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Observations of Milk Production and Weight Change in Beef Cows Fed Extruded Cottonseed

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ABSTRACT

The evaluation of three protein supplements was the focus of this study conducted during the summer of 1997. Cottonseed meal (CSM), extruded whole cottonseed (EWC), and extruded cull cottonseed (ECC) were utilized as protein supplements to lactating cows fed red top cane stubble hay under dry lot conditions. Purebred Angus cow-calf pairs (n = 24) were randomly sorted into two groups. The animals in each group received each of the same three protein supplements over a six-week period during late lactation (average of 142 to 186 days postpartum). Milk yield and cow and calf weight was measured at the beginning of the trial and at the end of each interval (approximately 2 weeks). The milk was analyzed for crude protein and milk fat using the Kjeldahl procedure and Babcock milk fat test, respectively. Crude protein level in CSM was much higher (41.0%) than EWC (21.8%) or ECC (22.8%), while crude fat levels of CSM (2.4%) were much lower than EWC (20.4%) and ECC (21.7%). An apparent advantage was seen for 18-hour milk yield with ECC (8.1 lb) or EWC (8.2 lb) over CSM (7.3 lb) as the protein supplement. There was also an apparent difference on cow weight change where the cows fed CSM gained more weight (0.88 lb/day) than those fed the ECC (−0.36 lb/day) or EWC (−0.42 lb/day). There were no apparent differences for calf weight gain, milk crude protein or milk fat across the three protein supplements. Moderate correlations were seen between milk yield and calf growth; however, correlations between cow weight change and milk yield were not strong.

KEYWORDS: Extruded cottonseed, Milk production, Beef cows, Weight gain

Milk yield in beef cattle has a strong impact on calf growth as well as the cow's future reproductive performance. Cattle breeders have placed emphasis on milk yield through the use of milk EPDs (Expected Progeny Differences) when selecting registered sires. The milk EPD of a bull expresses how many additional pounds of calf at weaning are expected due to his daughter's level of milk production compared to that of daughters of the average bull in the breed. Females with higher milk EPD's will generally produce more milk than their lower milk EPD counterparts. It is also believed that females producing large amounts of milk will not be as reproductively efficient as lower milking cows when feed resources are limited due to loss of body fat reserves. For many years,

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Table 1. Initial means and standard deviations for weight and milk traits among cows.

	Cow wt (lb)	Calf wt (lb)	Day of lactation	Milk EPD
Group 1	1234 ± 279	363 ± 79	159 ± 18	6 ± 6
Group 2	1300 ± 356	382 ± 78	156 ± 25	9 ± 5

emphasis has been placed on the production of beef calves with high weaning and yearling weights, resulting in cows with greater mature weights. Many breeds have also stressed emphasis for higher milk production. Several studies (Diaz et al., 1992; Marston et al., 1992; Mallinckrodt et al., 1993; Marshall et al., 1993) have verified that milk EPD indicates actual milk production. As a result, these changes in commercial cows have been achieved through selection, as well as through heterosis in crossbreeding systems. The effects of selection for increased mature weight and milk yield on reproductive performance in beef cows still is not completely understood (Fiss et al., 1988).

One important factor that can affect milk yield and composition as well as cow and calf weight gain is nutrition. It is necessary that cattle receive proper nutrition in order to achieve optimal performance. Nutritional values vary among different feedstuffs, and among feeds subjected to various processing methods. Extrusion is a processing technique that uses heat and pressure to modify feeds. Extruded feed stuffs are believed to have increased feeding values compared to non-extruded feeds due to the fact that they are more highly digestible. Additionally, they are thought to have an increased feed-grade fat source. According to Hancock (1992), this process involving both heat and pressure also eliminates many anti-nutritional factors, antigenic components, and toxicants in a variety of feedstuffs. Feeding of extruded cottonseed to lactating beef cows has not been thoroughly investigated. Therefore, the main focus of this study was to evaluate cottonseed meal and two extruded cottonseed products as protein supplements in a beef cow herd during late lactation to determine their effects on milk production and weight change.

EXPERIMENTAL PROCEDURES

Lactating Angus cows (n = 24) were used to study the effects of three cottonseed-based protein supplements on cow and calf weight change, and milk yield and composition. These females ranged from two to eight years of age with milk EPDs ranging from −5 to 15 (average of 7). This trial began on July 18, 1997 and concluded on August 27, 1997. The means and variation in initial cow weight, initial calf weight, days of lactation and milk EPD are shown in Table 1. These cows were milked four times at 12 to 14 day intervals. The cows were randomly split into two separate groups (12 cows in each), which allowed the feeding of two different protein supplements at one time. Two protein sources were evaluated within each of the three time periods. Each protein source was evaluated in each group of cows, during two different time periods. Pen space limitations prevented three groups of cows being used in a traditional Latin Square design.

When the trial initiated, the cows were also involved in a USDA-CSREES cooperative research project (S-277) dealing with milk yield, and thus had been milked twice earlier in this lactation. The calves were separated from the cows approximately 16-20 hours prior to milking and weighed at approximately 8:00 A.M on milk collection days. Each cow was injected intramuscularly with 1 ml of ace promizine and 2 ml of oxytocin approximately 15 minutes before milking to stimulate milk letdown. Each cow was milked

Table 2. Nutritional Aspects of Three Evaluated Protein Supplements and Hay.

Feedstuff	CP[1] (%)	EE[2] (%)
Cottonseed Meal	41.00[3]	2.41
Extruded Whole Cottonseed	21.79	20.41
Extruded Cull Cottonseed	22.83	21.67
Red Top Cane Stubble	7.50	.70

[1] Crude Protein

[2] Ether Extract

[3] Guaranteed at 41%, but not independently verified

in a squeeze chute with only her head restricted. Cow number and weight were recorded at time of milking. The udder of each cow was washed before being milked. Milk was collected in a plastic bucket under vacuum with a portable milking machine and weighed. Two, 30-ml samples were collected and put on ice to be later analyzed for protein and milk fat. The bucket was washed with water and reassembled between cows.

The milk samples collected were taken to the Food Technology Laboratory (Texas Tech University) to be analyzed for protein and milk fat. All of the samples used to determine protein percent were run in duplicate using the Kjeldahl procedure. Milk fat was measured using the Babcock milk fat test. Extra samples were collected during the final milking and sent to a commercial dairy lab. They were analyzed for protein and milk fat using infrared (MS50/Foss) technology. This external lab work was conducted in order to verify the accuracy of the previous lab work conducted during the project.

The cattle used in this trial were housed in dirt-floor pens (130 ft × 190 ft) at the Texas Tech Beef Center, fed once a day and had free access to water. During the first period of the trial, July 19, 1997-August 1, 1997, group 1 received extruded whole cottonseed (EWC) while group 2 was fed cottonseed meal (CSM). In the second period of the trial, August 2, 1997-August 13, 1997, group 1 was fed CSM and group 2 fed extruded cull cottonseed (ECC). During the third period, August 14, 1997-August 27, 1997, group 1 received ECC, and group 2 was fed EWC. Cows were in each period for 12-14 days. Each morning cattle were fed the designated protein supplement, which was either 3.0 lb/hd/d of CSM, or 6.0 lb/hd/d of either EWC or ECC. All cows were offered 35 lb/hd/d of red top cane stubble hay, which was chopped into approximately six-inch pieces using a Hesston BP 25 portable grinder. The analysis for crude protein and ether extract on the hay and all three supplements are listed in Table 2.

Yield, crude protein and fat content of milk, cow weight and weight change, and calf weight and weight change were analyzed. All traits were analyzed as repeated measure traits of the cows. Due to unbalance of data comparing protein supplement and time period, no formal statistical analyses are presented. Mean and standard errors are reported for traits of interest. Linear correlations between milk yield and cow weight change and calf weight change were calculated using SAS (1989).

RESULTS AND DISCUSSION

Preliminary analyses were conducted to determine whether time of milking (16 to 20 hour range) affected milk yield. Regressions of milk yield on time were not significant for any milk collection, indicating that all cows had completely filled udders and that order of milking was not important. Means for milk yield, crude protein, and butterfat

Table 3. Means and standard errors for milk characteristics.

Treatment	N	Yield (lb)	CP[1] (%)	BF[2] (%)
CSM[3]	24	7.3 ± .40	2.9 ± .05	2.8 ± .15
ECC[4]	24	8.1 ± .40	2.9 ± .05	2.9 ± .16
EWC[5]	24	8.2 ± .35	3.0 ± .04	3.0 ± .14

[1]Crude protein
[2]Butter fat
[3]Cottonseed meal
[4]Extruded cull cottonseed
[5]Extruded whole cottonseed

Table 4: Means and standard errors for weight change in cows and calves per protein supplement.

Treatment	# Days Fed	Cows (lb)	Calves (lb)
CSM[1]	26	22.7 ± 14.21	25.6 ± 4.38
ECC[2]	26	− 9.3 ± 14.37	22.7 ± 4.42
EWC[3]	28	− 11.9 ± 13.22	26.2 ± 4.07

[1]CSM = cottonseed meal
[2]ECC = extruded cull cottonseed
[3]ECC = extruded whole cottonseed

across treatments are listed in Table 3. When the cows in this trial were fed cottonseed meal (CSM) compared to the extruded products, milk yield was apparently decreased. Cows that were fed extruded whole cottonseed (EWC) and extruded cull cottonseed (ECC) produced an average of 3.73 kg and 3.68 kg, respectively, while cows fed CSM produced 3.32 kg of milk. There was no apparent difference between the two extruded supplements for milk yield. There were also no apparent differences in crude protein or fat content of milk among the three protein supplements. This is somewhat surprising because the extruded cottonseed supplements had much higher levels of fat than the CSM. The cows fed the CSM gained weight during the feeding trial (0.88 lb/day), while cows fed ECC and EWC lost 0.36 and 0.43 lb/day, respectively. All of the hay offered to the cows was consumed (35 lb/day/cow). Sanders (1998) concluded that the effects of extrusion had negative effects on ruminal digestion of dry matter and ruminal nitrogen disappearance but positive effects were associated with total dry matter digestibility in feedlot steers. This may explain cow weight loss in conjunction with increased nutritional demand for higher milk production. Sanders (1998) also reported that extruded cottonseed in the diet of growing beef steers did not alter volatile fatty acid profile in the rumen compared to cottonseed meal. There were no apparent differences among calf weights across the three protein supplements given to their dams. Calves in all three treatments gained weight throughout the trial.

