an unknown switching point was estimated to nest the spline function used by Redmon et al. (1996) and the quadratic function of Fieser et al. (2006). The following model has a switching point specified relative to FHS date:

$$\text{(16)} \quad Y(d_{it},FHS_{it}) = \begin{cases} \overline{Y} + \nu_{it} + u_t \quad \text{if } d_{it} \leq FHS_{it} - \delta \\ \overline{Y} + \rho_1(d_{it} - FHS_{it} - \delta) \\ \quad + \rho_2(d_{it} - FHS_{it} - \delta)^2 + \nu_{it} + u_t \\ \quad \text{if } d_{it} > FHS_{it} - \delta \end{cases},$$

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

Wheat Yield Estimation

Wheat grain yield was estimated by integrating the models used to determine the distribution of FHS:

$$\text{(17)} \quad \mathrm{E}[Y(d_{it},FHS_{it})] = \int_{-\infty}^{\infty} Y(d_{it},FHS_{it}) f(FHS_{it}) \mathrm{d}FHS_{it},$$

Since the FHS distributions were based on eight years of data the expected yield is:

$$\text{(18)} \quad \mathrm{E}[Y(d_{it},FHS_{ijt})] = \sum_{j=1}^{J} \frac{1}{J} \sum_{t=1}^{T} \times \int_{-\infty}^{\infty} \left\{ \left(Y(d_{it},FHS_{ijt}) f(\varepsilon_{ijt}) \mathrm{d}\varepsilon_{ijt} \right) \right\} / T,$$

where there are J variety categories and T years. The wheat yield response function (15) may be used to obtain:

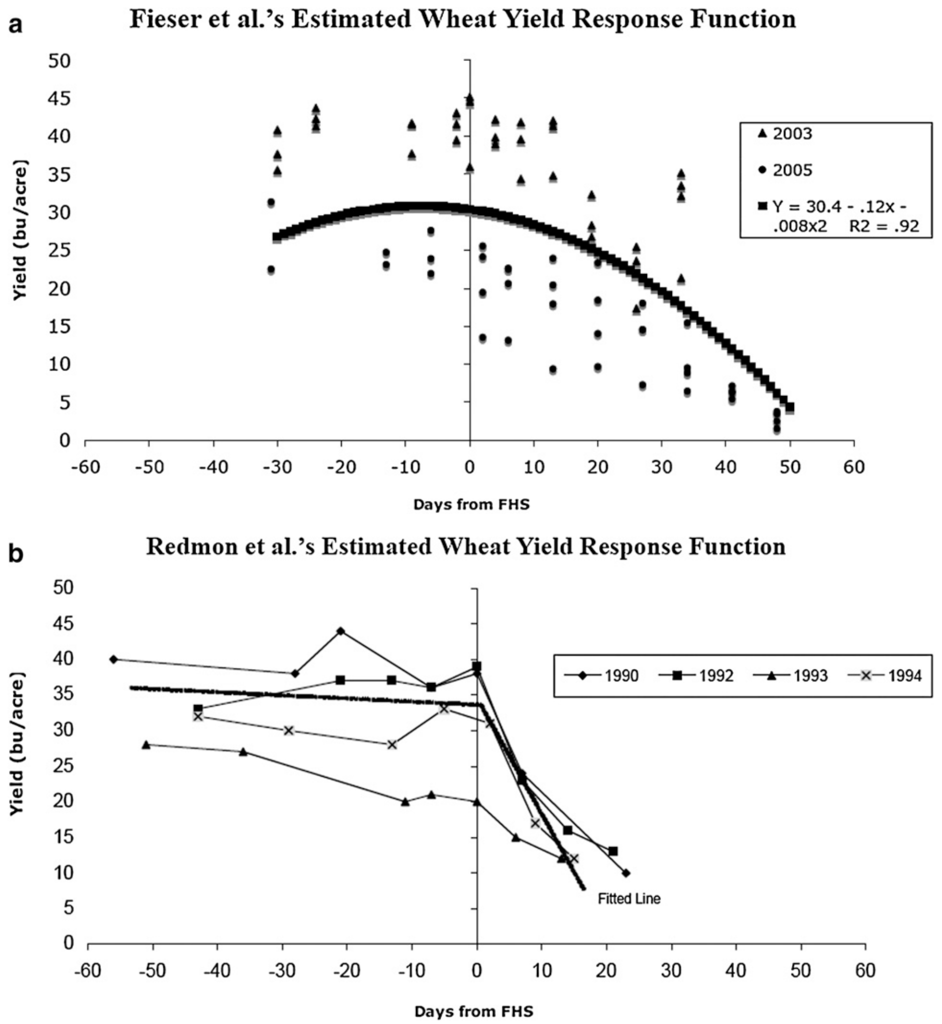

Figure 2. (a) Fieser et al.'s (2006) Estimated Wheat Yield Response to Different Grazing Termination Dates Expressed as Days before (−) or after (+) FHS. (b) Redmon et al.'s (1996) Estimated Wheat Grain Yield Relative to FHS of Ungrazed Wheat and Date of Grazing Termination Over a Four Year Period (1989–1990, 1991–1992, 1992–1993, and 1993–1994) Near Marshall, Oklahoma