Calf weights are usually expected to increase as milk production increases. In this case, the extruded products apparently increased milk production, but corresponding increases in calf weight gain were not seen. Moderate relationships were observed for overall milk production and calf weight gain. Results on cow and calf weight gains are summarized in Table 4. Milk yield at day 156 of lactation and cow weight change from days 142 to 156 of lactation had a correlation of −0.41 (P = 0.04). This was the only period that milk yield and cow weight change were significantly related. Additionally,

Cost of Production Analysis for the Texas Cow-Calf Industry

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ABSTRACT

Selected summary cost of production data gathered in Texas using the NCBA-IRM-SPA guidelines were reported and utilized to estimate a cost function for the Texas cow-calf industry. Results indicate that the economic cost of production for the cow-calf industry averaged $102.59 per cwt. over the 1992-1998 time period. It was found that a 1% increase in the per acre price of grazing results in a 0.141% increase in total cost for Texas cow-calf producers. In addition, the analysis found that a 1% increase in the per pound price of raised and purchased feed results in an expected 0.055% increase in total cost for Texas cow-calf producers.

KEYWORDS: cost of production, cow-calf industry

The cattle industry in Texas currently faces financial difficulty that is of concern not only to beef cattle producers in the state, but also to policy makers responsible for the economic well being of Texas agriculture. The extremely dry conditions experienced in Texas during 1998 forced producers to make difficult choices with respect to how they should handle their current investments in breeding cattle. The drought of 1998 came only two years after the extremely dry spring and summer of 1996. In 1996, the drought was compounded with the lowest cattle prices since the mid-1970's along with grain and forage prices that were historically very high. These factors make estimation of the cost structure of the Texas cow-calf industry an important objective that will help producers as they evaluate herd investment/disinvestment decisions. As well, this study will support development of sound policy, particularly government responses to drought for the Texas beef cattle industry.

In addition to these recent problems in Texas, the U.S. beef industry has experienced a persistent decline in annual per capita consumption of meat since the mid-1970's, falling from a high of 94.4 pounds per capita in 1976 to 66.9 pounds per capita in 1997 (Economic Research Service-USDA). As a result of the continued decline in per capita consumption of beef throughout the 1980's, the National Cattlemen's Beef Association Concentration/Integration Task Force commissioned a study of the beef cattle industry. This study (Johnson, et al.) determined that "The principal reason beef is losing ground to other meats is that its cost is rising relative to consumer costs for other meats. Only about three percent of beef's recent loss in market share can be attributed to a change in consumer preference." (Johnson, et al. p. ii). The Johnson, et al. study challenged cattle producers to lower their costs of production to regain both domestic and international market share.

The need to determine current costs of production and to make comparisons of alternative production systems in order to lower future production costs became evident in the early 1990's. However, a standardized method of measuring production and financial performance for beef cow-calf producers did not exist at that time. As a first step in meeting this challenge, the National Cattlemen's Beef Association National Integrated Resource Management Coordinating Committee developed a set of standardized guidelines for production and financial analysis for cow-calf producers known as the National Cattlemen's Beef Association Integrated Resource Management Standardized Performance Analysis (NCBA-IRM-SPA) guidelines.

The objectives of this paper are to: 1) report annual cost of production data from the last six years gathered using the NCBA-IRM-SPA guidelines (National Cattlemen's Beef Association); and 2) utilize these data to estimate a cost function for the Texas cow-calf industry. These summary data provide baseline information that is of interest to producers, researchers, and policy makers. The estimation of an aggregate cost function for the Texas cow-calf industry will be of interest to policy makers and researchers in determining the impact of input price changes on the cost structure of the Texas cow-calf industry. This analysis will focus on the impact that changes in feed prices and grazing costs have on the cost structure of the Texas cow-calf industry, which is of primary concern when government relief measures for drought are considered.

Review of Literature

There are several cost of production studies focusing on U.S. livestock agriculture that have been conducted, mostly concentrating on the feedlot and meat packing sectors (Hallam). Weimar et al. applied economic engineering techniques and found substantial economies of size associated with feed and waste handling equipment. Ball and Chambers estimated a cost function to measure returns to scale and technological change in the beef processing industry, finding that the meat packing industry displayed increasing returns to scale as relatively high priced labor was replaced with machine technology. Cooke and Sundquist estimated differences in cost efficiency among various sized firms engaged in corn production by breaking unit costs into measures of technological change over time, regional competitive advantage, economies of scale, and changing input prices. However, the literature is sparse with regard to estimation of cost functions for cow-calf production in Texas. This study employs a cost function approach to examine the impact of changes in feed prices and grazing costs on the cost structure of the Texas cow-calf industry.

Model

Utilizing the guidelines developed by the NCBA-IRM-SPA Subcommittee (National Cattlemen's Beef Association), cost of production data for Texas cooperators were collected for the 1992 to 1998 time period. The SPA guidelines divide these performance data for the beef cow-calf enterprise into four general areas that include: 1) Reproduction

Performance, 2) Production Performance, 3) Grazing and Raised Feed Land Use and Productivity, and 4) Financial and Economic Performance.

Primary and secondary measures of performance for each of the four areas of interest listed above are established in the SPA guidelines. This paper will focus on a subset of these measures, presenting data on selected primary measures for each area of performance listed above. For the area of Reproduction Performance, the primary measure used in this study is calf crop percentage. This measure is calculated by dividing the number of calves weaned in the particular production cycle by the number of cows that were exposed to a bull (by either natural or artificial service) and intended to be bred to calve in that particular production cycle. For the area of Production Performance, the primary measures used are actual weaning weights and pounds of calf weaned per exposed female. For the area of Grazing and Raised Feed Land Use and Productivity, the number of acres used for grazing, raising feed, and crop aftermath (crop residue) per exposed female are presented along with the amount of raised or purchased feed fed per breeding cow. For the area of Financial and Economic Performance, the total economic pre-tax cost per cwt. of weaned calf adjusted for non-calf revenue and percent return on assets are presented. Total economic pre-tax cost per hundredweight of production adjusted for non-calf revenues is defined as total operating costs plus total financial returns and economic opportunity costs less non-calf revenues (usually cull cow and bull sales) divided by total hundredweight of weaned calves produced. For financial measurement development, information is taken directly from the firm's income statement. Economic measurements include the firm's financial costs, while also taking into account the opportunity cost of resources used in the cow-calf enterprise. Opportunity costs are the value of the foregone alternative products the resources that were employed in weaned calf production could have produced (Leftwich). This distinction allows the producer and researcher to monitor progress of the individual firm using financial analysis, while economic measures allow for comparisons between firms and industries.

The model for the cost function developed in this study assumes that Texas cow-calf producers act as cost minimizers, behaving as shown in Equation

$$(1) \quad \text{minimize } C = \sum_{i=1}^{n} w_i x_i$$
$$\text{subject to } f(x_1, \ldots . x_n) = y_0$$

where C is total cost, w_i is the price for factor x_i, and y_0 is output at a parametrically assigned level (Silberberg). Given these conditions, the cost function (C^*) may be written as a function of input prices and output, when the input quantities (x_i^*) used are employed at cost minimizing levels, presented in equation (2) below.

$$(2) \quad C = \sum_{i=1}^{n} w_i x_i^*(w_1 \ldots w_n, y_0) = C^*(w_1, \ldots w_n, y_0)$$

Empirical Results and Discussion

The selected results for Texas producers who participated in the Standardized Performance Analysis program between 1992 and 1998 are shown in Table 1. There are 187 observations included in the summary statistics shown in Table 1. Each observation represents the results from one herd for one production cycle.

Table 1. Selected Summary Statistics for Production and Economic Measures Based on Standardized Performance Analysis for Texas Herds, 1992-1998.

Performance Measure	Minimum	Average	Maximum
Grazing, raised feed, and crop aftermath acres per exposed female	1.7	19.3	108.7
Pounds of raised/purchased feed fed per breeding cow	55	1,483	6,722
Calf crop or weaning percentage	54.8	82.4	100.0
Average weaning weight	318.0	525	691.0
Pounds weaned per exposed female	195.0	431.8	586.0
Economic Pretax Cost Non-calf Revenue Adjusted per cwt	$51.42	$102.59	$259.44
Percent Return on Assets - market value	(21.4)	1.3	26.6

The results for grazing, raised feed, and crop aftermath (crop residue) acres per exposed female range from a minimum of 1.7 acres per exposed female to a maximum of 108.7 acres per exposed female. These results are indicative of the wide variety of climatic conditions in Texas, ranging from high rainfall areas in the Eastern part of the state which support dense stocking rates to the arid regions in the Trans-Pecos region that support extensive grazing operations. The average grazing, raised feed, and crop aftermath (crop residue) acres per exposed female of 19.3 acres illustrates the high level of capital needed to support the cow-calf industry in Texas. The use of raised and purchased feed ranged from 55 to 6,722 pounds per breeding cow, with an average of 1,483 pounds of raised and purchased feed fed per breeding cow. The wide range in the use of raised and purchased feed is primarily linked to differences between intensive and extensive grazing systems, but was also impacted by drought conditions that occurred within the observed period. Reproductive performance in the cooperating herds ranged from a low of 54.8% calf crop, to a high of 100%, with an average of 82.4%. Many factors impacted the reproductive efficiency of the observed herds, including age and genetic composition of the cows within the herd, grazing systems and other management programs such as herd health along with nutritional levels that were affected by drought conditions that occurred within the observed period. Productive performance reflected by weaning weights for the cooperating herds averaged 525 pounds per weaned calf, and ranged from a low of 318 pounds to a high of 691 pounds. Productive performance reflected by pounds weaned per exposed female ranged from a low of 195 pounds to a high of 586 pounds, with an average of 431.8 pounds.

Economic performance measured by economic cost of production per cwt. of weaned calf averaged $102.59 per cwt., ranging from a low of $51.42 per cwt. to a high of $259.44 per cwt. The economic cost of production includes opportunity costs on owned capital, which generally exceeds the financial cost of production. The economic cost of production may be thought of as the level that the market price for calves must reach to hold capital in the cow-calf industry over the long term, and the level that would need to be exceeded for capital to be drawn into the cow-calf industry for expansion of the herd.

Financial performance measured by the percent return on the market value of assets averaged 1.3% for the participating herds, ranging from a low of −21.4% to a high of 26.6%. These results are representative of the low rates of return generally seen in production agriculture in the United States.

Start here

Table 2. Summary Statistics for Data Utilized in the Cost Function Estimation.

Variable	Mean	Maximum	Minimum	Standard Deviation
Feed Price ($/lb.)	$0.11	$0.73	$0.01	$0.10
Grazing Price ($/acre)	$12.19	$89.59	$0.79	$13.61
Other ($/head)	$202.00	$672.24	$7.79	$96.18
Total Pounds Weaned per herd	330,596	6,140,400	5,049	706,335
Total Economic Cost per herd	$270,014.46	$4,769,465.40	$5,727.00	$573,475.17

Table 3. Regression Results (Ordinary Least Squares).