$$\text{(19)}\quad \begin{aligned} E[Y(d_{it},FHS_{ijt})] &= \sum_{j=1}^{J}\frac{1}{J}\sum_{t=1}^{T} \\ &\times \int_{-\infty}^{\infty}\{\min(\overline{Y},\overline{Y}+\rho_1(d_{it}-FHS_{ijt}) \\ &+\rho_2(d_{it}-FHS_{ijt})^2)f(\varepsilon_{ijt})d\varepsilon_{ijt}\}/T \end{aligned}$$

Based on the distribution assumption of FHS, the normal density function of ε_{ijt} is expressed as:

$$\text{(20)}\quad f(\varepsilon_{ijt}) = \frac{1}{\sqrt{2\pi\sigma_{\varepsilon}^2}}\exp\left(-\frac{\varepsilon_{ijt}^2}{2\sigma_{\varepsilon}^2}\right),$$

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

Profit Maximizing Grazing Termination Date

Given the expected price response function (13), the expected weight function (14), and the wheat grain yield function (19), the expected returns model is:

$$\text{(21)}\quad \underset{d}{\text{Max}}\,E(\pi)=\begin{bmatrix} P_F\exp(\{\gamma_0+\gamma_1 W+\gamma_2 W^2 \\ \quad +\alpha d+\beta_1 Wd+\beta_2 Wd^2 \\ \quad +\sigma^2/2\}/100) \\ \times\{W_P+ADG\times d\}-C_C \end{bmatrix} SD + P_Y\left[\sum_{j=1}^{4}\frac{1}{J}\sum_{t=1}^{8}\int_{-\infty}^{\infty}\{\min(\overline{Y},\overline{Y} + \rho_1(d_{it}-FHS_{ijt})+\rho_2(d_{it}-FHS_{ijt})^2) \times f(\varepsilon_{ijt})d\varepsilon_{ijt}\}/8\right]-C_Y$$

P_F was set equal to \$81/cwt, the mean April futures steer price from 1992 to 2006. W_P was set equal to 550 pounds. P_Y was set equal to \$2.89 per bushel, the five year average price of wheat in June and July. Stocking density was set at 0.64 steers per acre, the average stocking density from previous studies. Expected returns were optimized for each of the eight models of FHS distribution for ADG levels of 2.5, 2.75, 3.0, and 3.5 pounds.

The estimated profit model can be expressed as:

$$\text{(22)}\quad \underset{d_M}{\text{Max}}\,E(\pi)=\begin{bmatrix} 81\exp(\{49.33-9.54W \\ \quad +0.43W^2+0.3d \\ \quad -0.04Wd \\ \quad +0.000025Wd^2 \\ \quad +8.38/2\}/100) \\ \times\{550+2.74d\}-C_C \end{bmatrix} 0.64 + 2.89\left[\sum_{j=1}^{4}\frac{1}{4}\sum_{t=1}^{8}\int_{-\infty}^{\infty}\{\min(31.87,31.87 -1.00(d-\hat{FHS}_{jt})+0.011(d-\hat{FHS}_{jt})^2) \times f_M(\varepsilon_{jt})d\varepsilon_{jt}\}/8\right]-C_Y,$$

where W is the selling weight, d_{it} is the optimal grazing termination date, $\hat{FHS}_{jt}$ is the estimated date of FHS depending on variety (j) and year (t), and $f_M(\varepsilon)$ is the distribution of the error term of the selected FHS model. The first order condition follows:

$$\text{(23)}\quad \frac{\partial E(\pi)}{\partial d_M}=\frac{\partial}{\partial d}[81\exp(\{49.33-9.54W +0.43W^2+0.3d-0.04Wd+0.000025Wd^2 +8.38/2\}/100)\times\{550+2.75d\}]0.64 + \frac{\partial}{\partial d}2.89\left[\sum_{j=1}^{4}\frac{1}{4}\sum_{t=1}^{8}\int_{-\infty}^{\infty}\{\min(31.87,31.87 -1.00(d-\hat{FHS}_{jt})+0.011(d-\hat{FHS}_{jt})^2) \times f_M(\varepsilon_{jt})d\varepsilon_{jt}\}/8\right]=0$$

Given the intractable nature of equation (23), MAPLE software was used to plot the expected profit (Equation 22) for each model (MAPLE, 2009). A grid search was used to determine the optimal grazing termination date for each. The value of information was also calculated for each of the eight information levels.