F-Value	1275.82
R^2	0.9656
Adjusted R^2	0.9648

	Beta Values	Standard Errors	P-values
Intercept	−1.136769	0.251119	0.0001
Grazing Price	0.141127	0.024629	0.0001
Feed Price	0.054687	0.023842	0.0229
Other	0.311393	0.034999	0.0001
Pounds Weaned	0.936724	0.015677	0.0001

To estimate the cost function developed in Equation 2 above, total production in pounds weaned and total economic cost were taken from the Standardized Performance Analysis results. Grazing prices for each observation were calculated by dividing the total economic grazing cost for each observation by the total number of grazing acres within each observation. Feed prices were calculated by dividing the economic cost of raised and purchased feed fed by the total pounds of raised and purchased feed fed for each observation. Remaining costs were grouped into a general category entitled Other. One hundred-eighty-seven observations were used for estimation purposes. Summary statistics for all variables are shown below in Table 2.

The logarithmic transformation of equation 2 (shown below in equation 3) was estimated using ordinary least squares regression with the proc reg procedure of PC-SAS for Windows Version 6.12. (SAS). The model results for this regression are shown in Table 3.

$$(3)\quad \ln(\text{TotalCost}) = \ln(\text{Grazing Price}) + \ln(\text{FeedPrice}) + \ln(\text{Other}) + \ln(\text{PoundsWeaned})$$

The overall fit of the model is acceptable, with an adjusted R^2 value of 0.9648 and a highly significant F statistic. The parameter estimate (Beta Value) for price of grazing (GRAZING PRICE) is statistically significant at the $P>0.0001$ level. The parameter estimate of 0.141127 indicates that as the price of grazing increases by 1% on a per acre basis, the total cost structure of Texas producers increases by approximately 0.14%. The parameter estimate for price of feed (FEED PRICE) is statistically significant at the $P>0.0229$ level. The parameter estimate of 0.054687 indicates that as the price of raised and purchased feed increases by 1% on a per pound basis, the total cost structure of Texas producers increases by approximately 0.055%.

Using the parameter estimate for FEED PRICE as an illustration, the reported increase in average hay prices from $56 per ton to $83 dollars per ton from September

1997 to September 1998 (Texas Agricultural Statistics Service) would result in a 2.6% increase in total costs for Texas producers. Evaluated at the sample mean of the data utilized in this study, it would then be expected that the average firm's total economic cost of production per hundredweight. would increase by $8.89 as a result of this change in the level of feed prices.

Conclusions and Need for Further Research

The objectives of this paper were to report selected summary cost of production data gathered in Texas using the NCBA-IRM-SPA guidelines and to utilize these data to estimate a cost function for the Texas cow-calf industry. Results indicate that the economic cost of production for the cow-calf industry averaged $102.59 per cwt. over the 1992-1998 time period. Given this cost level, it can be concluded that calf prices that are available in the spring of 1999 are not yet at levels high enough to encourage herd expansion. Average profitability as measured by return on assets at market value was 1.3%, reinforcing the hypothesis that cow-calf producers in Texas are engaged in an enterprise that underperforms relative to many alternative investments.

Estimation of a cost function for the Texas cow-calf industry provided reasonable results. These results should aid policy makers in assessing the impact of changing grazing and feed prices on the cost structure of Texas cow-calf producers. It was found that a 1% increase in the per acre price of grazing results in a 0.141% increase in total cost for Texas cow-calf producers. In addition, the analysis found that a 1% increase in the per pound price of raised and purchased feed results in an expected 0.055% increase in total cost for Texas cow-calf producers.

Further research is warranted to examine regional differences in cost of cow-calf production within Texas. Increased sample size should allow the data to be partitioned by geographic regions that are more and less dependent on raised and purchased feed in cow-calf production leading to regional parameter estimates that would be of use to both policy makers and producers.

REFERENCES

Ball, V. Eldon and R.G. Chambers. "An Economic Analysis of Technology in the Meat Products Industry." *American Journal of Agricultural Economics.* 64,4(1982):699-709.

Cooke, S.C. and W.B. Sundquist. "Cost Efficiency in U.S. Corn Production." *American Journal of Agricultural Economics.* 71,4(1989):1003-1010.Hallam, A. "Economies of Size and Scale in Agriculture: An Interpretive Review of Empirical Measurement." *Review of Agricultural Economics.* 13,1(1991): 155-172.

Johnson, D. Gale, J.M. Conner, T. Josling, A. Schmitz and G.E. Schuh. "Competitive Issues in the Beef Sector: Can Beef Compete in the 1990's?" Humphrey Institute Report No. 1, Hubert H. Humphrey Institute for Public Affairs, University of Minnesota, Minneapolis, MN, 1989.

Leftwich, R.H. The Price System and Resource Allocation. The Dryden Press, Hinsdale IL, 1976.

National Cattlemen's Beef Association. Guidelines for Production and Financial Performance Analysis for the Cow-Calf Producers: Cow-Calf SPA. Extension Service - U.S.D.A. Washington, D.C., January 1993.

SAS Institute Inc. PC-SAS for Windows Version 6.12. SAS Institute Inc., Cary, NC, 1996.

Silberberg, E. The Structure of Economics: A Mathematical Analysis. McGraw-Hill, Inc., 1978.

Texas Agricultural Statistics Service. "Texas Agricultural Facts." SM-20-98, Austin, TX, September 1998.

Economic Research Service - USDA. "Livestock Dairy and Poultry Situation and Outlook." LDP-M-56, Washington, DC, February 1999.

Weimar, M.R., A. Hallam and L.D. Trede. "Economies of Size, Tax Reform and Profitability of Alternative Feedlot Systems." *Journal of the American Society of Farm Managers and Rural Appraisers.* 52(April 1998):11-18.

Observations of Avian Nesting Activity in Burned and Non-burned Weeping Lovegrass CRP

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ABSTRACT

Weeping lovegrass (*Eragrostis curvula*) has been established on over one million acres of Conservation Reserve Program (CRP) lands in the Southern High Plains of Texas. Weeping lovegrass has been suggested to have minimal value as wildlife habitat, but little research is available to support this claim. We conducted nest searches during June and July 1996 and June 1997 to determine nesting activity in burned and non-burned weeping lovegrass CRP. Ten nests of three different species were located, nine in non-burned areas and one in burned areas. Although few nests were located, this study documents use of weeping lovegrass as nesting habitat by Cassin's sparrow, a species declining throughout its range, during drought. Prescribed burning did not improve weeping lovegrass for nesting habitat for at least one year after burning due to reduced cover.

KEYWORDS: *Aimophila cassinii*, Conservation Reserve Program, fire, prescribed burning

Populations of many grassland nesting birds have recently declined and habitat loss has been considered the major cause (Johnson and Schwartz, 1993; Peterjohn et al., 1995). The CRP was initiated in the 1985 Food Security Act to protect highly erodible lands, reduce crop surpluses, improve water quality, and enhance wildlife habitat (Bartlett, 1988). Land seeded to native grasses in CRP benefitted grassland nesting birds by providing suitable nesting and brood-rearing habitat (Berthelsen and Smith, 1995; Johnson and Schwartz, 1993). In addition to native grasses and other exotics, more than one million acres of weeping lovegrass were seeded during CRP on the Southern High Plains of Texas. Although weeping lovegrass is considered poor wildlife habitat, little research has been conducted to determine its value as wildlife habitat. Prescribed burning is commonly applied to weeping lovegrass to improve livestock production (Dahl and Cotter, 1984). However, avian nesting activity in weeping lovegrass and the impacts of prescribed burning on nesting activity is unclear. Our objective was to describe avian nesting activity in burned and non-burned weeping lovegrass CRP in the Southern High Plains of Texas.

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Table 1. Number of nests located in non-burned and burned weeping lovegrass CRP in June and July 1996 and July 1997. The nest located in a burned area is in parentheses.

	Nests Located			
Sampling Date	Cassin's sparrow	Mourning dove	Total	
	number			
4 June 1996	3	1	0	4
25 June 1996	3	0	(1)	4
31 July 1996	0	0	0	0
26 June 1997	1	1	0	2

METHODS

This study was conducted in 1996 and 1997 in central Lynn County, TX. Average annual precipitation is 20 inches, with most precipitation occurring in April, May, September, and October (NOAA, 1996). Annual precipitation in 1996 prior to burning was 57% below the long-term average. After burning, rainfall was 33% below the long-term average for April, May, and June. Precipitation in 1997 was 94% above average from 1 January to 1 June (NOAA, 1997).

The 360 acres of CRP were seeded to weeping lovegrass in 1989, and was divided into 12, 21 acre plots. Six randomly selected plots were burned independently in April 1996 and six non-burned plots were evaluated as controls. During burning, maximum air temperature was 73°F, minimum relative humidity was 26%, average wind speed was 10 mph, and average fine fuel load was 6050 lb/acre. Nesting cover in each plot was characterized by vertical structure, which was measured to the nearest 2-in segment at 25 points within each area using a Robel pole (Robel et al., 1970). Sighting distance to the Robel pole was 13 ft and measurements were read from 3.3 ft above the soil surface. Vertical structure was measured before burning in April 1996, immediately after burning, 3 months after burning (July 1996), and 15 months after burning (July 1997).

Nest searches were conducted on 4 June, 25 June, and 31 July 1996, and 26 June 1997 using a modified flushing rope (Labisky, 1957) and cable-chain device (Higgins et al., 1969). Ralph et al. (1993) indicated this technique is an effective method for estimating nest density in open grassland habitats. The 250 ft rope, with five 2.5 ft lengths of 3/8 in diameter chain attached, was stretched to an effective sampling length of 200 ft between two vehicles. Three spotters walked behind the rope to determine flushing locations of birds, and nests were found by systematically surveying flushing locations. The rope was dragged through the central 10 acres of the plot to avoid potential bias of edges. Nesting species were identified by plumage, song, identification of eggs at the nest, and visual observation of the nests during incubation. Sampling areas on 25 June 1996 and 26 June 1997 provided a comparison for nest densities in 1996 and 1997. In 1997, 5 acres were sampled per plot.

RESULTS AND DISCUSSION

Ten nests of three species, Cassin's sparrow (*Aimophila cassinii*), mourning dove (*Zenaida macroura*), and common nighthawk (*Chordeiles minor*), were located in the study area on four sampling dates (Table 1). All nests were located in non-burned areas, except

Table 2. Vertical structure (in) of non-burned and burned weeping lovegrass CRP prior to burning (April 1996 Pre fire), immediately after burning (April 1996 Post fire), 3 months after burning (July 1996), and 15 months after burning (July 1997).

	Sampling Periods			
Sampling Area	April 1996 (Pre fire)	April 1996 (Post fire)	July 1996	July 1997
	inches			
Non-burned	8.3 ± 0.8	8.3 ± 0.8	8.3 ± 0.8	12.6 ± 0.4
Burned	8.3 ± 0.8	0.4 ± 0.1	2.4 ± 0.4	9.1 ± 0.4

for the common nighthawk on 25 June 1996. Nesting cover, as estimated by vertical structure, was lower on burned areas than on non-burned areas for all post-burn sample periods (Table 2). In 1996, non-burned areas averaged 2.5 times more vertical structure than burned areas, which likely explains the preference for nesting in non-burned rather than burned areas. However, vertical structure on burned areas 15 months after burning was similar to non-burned areas at the initiation of the study.

Conservation Reserve Program grasslands seeded to native grasses have benefitted many grassland nesting bird species (Berthelsen and Smith, 1995; Johnson and Schwartz, 1993). In the Southern High Plains, CRP seeded to native grasses had Cassin's sparrow nest densities of at least 3 nests/acre (Berthelsen and Smith, 1995). In contrast, weeping lovegrass CRP in our study had one Cassin's sparrow nest to every 60 acres, which was consistent during a drought year as well as a wet year. Several species such as the grasshopper sparrow (*Ammodramus savannarum*) and western meadowlark (*Sturnella neglecta*) that commonly nest sympatrically with Cassin's sparrow in native grass stands, in roadside ditches (Bock and Scharf, 1994), and in CRP seeded to native grasses (Berthelsen and Smith, 1995), were absent in CRP seeded to weeping lovegrass. However, this CRP grassland was bordered by cotton (*Gossypium hirsutum*) on three sides, which provided minimal nesting habitat for grassland birds. Aside from about 700 acres of adjacent CRP, the nearest perennial grassland was more than 3 miles away, which may help explain the low nest density. Although few nests were found, this study documents use of weeping lovegrass as avian nesting habitat during a drought, and Cassin's sparrow nesting in late June, later than is reported for this species in the Southern High Plains. Additionally, Cassin's sparrow males used marestail (*Conyza canadensis*) and sunflowers (*Helianthus* spp.) for perching following breeding display flights in the open grassland habitat since no woody plants were available.

Management practices such as prescribed burning do not apparently improve weeping lovegrass for avian nesting habitat in the short term, either because insufficient thermal cover remains or inadequate vertical structure is present after a fire. The lack of adequate vertical structure on burned areas, or the close proximity of non-burned areas with greater vertical structure apparently deterred nesting for at least two nesting seasons after burning. Managers considering seeding perennial grasses in this area should evaluate species other than weeping lovegrass if providing habitat for grassland nesting birds is a management goal. However, in many situations, weeping lovegrass is the best multiple-use choice for soil conservation, forage production, and livestock production on sandy soils in the Southern High Plains. Additionally, fire in semi-arid environments should be applied in a mosaic array to provide nesting habitat in nearby non-burned areas. Land managers should recognize the potential impacts of burning to grassland bird nesting habitat in non-native semi-arid grasslands for at least two nesting seasons following burning.

REFERENCES

Bartlett, E.T. 1988. Social and economic impacts of the Conservation Reserve Program. *In* J.E. Mitchell ed. Impacts of the Conservation Reserve Program in the Great Plains. U.S. Forest Service Gen. Tech. Rep. RM-158. pp. 52-54.

Berthelsen, P. S., and L. M. Smith. 1995. Nongame bird nesting on CRP land in the Texas Southern High Plains. J. Soil and Water Conserv. 50:672-675.

Bock, C. E., and J. H. Bock. 1992. Response of birds to wildfire in native versus exotic Arizona grassland. Southwest. Nat. 37:73-81.

Bock, C. E., and W. C. Scharf. 1994. A nesting population of Cassin's sparrows in the Sandhills of Nebraska. J. Field Ornithol. 65:472-475.

Dahl, B. E., and P. F. Cotter. 1984. Management of weeping lovegrass in west Texas. Texas Tech Univ. Management Note 5.

Higgins, K. F., L. M. Kirsch, and L. M. Ball, Jr. 1969. A cable-chain device for locating duck nests. J. Wildl. Manage. 33:1009-1011.

Johnson, D. H., and M. D. Schwartz. 1993. The Conservation Reserve Program and grassland birds. Conserv. Biol. 7:934-937.

Labisky, R. F. 1957. Relation of hay harvesting to duck nesting under a refuge-permittee system. J. Wildl. Manage. 21:194-200.

NOAA. 1996. Texas climatological data. National Climatic Data Center, Asheville, NC.

NOAA. 1997. Texas climatological data. National Climatic Data Center, Asheville, NC.

Peterjohn, B. G., J. R. Sauer, and W. A. Link. 1996. The 1994 and 1995 summary of the North American Breeding Bird Survey. Bird Pop. 3:48-66.

Peterjohn, B. G., J. R. Sauer, and C. S. Robbins. 1995. Population trends from the North American Breeding Bird Survey. *In* T.E. Martin and D.M. Finch eds. Ecology and Management of Neotropical Migratory Birds. Oxford Univ. Press, New York.

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993 Handbook of field methods for monitoring landbirds. General Tech. Report PSW-GTR-144. Albany, California: Pacific Southwest Research Station, Forest Service, USDA; 41 p.

Robel, R.J., J.N. Briggs, A. Dayton, and L. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. J. Range Manage. 23:295-297.

Imidazolinone Herbicide Effects on Rotational Crops Following Peanut (*Arachis hypogaea* L.) in South Texas

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ABSTRACT

The effect of imazapic and imazethapyr on crops that may be rotated with peanut were studied in the field at three south Texas locations. Corn, cotton, grain sorghum, watermelon, potato, and sesame were planted the year following imazapic and imazethapyr POST application to peanut. Plant dry matter weights indicated cotton was most sensitive to a rotational program with imazapic in peanut. Dry matter weights with other crops were variable.

KEYWORDS: groundnut, Cadre, Pursuit

Imazethapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-7l]-5-ethyl-3-pyridinecarboxylic acid) and imazapic (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyrindinecarboxylic acid] are two imidazolinone herbicides cleared for use in peanut (*Arachis hypogaea* L.). Imazethapyr may be applied preplant incorporated (PPI), preemergence (PRE), ground cracking (GC), or postemergence (POST) for effective weed control (Wilcut et al., 1995). Imazethapyr applied PPI or PRE controls many troublesome weeds such as coffee senna (*Cassia occidentalis* L.), common lambsquarters (*Chenopodium album* L.), morningglory species (*Ipomoea* spp.), pigweed species (*Amaranthus* spp.) including Palmer amaranth (*Amaranthus palmeri* S. Wats.), prickly sida (*Sida spinosa* L.), purple and yellow nutsedge *Cyperus rotundus* L. and C. *esculentus* L., respectively), spurred anoda (*Anoda cristata* (L.) Schlecht.), and wild poinsettia (*Euphorbia heterophylla* L.) (Cole et al., 1989; Wilcut et al., 1991 a,b; Grichar et al., 1992; York et al., 1995).

Imazethapyr applied POST provides the broadest spectrum and most consistent control when applied within 10 days of weed emergence (Wilcut et al., 1991a, 1994a,b). Imazethapyr and imazapic are the only POST herbicides to control both yellow and purple nutsedge (Grichar et al., 1992; Richburg et al., 1993). Control is most effective when imazethapyr is applied to the soil or yellow nutsedge that is no more than 2 to 4 in tall (Richburg et al., 1993; Wilcut et al., 1994c; Wilcut et al., 1995).

Imazapic was cleared for use in peanut in the spring of 1996. It has shown outstanding activity on a number of weed species (Nester and Grichar, 1993; Grichar et al., 1994; Wilcut et al., 1993b, 1994b, 1995). Imazapic is similar to imazethapyr and controls all the weeds controlled by imazethapyr. In addition, imazapic controls two extremely common and troublesome weeds, Florida beggarweed (*Desmodium tortuosum* (S.W.) D.C.) and sicklepod (*Senna obtusifolia* (L.) Irwin & Barneby), which are not adequately controlled by imazethapyr. Whereas imazethapyr provides consistent control of many broadleaf and sedge species if applied within 10 days after emergence, imazapic has a longer time period for effectiveness of POST applications (Wilcut et al., 1993, 1995; Richburg et al., 1994, 1996). Imazapic also is effective for control of rhizome and seedling johnsongrass (*Sorghum halepense* (L.) Pers.), Texas panicum (*Panicum texanum* Buckl.), large crabgrass (*Digitaria sanguinalis* (L.) Scop.), southern crabgrass (*Digitaria ciliaris* (Retz.)Koel.), and broadleaf signalgrass *(Brachiaria platyphylla* (Griseb.)Nash) (Wilcut et al., 1993).

Both imazethapyr and imazapic persist in soil and can damage rotational crops. Monks and Banks (1991) observed slight corn (*Zea mays* L.) injury and severe cotton (*Gossypium hirsutum* L.) injury from imazaquin (another imidazolinone herbicide) applied to soybean (*Glycine max* (L.) Merr.) the previous year. Renner et al. (1988) observed significant corn injury from imazaquin applied the previous year in one of two years. No imazaquin injury to rice was observed in soybean-rice rotational studies by Helms et al. (1989). Imazethapyr has been observed to injury corn slightly (Mills and Witt, 1989). Johnson et al. (1992) reported slight but significant injury to rice (*Oryza sativa* L.) from imazethapyr applied the previous year to soybean. Rotational crops such as sugarbeet (*Beta vulgaris* L.), canola (*Brassica napus* L.), cauliflower (*Brassica oleracea* L.), broccoli (*Brassica oleracea* L.), and lettuce (*Lactuca sativa* L.) can also be damaged when planted following imazethapyr application (Fellows et al., 1990; Miller and Alley, 1987; Tickes and Umeda, 1991).

The persistence of imidazolinones in soil is influenced by degree of adsorption to soil, soil moisture content, temperature, and amount of exposure to sunlight (Allen and Casely, 1987; Malik et al., 1988; Manges, 1991). The degree of absorption to soil increases as organic matter content increases and pH decreases (Che et al., 1992; Loux et al., 1989). As the primary mode of decomposition is by microbial degradation, dissipation is most rapid in soils with temperatures and moisture contents that favor microbial activity (Goetz et al., 1990; Loux and Reese, 1992). Photodecomposition accounts for a small amount of imidazolinone degradation when the herbicide is on the soil surface but rainfall or incorporation remove the herbicide from exposure to light (Curran et al, 1992; Goetz et al., 1990).

Above pH 4.0 the carboxyl groups on imazethapyr dissociate, and adsorption of the resulting herbicide anion is negligible (Mangels, 1991). However, in the presence of clay at pH 5.0, fluorescence emission spectra indicate imazethapyr is adsorbed in the neutral form (Che et al., 1992). At pH 8.0, only the ionized form was observed even in the presence of clay. Increased adsorption and persistence were observed as soil pH dropped from 6.5 to 4.5 (Loux and Reese, 1992). Injury to crops seeded following imidazolinone herbicide use also increased as soil pH decreased from 7.7 to 6.0 (Fellows et al., 1990), indicating that increased adsorption, at pH 6.0, did not protect crops from imidazolinone herbicide residues.

Most of peanut soils of south Texas have a pH of 6.5 to 7.5 and organic matter contents of $\leq$ 1.5%. Therefore, in south Texas soils, imidazolinone herbicides are readily available for microbial degradation. Since these soils are low in organic matter and pH is near neutral, little of the imidazolinone herbicide should be absorbed on soil particles. Crops with low tolerance to the imidazolinone herbicides such as potatoes (*Solanum tubersum* L.) and cotton are grown in rotation with peanut in many areas where imazethapyr or imazapic are used.