Results

The date of FHS differs significantly across years. Results from the eight models of FHS are included in Table 1. The seventh model based on most information (year, variety, and thermal units at FHS) produced the best fit ($R^2 = 0.99$). The model is not intended to be used to forecast the occurrence of FHS in future years, rather to illustrate distributions of FHS over time and estimate FHS based on different levels of information. The estimated values of FHS are included in the expected return maximization equations to determine the value of information.

The estimated steer price function results are shown in Table 2. Heavier weight steers receive a lower price per pound, which is expected. The estimates of basis percent possess the expected signs and can be used to determine the expected cash price. The expected weight of cattle at grazing termination was assumed to be:

$$\text{(24)}\quad E[W(d)]=5.50+(ADG/100)d,$$

Selling weight depends on ADG and grazing termination date.

Results for the expected wheat grain yield function when FHS is known are included in Table 3. The parameter estimates have the expected signs. For the combined data the

Table 1. Estimates of the Distribution of First Hollow Stem (FHS) using Six Models of Regression (Models 2–7)

		Estimates[a]					
Statistic	Definition	Model 2 f(*FHS*/ Year)	Model 3 f(*FHS*/ Variety)	Model 4 f(*FHS*/ Variety, Year)	Model 5 f(*FHS*/ *FHSTU*)	Model 6 f(*FHS*/ Variety, *FHSTU*)	Model 7 f(*FHS*/ Variety, Year, *FHSTU*)
α_0	Intercept	54.57* (1.56)	73.60* (1.59)	57.59* (1.14)	38.64* (2.49)	46.34* (2.85)	23.97* (0.59)
$\beta_{t=1998}$	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	—	−10.74* (1.96)	−5.87* (0.63)	—	−7.07* (1.47)	−0.47* (0.21)
$\beta_{j=2}$	"Middle" Variety	—	−7.93* (2.72)	−1.93* (0.75)	—	−6.03* (2.40)	−0.03 (0.26)
$\beta_{j=3}$	"Late" Variety	—	−1.18 (1.89)	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)	0.08* (0.007)	0.11* (0.002)
σ^2	Variance of Error	27.70* (2.99)	96.33* (9.54)	10.99* (1.61)	69.74 (Mean Square Error)	58.44* (7.53)	1.30* (0.19)
R^2		0.71	0.20	0.86	0.42	0.46	0.99
Adj. R^2		0.70	0.19	0.86	0.41	0.45	0.99
Test for normality							
S-W	W statistic (*p*-value)	0.98 (0.02)	0.98 (0.001)	0.98 (0.03)	0.99 (0.03)	0.93 (0.0001)	0.84 (0.0001)
Test for heteroskedasticity							
B-P	F value (*p*-value)	71.52 (0.0001)	16.75 (0.0001)	124.19 (0.0001)	145.36 (0.0001)	43.41 (0.0001)	1233.27 (0.0001)

Notes: *FHSTU* represents cumulative thermal units (cd) present after January 1 at the wheat growing location in Stillwater, Oklahoma. 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 normally distributed. The Shapiro-Wilk (S-W) test confirms that all the errors are normally distributed. Heteroskedasticity tests were done to test if the variance of the disturbance term is constant. The Breusch-Pagan (B-P) test shows that heteroskedasticity exists, so regression was corrected.

[a] Asymptotic standard errors are shown in parentheses.

* Represents significance at the 5% level.

Table 2. 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^2_μ	Variance of year random effect	2.80* (1.08)
σ^2_ε	Variance of error term	8.38* (0.29)
−2LL	−2 Log likelihood	8601.3
R^2	Measure of fit	0.76
Adj. R^2	Adjusted measure of fit	0.76
Test for normality		
S-W	W statistic (p value)	0.99 (0.0001)
Test for heteroskedasticity		
B-P	F value (p-value)	1088.65 (0.0001)
Estimated response function		
Basis %	$49.33 - 9.54W + 0.43W^2 + 0.30d - 0.04Wd + 0.000025Wd^2$	

Notes: The parameter estimates were estimated using PROC MIXED in SAS with year random effects and corrected for heteroskedasticity. Normality tests were performed to test if the errors were normally distributed. The Shapiro-Wilk (S-W) test confirms that all the errors are normally distributed. Heteroskedasticity tests were done to test if the variance of the disturbance term is constant. The Breusch-Pagan (B-P) test shows that heteroskedasticity exists, so regression was corrected.

[a] Asymptotic standard errors are in parentheses.

* Represents significance at the 5% level.

estimates indicate that for the initial day cattle are grazed past FHS, wheat yield is expected to decrease by approximately one bushel per acre and continue to decline at a decreasing rate as grazing continues.

A chart of five wheat grain yield functions is contained in Figure 3. The chart includes the graphs of the original Redmon et al. (1996) function; the original Fieser et al. (2006) function; the Redmon et al. (1996) data with the plateau function; the Fieser et al. (2006) data with the plateau function; and the plateau function fitted with the combined data. For the combined data and unique plateau functional form, results show that grazing one week past FHS is expected to decrease grain yield by 6 bushels per acre from 32 to 26. For the base price of $2.89 per bushel, this represents a loss in grain returns of $17.34 per acre. For an ADG of 2.75 pounds, a stocking density of 0.64 steers per acre and a steer price of $81/cwt, grazing one week past FHS generates only $9.98 per acre in additional steer returns.

For the base wheat price of $2.89 per bushel, ADG of 2.75 pounds, and a stocking density of 0.64 steers per acre, the steer price would need to be $144/cwt to compensate for the value of wheat grain lost by grazing one additional week. Alternatively, for a steer sale price of $81/ cwt, ADG of 2.75 pounds, and stocking density of 0.64 steers per acre, wheat price would need to fall below $1.66 per bushel to justify grazing one week past FHS. Therefore, for an ADG of 2.75 pounds, stocking density of 0.64 steers per acre, steer prices of $81/cwt or higher, and wheat prices of $1.66 per bushel or lower, profits would be maximized by extending grazing for a week past FHS. However, for most expected levels of parameter values based on historical ranges, the gain in steer value from grazing an additional week past FHS would not be sufficient to offset the loss in wheat grain value. These findings follow from the assumption that most producers would not be able to increase stocking density in the last week of the grazing season and that ADG during the last week is the same as ADG during prior weeks.

To compensate for the loss in wheat grain revenue from grazing cattle past FHS would require (1) adding steers to increase the stocking density from traditional fall-winter levels and (2) substantial forage required to provide nutrients necessary for the steers to achieve high ADG. For example, for a wheat grain loss of $17.34 per acre from grazing one week past FHS, the breakeven stocking densities would be 1.11 steers per acre for an ADG of 2.75 pounds, and 0.87 steers per acre for a an ADG of 3.5 pounds.

Table 3. Plateau Model of Wheat Yield as a Function of First Hollow Stem (FHS) and Removal Date (*d*) with Known and Unknown Switching Points

Known Switching Point		Estimates[a]		
Statistic	Definition	Fieser et al. Data	Redmon et al. Data	Combined Data[b]
ρ_1	Parameter estimate of (*d-FHS*)	−0.25	−1.70*	−1.00*
		(0.12)	(0.27)	(0.12)
ρ_2	Parameter estimate of $(d\text{-}FHS)^2$	−0.004	0.025	0.011*
		(0.003)	(0.01)	(0.003)
$\overline{Y}$	Expected wheat yield plateau	30.62	32.42*	31.87*
		(5.22)	(2.67)	(2.53)
σ^2_u	Variance of year random effect	52.85	26.66	35.74
		(53.60)	(19.76)	(21.47)
σ^2_ν	Variance of error term	26.89	8.61*	48.69*
		(4.22)	(2.44)	(6.69)
−2LL	−2 Log likelihood	517.6	157.3	732.1

$$Y(d,FHS_{it})^{b} \quad \begin{cases} 31.87 & \text{if } d \leq FHS_{it} \\ 31.87 - 1.00(d - FHS_{it}) - 0.011(d - FHS_{it})^2 & \text{if } d > FHS_{it} \end{cases}.$$

Unknown Switching Point		Estimates[a]
Statistic	Definition	Combined Data[b]
ρ_1	Parameter estimate of (*d-FHS*)	−0.90*
		(0.16)
ρ_2	Parameter estimate of $(d\text{-}FHS)^2$	0.009
		(0.004)
$\overline{Y}$	Expected wheat yield plateau	32.90*
		(2.71)
δ	Delta (in days)	−2.00
		(2.24)
σ^2_δ	Variance of delta	4.97
σ^2_u	Variance of year random effect	39.92
		(26.95)
σ^2_ν	Variance of error term	42.20*
		(5.16)
−2LL	−2 Log likelihood	731.2

$$Y(d,FHS_{it}) \quad \begin{cases} 32.90 & \text{if } d \leq FHS_{it} + \delta \\ 32.90 - 0.90(d - FHS_{it}) + 0.009(d - FHS_{it})^2 & \text{if } d > FHS_{it} + \delta \end{cases}.$$

Notes: The parameter estimates were estimated using PROC NLMIXED in SAS with year random effects and corrected for heteroskedasticity.