Few studies could be found describing the effects of imazapic soil residues to rotational crops. Wixson and Shaw (1992) planted corn, grain sorghum [*Sorghum bicolor* (L.) Moench], cotton, rice, wheat (*Triticum aestivum* L.), and Italian ryegrass (*Lolium multiflorum* Lam.) directly into treated soil in the field after imazapic was incorporated.

Table 1. Schedule of events for rotational studies at each location.

Event	Location		
	Pearsall	Yoakum	Waller
Pendimethalin applied	April 19, 1995	June 20, 1995	June 15, 1995
Peanut planted	April 19, 1995	June 20, 1995	June 16, 1995
Variety	GK-7	GK-7	Tamspan 90
Imazethapyr/imazapic applied	May 9, 1995	July 10, 1995	July 20, 1995
Peanut dug	Sept 17, 1995	Oct 11, 1995	Oct 18, 1995
Corn planted	Feb 19, 1996	April 2, 1996	April 2, 1996
Melons planted	April 18, 1996	April 22, 1996	April 22, 1996
Cotton planted	April 18, 1996	April 22, 1996	April 22, 1996
Milo planted	March 26, 1996	April 2, 1996	April 2, 1996
Sesame planted	April 18, 1996	April 22, 1996	April 22, 1996
Potatoes planted	Feb 19, 1996	April 2, 1996	April 2, 1996
Corn harvested	April 18, 1996	May 21, 1996	May 24, 1996
Cotton harvested	—	June 14, 1996	—
Melons harvested	—	June 14, 1996	—
Milo harvested	May 23, 1996	May 21, 1996	May 24, 1996
Sesame harvested	—	June 14, 1996	—
Potatoes harvested	May 18, 1996	—	May 24, 1996
Soil type	Duval loamy fine sand	Tremona loamy fine sand	Katy fine sandy loam
% Organic matter	< 1%	< 1%	< 1%
pH	7.1	6.4	7.8

Imazapic rates of 0.055 lb/A did not reduce shoot weight or emergence of any of the species, but 20% or less visual injury was observed for all crops 28 d after planting. Grimes et al. (1995) felt that imazapic injury to rice grown in rotation with soybean may be reduced by implementing a later rice planting date. They felt the later date allowed time for more herbicide degradation in the soil. Herbicide metabolism by the rice plant may also be greater at the later planting date due to warmer temperatures (Grimes et al., 1995).

MATERIALS AND METHODS

In 1995 and 1996, studies were conducted at three locations in South Texas to determine the effect of imazethapyr or imazapic applied POST on peanut (*Arachis hypogaea* L.) to crops planted the following year. These studies were conducted near Pearsall in Frio County, near Yoakum in Lavaca County, and near Waller in Waller County. These locations represent three different average rainfall amounts. The average annual rainfall for Waller County is approximately 45 in while the Frio County average is approximately 28 in. The average for Lavaca County is intermediate at 38 in.

A schedule of operations and specifics about the test area are included in Table 1. Land preparation procedures followed those commonly practiced by south Texas peanut producers. This includes discing the area, flatbreaking, and then bedding the soil, prior to application of a herbicide. Prior to planting of peanuts, pendimethalin [*N*-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine] at 1.0 lb/A was applied and incorporated 2 in deep with tractor-driven power tiller to control Texas panicum (*Panicum texanum* L.), Palmer amaranth (*Amaranthus palmari* S. Wats.), and southern crabgrass [*Digitaria ciliaris* (Retz.) Koel].

The soil type at Pearsall was a Duval loamy fine sand (fine-loamy, mixed, hyperthermic Aridic Haplustalfs), at Yoakum the soil was a Tremona loamy fine sand (thermic Aquic Arenic Palenstalfs), and at Waller the soil was a Katy fine sandy loam (Udalf Paleudalf).

Peanuts were planted immediately after the incorporation of pendimethalin. 'GK-7' variety was planted at Pearsall and Yoakum while 'Tamspan 90' was planted at Waller. Seeding rate for 'GK-7' was 90 lb/A while for 'Tamspan 90' the seeding rates was 70 lb/A.

Plot size at each location was 8 rows spaced 36 in apart and 100 ft long. The larger plot size was to prevent herbicide contamination in adjacent plots by any soil movement with various farm implements. The follow crops were planted parallel in these plots in the middle 4 rows in a 33 ft length. All harvest data were taken from these 4 rows. The experimental design for all studies was a randomized complete block with four replications. Supplemental irrigation was applied as needed to peanut and any follow crop.

POST treatments were applied 20 days after planting (DAP)[1] at Pearsall and Yoakum and 35 DAP at Waller. Treatments included an untreated check, imazethapyr applied at 0.063 lb/A, and imazapic applied at 0.035, 0.063, and 0.13 lb/A. A nonionic surfactant[2], at a rate of 0.25% v/v, was added to each treatment. Treatments were applied in water at 20 gal/A at 26 psi with a compressed-air bicycle sprayer.

Peanuts were harvested in the fall and the test area was allowed to lay fallow until the following spring when follow crops were planted. However, at the Pearsall location, the producer disked the test area twice in December prior to leaving fallow until the spring. Prior to planting of follow crops the land was prepared with a disk and field cultivator operated at a 2.5 in depth.

Corn 'Yellow Dent', cotton 'DP-50', melons 'Black Diamond', milo 'DK-54', sesame 'S-17', and potatoes 'Red La Soya' were planted parallel to the previous year's treatment. Corn, cotton, milo, and sesame were planted with the appropriate seed drill while melons and potatoes were seeded by hand. Melons were planted 36 in apart while potatoes were planted 12 in apart.

Each crop was harvested by cutting the stem at the ground line and green matter was forced air dried at 160°F for 96 h. The follow crops were not carried to yield because of problems with water management on a small scale throughout the growing season and also the authors felt that the initial growth would show any carryover effects with the imidazolinone herbicides. Also only limited space was available at each location to observe the numerous follow crops effects and weeds would become a problem in follow crops if the different crops were allowed to grow to maturity.

Corn was harvested 58 DAP at Pearsall, 49 DAP at Yoakum, and 52 DAP at Waller. Cotton was harvested 53 DAP at Yoakum, but was not harvested at Pearsall because of high number of Palmer amaranth which emerged about the same time as cotton and prevented any cotton growth or at Waller because of poor soil moisture after planting

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[1] Abbreviations: DAP, days after planting.

[2] X-77 Valent USA Corp., 1333 N. California Blvd., Walnut Creek, CA 94596-8025. Nonionic surfactant with 80% principal functioning agents as: alklarylpolyoxy ethylene glycols, free fatty acids, and isopropanol.

Table 2. Biomass yields of crops seeded one year after imazapic and imazethapyr at Pearsall.

Herbicide	Rate	Follow crop Corn	 Potatoes	 Grain sorghum
	lb ai/A		g/ft^2	
Check	—	63	76	242
Imazapic	0.063	65	64	227
Imazapic	0.032	55	68	255
Imazapic	0.063	64	86	206
Imazapic	0.124	55	60	248
LSD (0.05)		NS	NS	NS

which resulted in sporadic plant stands. Melons were harvested 53 DAP at Yoakum and 33 DAP at Waller. Melons were not harvested at Pearsall because of difficulty in obtaining plant stands due to Palmer amaranth (*Amaranthus palmeri*) competition. Grain sorghum was harvested 58 DAP at Pearsall, 49 DAP at Yoakum, and 52 DAP at Waller. Sesame was not harvested at Pearsall or Waller because of difficulty in obtaining plant stands. Potatoes were harvested 88 DAP at Pearsall and 52 DAP at Waller. Potatoes were not harvested at Yoakum because of blowing sands which resulted in poor potato growth. The spring of 1996 was not only dry but will be remembered as having above normal winds which moved soil in some areas.

Dry weight yield data from each crop were analyzed separately for each site. Variation due to differences of environmental conditions at each site prevented the combining of data. Differences between herbicide treatments and the untreated check were separated using Fisher's Protected LSD Test at the 0.05 level of significance.

RESULTS AND DISCUSSION

Pearsall Location

Corn, potatoes, and grain sorghum vegetative growth yields were not reduced with either imazapic or imazethapyr, although there were trends toward reduced potato growth with the 0.13 lb/A (2X) rate of imazapic (Table 2). Mayer and Esau (1996) reported, in southern Alberta, potato yields from imazethapyr treated plots were significantly reduced by imazethapyr. They also noted that potato tubers in imazethapyr treated plots had many growth cracks that reduced marketable yields. Two years after application, imazethapyr did not reduce potato yields (Mayer and Esau, 1996). Southern Alberta, in contrast to south Texas, have short summers, mean temperatures above 50°F for only May to September and a mean annual rainfall of 10.7 in (Grace and Hobbs 1986) which limit microbial decomposition.

Imazapic also did not affect dry weight of corn or grain sorghum. In contrast other research has found imazaquin {2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-71]-3-guinolinecarboxylic acid} and imazethapyr residues injured corn (Renner et al 1988a, 1988b). However, Wixson and Shaw (1992) reported in studies in Mississippi that visual injury (striped leaves, shortening of internodia, and reduction in plant height)

Table 3. Biomass yields of crops seeded one year after imazapic and imazethapyr at Waller.

		Follow crop			
Herbicide	Rate	Corn	Grain sorghum	Potato	Melons
	lb ai/A	g/ft^2			
Check	—	405	332	104	46
Imazethapyr	0.063	486	432	157	67
Imazapic	0.032	352	462	141	34
Imazapic	0.063	415	408	172	24
Imazapic	0.124	328	328	108	28
LSD (0.05)		NS	NS	NS	NS

symptoms were observed on corn and grain sorghum with imazapic but was not reflected in a reduction of biomass.

Waller Location

Although not significant, corn and melons exhibited trends toward reduced growth following imazapic (Table 3). Imazapic at 0.063 lb/A treated plots produced corn dry weight yields comparable with the untreated check while increasing the rate of imazapic reduced melon growth. Renner et al. (1988a, 1988b) found that corn was injured by both imazaquin and imazethapyr at 10.5g ai/A. Imazapic controls burgherkin (*Cucumis anguria* L.) and citronmellon [*Citrullus lanatus* var. *citroides* (Bailey) Mansf.] (authors personal observation). Since melon is a close relative of these two weed species it is not surprising that some reduced growth was noted following imazapic application.

Grain sorghum and potato dry weights were not affected by imazapic (Table 3). This grain sorghum data agrees with results from Mississippi (Wixson and Shaw 1992). Similarly, imazaquin at rates of up to 227g/A did not reduce emergence of grain sorghum (Basham et al. 1987). However, as the rate of imazapic increased grain sorghum injury increased (Wixson and Shaw 1992).