[a] Asymptotic standard errors are in parentheses.

[b] Based on data from Fieser et al. (2006) and Redmon et al. (1996).

* Represents significance at the 5% level.

Results from the wheat yield model with an unknown switching point are also presented in Table 3. This model is used to test whether the date of FHS is the appropriate spline point. The estimated value of δ, −2.00 days, is not significantly different from zero. This finding confirms that, as expected, the spline point of wheat yield (i.e., the point at which grazing significantly decreases wheat grain yield) is approximately at the occurrence of FHS.

Optimal removal dates and cost of grazing one week past FHS for each of the eight models for the four ADG levels are reported in Table 4. For most situations, it is optimal to remove

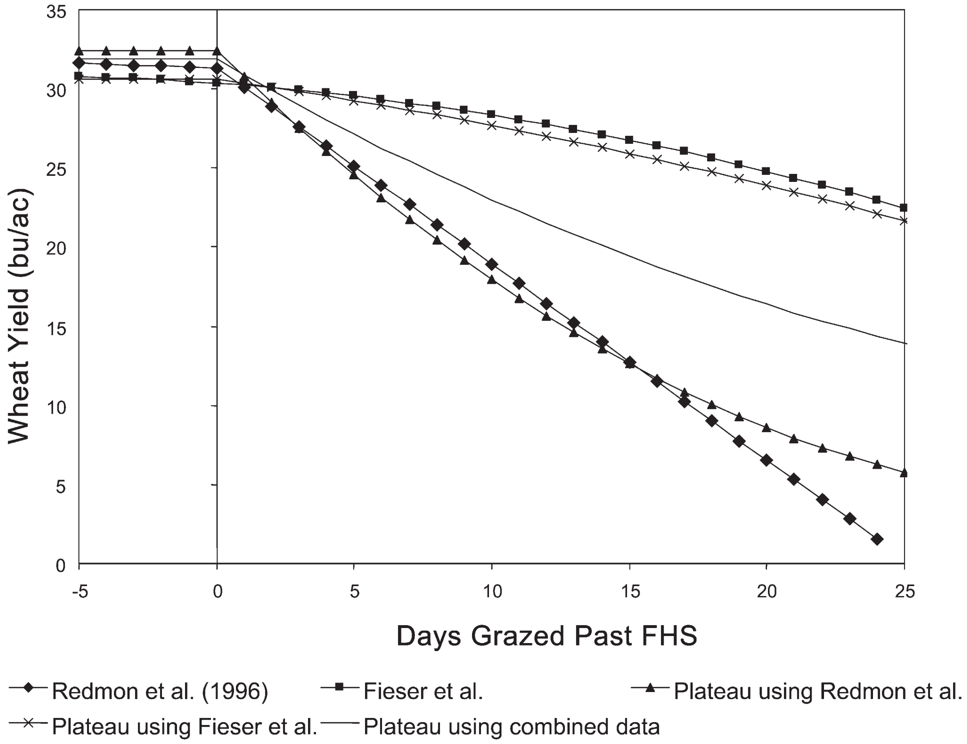

Figure 3. Estimated Wheat Yield Functions Based on Redmon et al. (1996) and Fieser et al. (2006). Data with the Original Functional Forms, the Plateau Functional Form for Both Data Sets, and the Plateau Functional Form with the Combined Data

steers from the dual-purpose wheat at or before FHS. However, when the distribution of FHS is based on variety (Model 3), for an ADG of 3.5, it is optimal to graze three days past FHS. The finding is sensitive to steer weight and ADG. For heavy fast-gaining steers, the net returns curve is relatively flat around FHS such that the optimal time to remove steers is around (rather than precisely at) FHS. However, for most situations the optimal time to terminate grazing is at or before FHS. With perfect information, the optimal time to terminate grazing is at FHS.

The value of FHS information for each of the eight situations and each of the four ADG levels is also reported in Table 4. The extension service in the region provides date of FHS information via e-mail and on web sites for most varieties that are grown. This information is worth from \$2.72 to \$3.02 per acre depending on ADG. This is a substantial quantity given that several million acres of dual-purpose wheat are produced in the region.

Table 5 includes estimates of the marginal values of one additional day and one additional week of grazing past FHS. Grazing one day past FHS increases steer returns between \$1.42 and \$1.92 per acre, while wheat returns are decreased by \$2.92 per acre. This tradeoff value can be represented in the marginal ratio between −1.5 and −2.1 of wheat loss relative to cattle gains. Grazing one week past FHS generates additional steer returns between \$10.56 and \$11.32 per acre, while decreasing wheat returns by \$21.65 per acre (i.e., a marginal ratio between −1.9 and −2.1). Thus, the increase in steer returns from grazing past FHS is generally not sufficient to offset the decrease in wheat returns.

Discussion

The FHS information was based on 52 winter wheat varieties over eight years at one location. The extension service in the region monitors

Table 4. Estimated FHS, Expected Returns, Removal Date (d), Value of Information, and Cost of Grazing One Week Past FHS

Level of Information	Average Daily Gain (lb/hd/day)	Estimated Variance[a]	Estimated FHS (FHS_M)	Estimated Gross Returns $E(\pi)$ at d^{*}[b]	Value of Information $V(\Omega/I_M)$[b]	Estimated Optimal Removal Date d^{*}	Cost of Grazing 1 week past FHS[c]
Model 1:	2.5	118.31	March 6	$487	—	65–March 5	$3.48
f(*FHS*/No	2.75			$492	—	66–March 6	$3.05
Information)	3.0			$498	—	66–March 6	$2.52
	3.5			$508	—	68–March 8	$2.00
Model 2:	2.5	27.70	March 6	$492	$5.12	65–March 5	$6.80
f(*FHS*/Year)	2.75			$497	$5.11	66–March 6	$5.79
	3.0			$503	$5.12	66–March 6	$5.64
	3.5			$513	$5.10	66–March 6	$4.85
Model 3:	2.5	96.33	March 6	$489	$1.50	66–March 6	$3.35
f(*FHS*/Variety)	2.75			$494	$1.72	66–March 6	$2.65
	3.0			$500	$1.72	67–March 7	$2.57
	3.5			$510	$1.53	69–March 9	$1.46
Model 4:	2.5	10.99	March 6	$494	$7.14	66–March 6	$8.44
f(*FHS*/Variety,	2.75			$500	$7.40	66–March 6	$7.49
Year)	3.0			$505	$7.17	66–March 6	$7.16
	3.5			$515	$6.89	66–March 6	$6.19
Model 5:[d]	2.5	69.74	March 6	$489	$2.16	65–March 5	$4.72
f(*FHS*/*FHSTU*)	2.75			$494	$2.10	66–March 6	$3.87
	3.0			$500	$2.11	66–March 6	$3.63
	3.5			$510	$2.04	67–March 7	$2.93
Model 6:[d]	2.5	58.44	March 6	$490	$2.83	65–March 5	$5.22
f(*FHS*/Variety,	2.75			$495	$3.02	65–March 5	$4.63
FHSTU)	3.0			$501	$2.79	66–March 6	$3.92
	3.5			$511	$2.72	67–March 7	$3.54
Model 7:[d]	2.5	1.30	March 6	$497	$9.21	66–March 6	$10.68
f(*FHS*/Variety,	2.75			$502	$9.50	66–March 6	$9.58
Year, *FHSTU*)	3.0			$507	$9.59	66–March 6	$9.35
	3.5			$518	$9.33	66–March 6	$9.21
Model 8:	2.5	0	March 6	$497	$10.05	66–March 6	$11.09
f(*FHS*/Perfect	2.75			$503	$10.33	66–March 6	$10.78
Information)	3.0			$508	$10.14	66–March 6	$10.33
	3.5			$519	$10.47	66–March 6	$10.60

[a] Estimated Variance represents the variance of FHS dates between years 1998–2005 in Model 1, and the mean squared error estimates from the ANOVA models of the distribution of FHS in Models 2 through 7.

[b] Gross returns are based on $/ac. Returns include the revenues generated from cattle and wheat per acre. Returns do not include purchase or production costs of cattle or wheat.

[c] Cost of grazing one week past FHS is in $/ac.

[d] FHS based on models 5, 6, and 7 was calculated using average *FHSTU* of 350 cd.