Yoakum Location

Corn, grain sorghum, melon, and sesame plant dry weights were not affected by imazapic. However, there were trends to reduced plant growth when corn or grain sorghum following imazapic applications to peanut (Table 4.) Sesame emergence and growth have been affected by imazapic and imazethapyr application on a heavier soil type with higher organic matter (authors personal observation). Loux et al (1989) observed low herbicide dissipation rates of imazaquin, imazethapyr, and clomazone {2-[(2-chlorophenl)-methyl]-4,4-dimethyl-3-isoxazolidinone} in a soil with high organic matter. Miller and Allen (1987) noted that alfalfa (*Medicago sativa* L.), pinto bean (*Phaseolus vulgaris* L.), corn, and sunflower (*Helianthus annus* L.) were not injured and stands were not reduced when these crops were planted into areas which had been treated the previous fall with imazapic.

Cotton dry matter yields were significantly reduced with imazethapyr and imazapic. York and Wilcut (1995) expressed a concern about imazethapyr and imazapic carryover

Table 4. Biomass yields of crops seeded one year after imazameth and imazethapyr at Yoakum.

Herbicide	Rate	Cotton	Sesame	Corn	Melons	Grain sorghum
		Follow crop				
	lb ai/A	g/ft^2				
Check	—	61	22	330	60	197
Imazethapyr	0.063	29	32	229	56	147
Imazapic	0.032	42	19	316	118	156
Imazapic	0.063	22	23	186	80	118
Imazapic	0.124	—	29	200	105	164
LSD (0.05)		29	NS	NS	37	NS

Table 5. Rainfall received from POST imidazolinone application until follow crop harvest.

Time[a]	Pearsall	Yoakum	Waller
	Location		
30 D	3.0	3.4	3.5
60 D	2.2	5.1	5.4
90 D	1.1	4.3	4.2
120 D	1.5	0.3	1.2
150 D	3.1	1.1	3.6
180 D	1.8	2.1	3.6
210 D	2.8	0.2	0.2
240 D	0.8	2.1	1.8
270 D	0	0.7	0.4
300 D	0	2.7	2.2
330 D	0.6	4.0	3.9
TOTAL	16.9	26.0	30.0

[a] Days after POST application of imazethapyr or imazapic.

to cotton following a peanut rotation. Wixson and Shaw (1992) noted that imazapic did not reduce the emergence of cotton but did cause visual injury symptoms. They concluded that cotton tolerated imazapic at up to 0.055 lb/A in the field.

Since imazapic is used only as a POST herbicide it may be less phytotoxic to rotational crops. Imazaquin applied POST is much less phytotoxic to rotational crops than when incorporated into the soil due to increased dissipation (Renner et al. 1988a).

The amount of rainfall and/or irrigation may have influenced persistence of imazapic in the soil. Microbial degradation of these herbicides tends to increase as soil moisture increases (Goetz et al. 1990). However, at each of the three locations, rainfall following imidazolinone application was approximately 40% below the yearly average (Table 5).

Warm temperatures (Table 6) in the south Texas area may have played a role in lack of rotational crop injury. Cooler temperatures have been shown to decrease the metabolism rate (two-fold decrease per 41°F temperature decrease) of imazethapyr applied POST to soybean (Malefyte and Quakenbush 1991). Grimes et al (1995) noted in a study with rice (*Oryza sativa* L.) following imazapic in soybeans that earlier planted rice showed more injury from imazapic than the later planting. They concluded that rice emergence

Table 6. Average monthly air temperatures at Waller, Yoakum, Pearsall following imidazolinone POST applications.

	Location		
Time	Yoakum	Waller	Pearsall °F
30 D	79	81	82
60 D	84	85	86
90 D	83	85	86
120 D	80	82	81
150 D	71	70	73
180 D	62	61	61
210 D	56	57	54
240 D	52	52	53
270 D	57	59	58
300 D	56	58	58
330 D	69	69	70

was slower under cooler temperatures which resulted in more emerging plant exposure to the herbicide in the soil.

These studies indicate that cotton was the most sensitive crop to the use of imazapic in a peanut rotation program. This agrees with work in Virginia-Carolina are (York and Wilcut, 1995). However, Wixson and Shaw (1992) in Mississippi reported cotton tolerated imazapic up to 0.055 lb/A. Corn, melon, and potato sensitivity to imazapic varied from location to location. In central and west Texas when temperatures are cooler, the use of imazapic in peanuts may create more of a problem with rotation due to reduced microbial breakdown of the herbicide.

LITERATURE CITED

Allen, R. and J. C. Casely. 1987. The persistence and mobility of AC 222,293 in cropped and fallow land. Proc. Br. Crop Prot. Conf. p. 569-576.

Basham, G. W., T. L. Lavy, L. R. Oliver, and H. D. Scott. 1987. Imazaquin persistence in three Arkansas soils. Weed Sci. 35:576-582.

Che, M., M. M. Loux, S. J. Traina, and T. J. Logan. 1992. Effect of pH on sorption and desorption of imazaqin and imazethapyr on clays and humic acid. J. Environ. Qual. 21:698-703.

Cole, T. A., G. R. Wehtje, J. W. Wilcut, and T. V. Hicks. 1989. Behavior of imazethapyr in soybeans (*Glycine max*), peanuts (*Arachis hypogaea*), and selected weeds. Weed Sci. 37:639-644.

Curran, W. S., M. M. Loux, R. A. Liebl, and F. W. Simmons. 1992. Photolysis of imidazolinone herbicides in aqueous solutions and on soil. Weed Sci. 40:143-148.

Fellows, G. M. , P. K. Kay, G. R. Carlson, and V. R. Stewart. 1990. Effect of AC 222,293 soil residues on rotational crops. Weed Technol. 4:48-51.

Grace, B. and E. H. Hobbs. 1986. The climate of the Lethbridge agricultural area: 1902-1985. LRS Mimeo Report 3 (Revised) Research Station, Lethbridge, AB. 39p.

Goetz, A. J., T. L. Lavy, and E. E. Gbur. 1990. Degradation and field persistence of imazethapyr. Weed Sci. 38:421-428.

Grichar, W. J., A. E. Colburn, and P. R. Nester. 1994. Weed control in Texas peanut with Cadre. Proc. Am. Peanut Res. and Educ. Soc., Inc. 26:70.

Grichar, W. J., P. R. Nester, and A. E. Colburn. 1992. Nutsedge (*Cyperus* spp.) control in peanuts (*Arachis hypogaea*) with imazethapyr. Weed Techno. 6:396-400.

Grimes, C. F., J. M. Chandler, and P. R. Nester. 1995. Response of soybean (*Glycine max*) and rice (*Oryza sativa*) in rotation to AC 263,222. Weed Technol. 9:504-511.

Helms, R. S., T. N. Tripp, R. J. Smith, Jr., F. L. Baldwin, and M. Hackworth. 1989. Rice (*Oryza Sativa*) response to imazaquin residues in a soybean (*Glycine max*) and rice rotation. Weed Technol. 9:513-517.

Johnson, D. H., R. E. Talbert, J. D. Beaty, C. B. Guy, and R. J. Smith. 1992. Rice response following imazaquin, imazethapyr, chlorimurion, and clomazone use. Proc. South. Weed Sci. Soc. 45:371.

Loux, M. M. and K. D. Reese. 1992. Effect of soil pH on adsorption and persistence of imazaquin. Weed Sci. 40:490-496.

Loux, M. M., R. A. Liebl, and F. W. Slife. 1989. Adsorption of imazaquin and imazethapyr on soils, sediments, and selected adsorbents. Weed Sci. 37:712-718.

Malefyte, T., and L Quakenbush. 1991. Influence of environmental factors on the biological activity of the imidazolinone herbicides. p. 103-127 *in* L. Shaner and S. O'Connor, ed. The Imidazolinone Herbicides. CRC Press, Inc., Boca Raton, FL.

Malik, N., D. E. Cole, A. L. Darwent, and J. R. Moyer. 1988. Imazethapyr (Pursuit)—a promising new herbicide for forage legumes. Forage Notes 32:42-45.

Mangels, G. 1991. Behavior of the imidazolinone herbicides in soil—A review of the literature. p. 191-209 *in* D. L. Shaner and S. L. O'Connor, eds. The Imidazolinone Herbicides. CRC Press, Boca Raton, FL.

Miller, S. D. and H. P. Alley. 1987. Weed control and rotational crop response with AC 222,293. Weed Technol. 1:29-33.

Mills, J. A. and W. W. Witt. 1989. Efficacy, phytotoxicity, and persistence of imazaquin, imazethapyr, and clomazone in no-till double-crop soybeans (*Glycine max*). Weed Sci. 37:353-359.

Monks, C. D. and P. A. Banks. 1991. Rotational crop response to chlorimuron, clomazone, and imazaquin applied the previous year. Weed Sci. 39:629-633.

Moyer, J. R. and R. Esau. 1996. Imidazolinone herbicide effects on following rotational crops in southern Alberta. Weed Technol. 10:100-106.

Nester, P. R., and W. J. Grichar. 1993. Cadre combinations for broadleaf weed control in peanut. Proc. South. Weed Sci. Soc. 46:317.

Renner, K. A., W. R. Meggitt, and R. A. Leavitt. 1988a. Influence of rate, method of application, and tillage on imazaquin persistence in soil. Weed Sci. 36:90-95.

Renner, K. A., W. F. Meggitt, and D. Penner. 1988b. Response of corn (*Zea mays*) cultivars to imazaquin. Weed Sci. 36:625-628.

Richburg, J. S., III, J. W. Wilcut, D. L. Colvin, and G. R. Wiley. 1996. Weed management in southeastern peanut (*Arachis hypogaea*) with AC 263,222. Weed Technol. 10:145-152.

Richburg, J. S., III, J. W. Wilcut, and G. R. Wehtje. 1993. Toxicity of foliar and/or soil applied AC 263,222 to purple (Cyperus rotundus) and yellow nutsedge (*C. esculentus*). Weed Sci. 42:398-402.

Tickes, B. R. and K. Umeda. 1991. The effect of imazethapyr upon crops grown in rotation with alfalfa. Proc. Soc. West. Weed Sci. 44:97.

Wilcut, J. W., A. C. York, W. J. Grichar, and G. R. Wehtje. 1995. The biology and management of weeds in peanut (*Arachis hypogaea*). pp. 207-244. *In* H. E. Pattee and H. T. Stalker (eds.) Advances in Peanut Science. Amer. Peanut Red. Educ. Soc., Inc., Stillwater, OK.

Wilcut, J. W., J. S. Richburg, III, E. F. Eastin, G. R. Wiley, F. R. Walls, Jr., and S. Newell. 1994a. Imazethapyr and paraquat systems for weed management in peanut (*Arachis hypogaea*). Weed Sci. 42:601-607.

Wilcut, J. W., J. S. Richburg, III, G. Wiley, F. R. Walls, Jr., S. R. Jones, and M. J. Iverson. 1994b. Imidazolinone herbicide systems for peanut (*Arachis hypogaea*). Peanut Sci. 21:23-28.