Table 5. Marginal Values of One Additional Day and One Additional Week of Extended Grazing, Relative to First Hollow Stem (FHS)

Grazing Termination Date (d)	Average Daily Gain (lb/hd/day)	Cattle Returns ($/acre)	Wheat Returns ($/acre)	Cattle & Wheat Returns ($/acre)	Marginal Cattle Returns from Extended Grazing ($/acre)	Marginal Wheat Returns from Extended Grazing ($/acre)	Ratio of Wheat Loss to Cattle Gains from Extended Grazing
At FHS	2.5	$405	$92	$497	—	—	—
At FHS	2.75	$411	$92	$503	—	—	—
At FHS	3.0	$416	$92	$508	—	—	—
At FHS	3.5	$427	$92	$519	—	—	—
1 day after FHS	2.5	$406	$89	$496	$1.42	−$2.92	−2.1
1 day after FHS	2.75	$412	$89	$501	$1.54	−$2.92	−1.9
1 day after FHS	3.0	$418	$89	$507	$1.67	−$2.92	−1.7
1 day after FHS	3.5	$429	$89	$518	$1.92	−$2.92	−1.5
1 week after FHS	2.5	$416	$70	$486	$10.56	−$21.65	−2.1
1 week after FHS	2.75	$421	$70	$492	$10.86	−$21.65	−2.0
1 week after FHS	3.0	$427	$70	$498	$11.32	−$21.65	−1.9
1 week after FHS	3.5	$438	$70	$509	$11.05	−$21.65	−2.0

Note: The values in this table are representative of a "Perfect Information" scenario based on a cattle cash price between $85–$89/cwt (depending on ending weight) from the estimated price response function found in this study, a cattle stocking density of 0.64 head/acre, a wheat price of $2.89/bushel, and estimated average wheat yields of 52 varieties from the estimated wheat yield response function from the combined data as presented.

wheat growth on variety trial plots and provides date of FHS information via e-mail, newsletters, and on web sites for most varieties that are grown. However, the distribution of FHS over time and variety does not account for variability across fields or locations. Since FHS is a function of weather, moisture, and planting date, the occurrence of FHS differs across fields. The information provided by the extension service can be used to inform producers that FHS has occurred in the variety trial plots. However, it is not a precise indicator for each field in the region. Precise identification of FHS on a specific field would require monitoring of an established plot in the field on which steers have not been permitted to graze. This is not a costless activity. Additional research would be required to determine if the expected benefits of maintaining and monitoring an enclosed area in each dual-purpose wheat field would exceed the expected costs of doing so.

Data produced in experiment station trials were used to estimate a unique wheat yield function and a profit maximization model to determine that grazing past FHS decreases overall returns of dual-purpose wheat enterprises. On average, the value of the grain yield lost from grazing past FHS exceeds the value of the additional steer weight gain. The optimal time to remove cattle from grazing in a typical year is at or before the occurrence of FHS. Knowledge of the date of FHS is valuable.

The findings reconcile conflicting results of prior studies. Fieser et al. (2006) had extremely high forage mass in the 2003 study period (more than twice the amount of forage mass than in their 2005 study period). This, coupled with unusual wheat growing conditions and heavy steers provided results inconsistent with those found by Redmon et al. (1996). The current study extended the prior research by combining information from both prior studies, estimating a unique wheat grain yield response function, determining a price response function, and calculating the value of information regarding FHS.

[Received March 2008; Accepted August 2009.]

References

Arzadún, M.J., J.I. Arroquy, H.E. Laborde, and R.E. Brevedan. "Effect of Planting Date, Clipping Height, and Cultivar on Forage and Grain Yield of Winter Wheat in Argentinean Pampas." *Agronomy Journal* 98(2006):1274–79.

Brorsen, B.W., O.L. Walker, G.W. Horn, and T.R. Nelson. "A Stocker Cattle Growth Simulation Model." *Southern Journal of Agricultural Economics* 15(1983):115–22.

Coulibaly, N., D.J. Bernardo, and G.W. Horn. "Energy Supplementation Strategies for Wheat Pasture Stocker Cattle under Uncertain Forage Availability." *Journal of Agricultural and Applied Economics* 28(1996):172–79.

Dickens, W.T. "Error Components in Grouped Data: Is It Ever Worth Weighting?" *The Review of Economics and Statistics* 72(1990):328–33.

Edwards, J., B. Tipton, C. Bensch, and R. Kockenower. "First Hollow Stem Explained." Oklahoma State University, Department of Plant and Soil Sciences. Wheat Production Newsletter Vol. 3, No. 7, 2007.

Edwards, J.T., B.F. Carver, and M.E. Payton. "Relationship of First Hollow Stem and Heading in Winter Wheat." *Crop Science* 47(2007): 2074–77.

Edwards, J., B. Hunger, B. Carver, and T. Royer. "Wheat Variety Comparison Chart." Oklahoma State University, Department of Plant and Soil Sciences. Production Technology Report Vol. 18, No. 6, 2006.

Epplin, F.M., I. Hossain, and E.G. Krenzer. "Winter Wheat Fall-Winter Forage Yield and Grain Yield Response to Planting Date in a Dual- Purpose System." *Agricultural Systems* 63(2000):161–73.

Epplin, F.M., E.G., Jr. Krenzer, and G. Horn. "Net Returns from Dual-Purpose Wheat and Grain-Only Wheat." *Journal of the ASFMRA* 65(2001):8–14.

Fieser, B.G., G.W. Horn, J.T. Edwards, and E.G. Krenzer, Jr. "Timing of Grazing Termination in Dual-Purpose Winter Wheat Enterprises." *The Professional Animal Scientist* 22(2006): 210–16.

Horn, G.W. "Growing Cattle on Winter Wheat Pasture: Management and Herd Health Considerations." *Veterinary Clinics of North America: Food Animal Practice* 22(2006): 335–56.

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

Hossain, I., F.M. Epplin, and E.G. Krenzer, Jr. "Planting Date Influence On Dual-Purpose Wheat Forage Yield, Grain Yield, And Test Weight." *Agronomy Journal* 95(2003):1179–88.

Kaitibie, S., F.M. Epplin, B.W. Brorsen, G.W. Horn, E.G., Jr. Krenzer, and S.I. Paisley. "Optimal Stocking Density for Dual-Purpose Winter Wheat Production." *Journal of Agricultural and Applied Economics* 35(2003a): 29–38.

Kaitibie, S., F.M. Epplin, G.W. Horn, E.G., Jr. Krenzer, and S.I. Paisley. "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, 2003b.

Krenzer, E.G., and G. Horn. "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, 1997.

MAPLE. "Maplesoft". Internet site: http://www.maplesoft.com/ (Accessed August 11, 2009).

Pinchak, W.E., W.D. Worrall, S.P. Caldwell, L.J. Hunt, N.J. Worrall, and M. Conoly. "Interrelationships of Forage and Steer Growth Dynamics on Wheat Pasture." *Journal of Range Management* 49(1996):126–30.

Ralston, R.E., T.O. Knight, K.H. Coble, and L.A. Lippke. "The Wheat and Stocker Cattle Analyzer: A Microcomputer Decision Aid For Evaluating Wheat Production and Stocker Cattle Grazing Decisions." *Southern Journal of Agricultural Economics* 22(1990):185–93.

Redmon, L.A., G.W. Horn, E.G., Jr. Krenzer, and D.J. Bernardo. "A Review of Livestock Grazing and Wheat Grain Yield: Boom or Bust?" *Agronomy Journal* 87(1995):137–47.

Redmon, L.A., E.G., Jr. Krenzer, D.J. Bernardo, and G.W. Horn. "Effect of Wheat Morphological Stage at Grazing Termination on Economic Return." *Agronomy Journal* 88(1996): 94–97.

Rodríguez, A., J.N. Trapp, O.L. Walker, and D.J. Bernardo. "A Wheat Grazing Systems Model for the U.S. Southern Plains: I. Model Description and Performance." *Agricultural Systems* 33(1990):41–59.

SAS Institute Inc. The NLMIXED Procedure. Internet site: http://v8doc.sas.com/sashtml/ (Accessed August 11, 2009).

Taylor, K.W., F.M. Epplin, D.S. Peel, and G.W. Horn. "Value of an Extended Grazing Season and Value of Monensin Supplements for Stocker Cattle Grazing Winter Wheat Pasture." *Journal of the American Society of Farm Managers and Rural Appraisers* 70(2007):59–71.

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

U.S. Department of Agriculture. Market News Information Service, Livestock, Grain & Hay. Oklahoma Market Report. Oklahoma City, Oklahoma. Internet site: http://www.oda.state.ok.us/mktdev-reports.htm (Accessed August 11, 2009). Archived price data available from the Livestock Marketing Information Center, http://www.lmic.info/ (Accessed August 11, 2009), 1992–2005.

———. Oklahoma Agricultural Statistics. Archived price data available in the annual bulletin, Internet site: http://www.nass.usda.gov/Statistics_by_State/Oklahoma/index.asp (Accessed August 11, 2009), 2006.

Whitson, R.E., R.D. Lacewell, L.L. Jones, and J. Shipley. "Economic Implications of the 1973 Farm Program on Wheat and Beef Production—Southern High Plains Winter Wheat Area." *Southern Journal of Agricultural Economics* 5(1973):37–44.

Zhang, X.C., W.A. Phillips, J.D. Garbrecht, J.L. Steiner, and L.A. Hunt. "A Wheat Grazing Model for Simulating Grain and Beef Production: Part I-Model Development." *Agronomy Journal* 100(2008):1242–47.