Wilcut, J. W., A. C. York, and G. R. Wehtje. 1994c. The control and interaction of weeds in peanut (*Arachis hypogaea*). Rev. Weed Sci. 6:177-205.

Wilcut, J. W., E. F. Eastin, J. S. Richburg, III, W. K. Vencill, F. R. Walls, and G. Wiley. 1993. Imidazolinone systems for southern weed management in resistant corn. Weed Sci. Soc. Amer. 33:5.

Wilcut, J. W., F. R. Walls, Jr., and D. N. Norton. 1991a. Imazethapyr for broadleaf weed control in peanuts (Arachis hypogaea). Peanut Sci. 18:26-30.

Wilcut, J. W., F. R. Walls, Jr., and D. N. Norton. 1991b. Weed control, yield, and net returns using imazethapyr in peanuts (*Arachis hypogaea*). Weed Sci. 39:238-242.

Wixson, M. B. and D. R. Shaw. 1992. Effects of soil-applied AC 263,222 on crops rotated with soybean (*Glycine max*). Weed Technol. 6:276-279.

York, A. C., J. W. Wilcut, C. W. Swann, D. L. Jordan, and F. R. Walls, Jr. 1995. Efficacy of imazethapyr in peanut (*Arachis hypogaea*) as affected by time of application. Weed Sci. 43:107-116.

York, A. C., J. W. Wilcut, C. W. Swann, D. L. Jordan, and F. R. Walls, Jr. 1995. Efficacy of imazethapyr in peanut (*Arachis hypogaea*) as affected by time of application. Weed Sci. 43:107-116.

York, A. C. and J. W. Wilcut. 1995. Potential for Cadre and Pursuit applied to peanuts to carryover to cotton in North Carolina and Georgia. Proc. Beltwide Cotton Conf. 1:602.

Using Cattle to Disperse Seeds for Winter Forage Plants

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ABSTRACT

The effectiveness of using cattle to disperse cool-season plant seeds was assessed in 4 trials. In Trial 1, 4 steers were fitted with total fecal collection bags and fed seeds from 6 different cool season forage species to determine seed recovery rate. The 6 species used were Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM.), hairy vetch (*Vica villosa* Roth.), perennial ryegrass (*Lolium perenne* L.), western wheatgrass (*Elytrigia smithii* (Rydb.) Nevski), Maximilian sunflower (*Helianthus maximiliani* Shrade.), and Engelmann daisy (*Engelmannia pinnatifida* Nutt.). Seed recovery varied ($P<0.05$) among species with 75% of Illinois bundleflower seeds recovered to no seeds of western wheatgrass recovered. In Trial 2, *in situ* and *in vitro* digestion techniques were used to assess seed weight loss to digestion. Hairy vetch and Engelmann daisy both lost more than 16% of their weight while all other seeds lost 5% or less of their weight during rumen incubation. During *in vitro* digestion, hairy vetch and Engelmann daisy lost 29% and 15% of their weight, respectively. Trial 3 assessed the affect of digestion on germination of surviving seeds. Seeds were collected from feces and placed in petri dishes along with nonfed seeds to compare germination before and after ingestion. Passing through the digestive tract of cattle reduced germination of all species except Illinois bundleflower. In Trial 4, seedling emergence and establishment were compared among seeds deposited in dung pats and seeds planted using traditional agronomic techniques. Perennial ryegrass established in dung pats, while others did not. Collectively, these results indicate that perennial ryegrass and Illinois bundleflower may be suitable candidates for fecal seeding while others are not because they are unable to pass through the ruminant digestive system and germinate.

KEY WORDS: fecal, cool-season, improvements, seeding, digestion, germination

INTRODUCTION

Seeding of rangelands has become widely used for improvement of range sites since its emergence as a technology about 100 years ago (Call and Roundy, 1991). In the semiarid southwest, these efforts often are aimed at increasing warm-season grass production, but cool-season forages are also an important component of productive rangelands in the southwest.

Successful reseeding efforts are difficult because revegetation processes in the semiarid southwest are regulated by episodic environmental conditions rather than average conditions (Call and Roundy, 1991). Seedling germination, establishment, and persistence occur during infrequent years of well above-average precipitation (Westoby, 1980). Traditional seeding methods often fail to overcome environmental and climatic factors that limit

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seedling success and can be very expensive (Valentine, 1989). Seedling recruitment will fail if requirements for seed germination and seedling establishment are not met by the microsite (Grubb, 1977; Harper, 1977; Winkel et al., 1991). Thus, seedling establishment is often the result of the number of seeds that are deposited in favorable microsites rather than the total number of seeds dispersed (Harper et al., 1965; Young, 1988).

The number of favorable microsites may be increased by using livestock to disseminate seeds in feces (Akbar et al., 1995). Seeds delivered in dungpats should benefit from the microsite's high organic matter, high moisture content, short-term avoidance of grazing, and short-term reduction of competition with pre-existing vegetation. For instance, fecal delivery of switchgrass (*Panicum virgatum* L.) was advantageous over the traditional broadcast seeding (Ocumpaugh et al., 1996). On fecal-seeded plots, switchgrass recruitment was equal to or greater than the recruitment of switchgrass on broadcast-seeded plots, and fecal-seeded plants were larger than broadcasted-seed plants. Several other species of seeds survive the digestive system of livestock (Harmon and Keim, 1934; Dore and Raymond, 1942; Burton and Andrews, 1948; Janzen, 1981), and a large portion of seeds may remain viable (Heady, 1954; Lehrer and Tisdale, 1956; Peinetti et al., 1993; Wallander et al., 1995).

Using cattle to disseminate seeds is promising, but the approach has not been used extensively to establish cool-season forages in the semi-arid southwest. We conducted a series of trials to assess the effectiveness of using cattle to disperse seeds from cool-season forage plants and to identify differences in seed recovery, germination, and establishment among species after ingestion by cattle.

MATERIAL AND METHODS

Animals and Feeding

In Trials 1, 3, and 4, we used 4 crossbred steers weighing approximately 200 kg. Steers were kept at the Angelo State University (ASU) Management, Instruction, and Research (MIR) Center and housed in 3 m × 6 m pens. Steers were fed a basal ration (1.5% BW) (Table 1) and Sudan hay to meet maintenance requirements (NRC 1984). Water was provided ad libitum. In Trial 2, we relied on a ruminally cannulated steer for an *in situ* digestion trial and for rumen fluid collection for a two-stage *in vitro* digestion trial. The steer was fed the same basal ration (1.5% BW) and Sudan hay for 21 days prior to Trial 2.

Trial 1: Seed Recovery

To assess seed recovery rates from different cool season forage species, 4 steers were fitted with fecal collection bags. Seeds were intermixed with the basal ration and fed to the steers. Seeds from 6 different plant species were fed on separate occasions to individual steers (n = 4), with each seed fed to all steers once and feces collected until no seeds were found in samples. Two grasses were used along with 2 legumes and 2 composites. All selected plant species were cool-season plants, palatable forages, and adapted for survival in the semi-arid southwestern U.S. These included western wheatgrass (*Elytrigia smithii*

Table 1. Ingredients and nutrient content of ration fed to steers to meet maintenance requirements.

Ingredient	Percent (%) in Diet
Alfalfa, 17% dehy	25.0
Corn	48.8
Cottonseed meal	8.8
Gin Trash	15.0
Beef Premix[1]	2.5
Nutrient	
Crude Protein	14.5
Digestible Energy	2.8
Crude Fiber	13.2
Total Digestible Nutrients (TDN)	62.5

[1] Beef premix included Lasalocid (1158 g/907kg), 22.8% Ca, 22.8% Salt, 1.4% Mg, .21% Zn, .1% Mn, 3.9 ppm Se, and 18,182 IU/Kg Vitamin A.

(Rydb.)Nevski), and perennial ryegrass (*Lolium perenne* L.), Illinois bundleflower (*Desmanthus illinoensis* (Michx.) MacM.), hairy vetch (*Vicia villosa* Roth.), Engelmanndaisy (*Engelmannia pinnatifida* Nutt.), and Maximillian sunflower (*Helianthus Maximiliani* Shrade.). We fed 113 g of each seed to each steer because individual seed size and weight varied among species. Seeds were fed at a given weight rather than a set number to minimize the effect of feed-to-seed ratio on loss of seeds to mastication.

Each morning of the trial, each steer's feces was collected, weighed, thoroughly mixed, and a 200 g sample was collected. Feces were washed through a series of screens to recover seeds. The number of seeds recovered and the weight of the fecal sample was used to estimate the total number of seeds in the fecal collection for that day. After a minimum collection period of 4 d, seed recovery was terminated when no seeds were found in fecal samples. Each steer was monitored separately and the average percentage seed recovery was estimated for each day and across all days.

Trial 2: Seed Digestion

In Situ Digestion

A ruminally cannulated steer was used to estimate seed weight loss from rumen digestion. We assumed that seed weight loss would result from seed digestion or seed damage from digestion which would reduce seed viability. Seeds were sealed in porous nylon bags, weighed, and incubated in duplicate along with blanks in the rumen for 12 and 24 hours. Bags were extracted, thoroughly washed, dried at 105° C for 12 hrs, and re-weighed to determine percent seed weight loss to rumen fermentation. Weight gained by blanks was used as a correction factor when determining weight lost by seeds.

In Vitro Digestion

Each species seed was exposed to a two-stage *in vitro* digestion technique (Tilley and Terry, 1963) to quantify seed weight loss to rumen and abomasal digestion. Rumen fluid

Start here

was collected from a ruminally cannulated steer fed the same basal ration and Sudan hay diet as in Trial 1. Samples in triplicate and blanks were incubated in rumen fluid for 48 hrs and a HCL-pepsin solution for 24 hrs. After incubation, residual material was dried at 105° C for 12 hrs and re-weighed to determine the average weight loss of seeds. Weight gained by blanks was used as a correction factor.

Trial 3: Seed Germination

An estimate of the difference in germination of fed and nonfed seeds was made for each species. Seeds from the fed treatment were obtained by washing dung through a series of screens. Fed and nonfed seeds were placed on moist filter paper in petri dishes. Eight replicate treatments were assigned to petri dishes completely at random. Treatments were a factorial combination of species and fed or nonfed. Each petri dish received 4 seeds. The dishes were placed under a bank of fluorescent and incandescent lights and maintained at a temperature of 25° C. Lights were on for 12 hours (day), and off for 12 hours (night) each day. Moisture was added as needed. Seeds were monitored and seedlings removed every 7 days for 21 days. On day 21, all remaining ungerminated seeds were collected and percentage germination calculated. Engelmann daisy and western wheatgrass were excluded from this experiment because low recovery rates made collection of adequate seed numbers impractical.

Trial 4: Seeding

A single site was selected for the seeding trial on a plowed field adjacent to the MIR Center. Each seed was hand-seeded on 4 randomly assigned 0.5 m × 8 m replicates with 100 seeds per replicate. Dung pats for each species were randomly assigned to 3- 0.5 m × 8 m replicates with 8 dung pats per replicate. Feces was collected 2 days after feeding seeds to steers. All fecal material was combined and throughly mixed. Fecal material was shaped by hand 30 cm-diameter dung pats. The number of seeds per dung pat was estimated based on seed recovery rate from Trial 1. Half of the hand-seeded and fecal-seeded plots were watered weekly to promote establishment. A sprinkler was used to simulate rainfall at the rate of approximately 3 cm per hour. When watering, the sprinkler was moved periodically to adjust for wind and droplet patterns. The number of emerging seedlings were marked and recorded every 7 days for 42 days.

Statistical Analysis

Differences in survival of seeds fed to steers was determined by analyzing data using repeated measures analysis of variance because data was collected over several days (Hicks, 1993). Species of seed served as the main effect and steers served as replications. In Trial 2, differences among species of seeds was compared using analysis of variance for the *in situ* and *in vitro* digestion trials. Differences in germination among fed and nonfed seeds and differences among species was assessed using repeated measures of analysis of variance in Trial 3. The least significant difference (LSD) test was used to

Table 2. Percentage (%) seed survival of 6 cool season forages fed to steers in a mixed ration. Total fecal collections were used to recover seeds in dung.

Species	Percent Seed Recovery
Engelmanndaisy	1.5^{c}
Maximillian sunflower	29.1^{bc}
hairy vetch	40.6^{b}
Illinois bundleflower	75.0^{a}
perennial ryegrass	37.3^{b}
western wheatgrass	0.0^{d}

$^{a\text{-}d}$Means with different superscripts differ ($P<0.05$)

determine differences among means when $P \leq 0.05$ (Gomez and Gomez ,1984). Data from Trial 4 was not analyzed because of limited emergence and establishment.

RESULTS

Trial 1: Seed Recovery

The first objective of this study was to determine the percentage of seeds remaining intact after passage through the digestive system of cattle. More ($P<0.05$) Illinois bundleflower seeds remained intact than the other species; 75% of Illinois bundleflower seeds were found whole in the feces (Table 2). Fewer hairy vetch, perennial ryegrass, and Maximillian sunflower seeds were recovered than Illinois bundleflower, while few seeds of Engelmanndaisy were recovered. No western wheatgrass seeds were found in fecal samples.

Daily recovery rate of seeds differed ($P<0.05$) across the 4 days of fecal collection (Figure 1). More seeds were deposited in dung on day 2 than on days 1, 3, and 4. No seeds were recovered after day 4.

Trial 2: Digestion of Seeds

Hairy vetch and Engelmanndaisy seeds showed significant ($P<0.05$) weight loss during *in situ* incubation (Table 3). Illinois bundleflower, Maximillian sunflower, perennial ryegrass, and western wheatgrass showed little weight loss to rumen digestion.

An *in vitro* digestion trial was used to quantify the combined effect of rumen and abomasal digestion. Hairy vetch lost more ($P<0.05$) weight during digestion than the remaining species (Table 4).

Trial 3: Seed Germination

The potential success of fecal seeding depends on the germinability of seeds after fecal deposition. Engelmanndaisy and western wheatgrass were excluded from the germination test because of their low recovery after digestion. Germination was reduced ($P<0.05$) for all species except Illinois bundleflower (Table 5). Hairy vetch seeds did not germinate after passage through the digestive tract of steers. Perennial ryegrass and

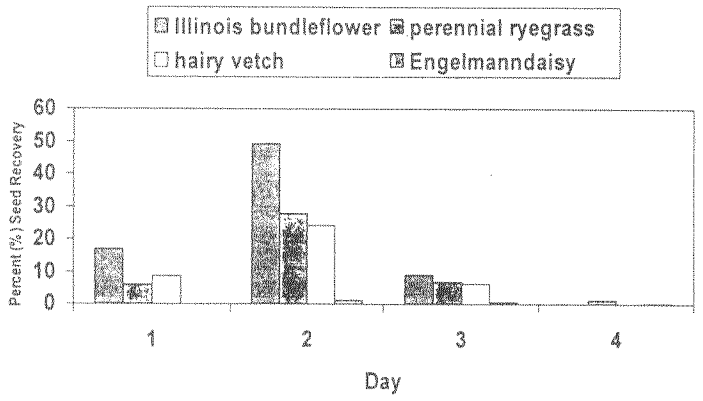

Figure 1. The percentage of seeds fed that was found whole in the feces each day for 4 days after ingestion. Means were averaged across all steers. Western wheatgrass seeds were not found in feces. No seeds were found after the fourth day after ingestion.

Table 3. Percentage (%) weight loss of seeds after 12 and 24 hours of *in situ* digestion

	Percent Weight Loss	
Species	12-hour	24-hour
Engelmanndaisy	14.0^{a}	19.3^{a}
Maximilian sunflower	3.9^{d}	3.7^{d}
hairy vetch	13.3^{b}	19.1^{a}
Illinois bundleflower	4.2^{cd}	5.1^{c}
perennial ryegrass	2.8^{e}	3.1^{e}
western wheatgrass	4.5^{d}	5.8^{b}

[a-e] Means within columns with different superscripts differ ($P<0.05$)

Table 4. Percentage (%) weight loss of seeds during *in vitro* digestion.

Species	Percent Weight Loss
Engelmanndaisy	15.3^{b}
Maximilian sunflower	29.2^{a}
hairy vetch	18.0^{b}
Illinois bundleflower	18.0^{b}
perennial ryegrass	14.0^{b}
western wheatgrass	14.7^{b}

[a-b] Means within columns with different superscripts differ ($P<0.05$)

Table 5. Percentage (%) germination for both fed and nonfed seeds.

Species	Percent Germination		
	Fed	Nonfed	Difference[1]
hairy vetch	0.0^{d}	72^{b}	S
Illinois bundleflower	27.5^{b}	27.5^{c}	NS
Maximillian sunflower	15.0^{c}	22.5^{c}	S
perennial ryegrass	75.0^{a}	97.5^{a}	S

[a-d] Means within columns with different superscripts differ ($P<0.05$).

[1] Differences ($P<0.05$) for before and after feeding seeds.

Table 6. Percentage (%) germination of seedlings emerging in Trial 4 from dungpats and the broadcast treatment.

Species	Percent Germination	
	Broadcast-seeded	Fecal-seeded
perennial ryegrass	3.0	3.7
hairy vetch	2.2	0.2

Maximillian sunflower showed some reduction in germination. More perennial ryegrass seeds germinated than any other species used (Table 5).

Trial 4: Seeding

Perennial ryegrass was the first species to emerge in dungpats and in broadcast-seeded plots. Weekly watering improved germination as 20 of the 22 perennial ryegrass seedlings that emerged were from watered dungpats (Table 6). Maximillian sunflower also emerged from dung pats. Hairy vetch and perennial ryegrass seedlings emerged in both the watered and unwatered broadcast treatments, but only 1 hairy vetch seed emerged from a dungpat.

DISCUSSION

Of the 6 cool season forage plants used in this study, Illinois bundleflower, perennial ryegrass, and Maximillian sunflower may be successfully established by fecal seeding. More seeds of perennial ryegrass germinated and established in dungpats, and it had the highest germination both before and after passage through the digestive tract of cattle. Only 1 seedling of Maximillian sunflower emerged from dungpats, but some seeds germinated in the laboratory.

No Illinois bundleflower emerged from dung pats. Nevertheless, more Illinois bundleflower seeds remained intact after ingestion and defecation by cattle, and it had a high germination rate in the laboratory after passage through cattle. Thus, data from Trials 1 and 3 suggest that Illinois bundleflower may be another potential candidate for fecal seeding.

Engelmann daisy, western wheatgrass, and hairy vetch are not viable choices for fecal seeding. Engelmann daisy and western wheatgrass did not survive the digestive system of cattle; both had significant weight losses during *in situ* digestion, and hairy vetch had significant weight losses during *in vitro* digestion.

The lack of germination of hairy vetch seeds recovered from feces in the laboratory may have resulted from damage during the collection and washing of seeds. When placed in petri dishes, hairy vetch seeds recovered from feces swelled and ruptured. By the end of the 21 days of the experiment, all fecal-collected hairy vetch seeds had molded and decayed. This supports the observation by Simao, Neto, and Jones (1987) that legume seeds disintegrate more readily than grass seeds when damaged. In addition, only 1 hairy vetch seedling emerged from dung while 9 seedlings emerged from the broadcast seedings.

During the planning of this study, 6 species were selected: 2 from the Fabaceae family, 2 from the Asteraceae family, and 2 from the Poaeceae family. Theoretically, species from the same family should be more likely to respond in a similar manner; species in the same family typically have similar types of seeds. For instance, both Illinois bundleflower and hairy vetch have hard seed coats that are typical of seeds produced in pods. However, 1 species will germinate after passage through the digestive tract, and the other did not. Similarly, Engelmann daisy and Maximilian sunflower are from the same family (Asteraceae), but responded differently to rumen digestion.

Perennial ryegrass and western wheatgrass also differed ($P<0.05$) in recovery from digestion. Survival of digestion and emergence of perennial ryegrass in dung pats could be due to evolutionary adaptations to grazing animals. The "foliage is the fruit" hypothesis suggests that some plants evolved with herbivores and are selected for traits that attract herbivores and lead to ingestion and passing of seeds (Janzen, 1984). Under this hypothesis, a plant would have increased reproductive success if its seeds were ingested and dispersed by herbivores. Studies with buffalograss (*Buchloe dactyloides*) and blue grama (*Bouteloua gracilis*), 2 species that evolved with bison herbivory, support this hypothesis (Quinn et al., 1994; Wicklow et al., 1984; Ortmann et al., 1999). Furthermore, perennial ryegrass is a short-lived perennial and should rely more on seed production and dispersal than longer-lived perennial grasses like western wheatgrass which rely heavily on vegetative reproduction (Booth and Haferkamp, 1995).

Passage through the digestive tract reduced germinability for all species of seeds tested except Illinois bundleflower. Reduction of germinability was also observed by Ocumpaugh et al. (1996) with switchgrass, and by Willms et al.(1995) with cicer milkvetch (*Astragalus cicer* L.). Germination may have been reduced further by the characteristics of the dungpat, especially when germination did not occur quickly after deposition. Akbar et al. (1995) reported that crust formation, and decreasing moisture content caused a lack of favorable conditions for gemination in dungpats 4 weeks after placement. However, in the watered treatment in this study, seedlings emerged up to 19 weeks post-dung pat placement. The moisture added to the dungpats from the simulated rainfall probably softened the crust enough for those seedlings to emerge. In addition, weathering of dungpats may create favorable conditions for establishment (Akbar et al., 1995).

Some seed damage and reduced germination in dung pats was probably due to the combined effect of digestion and seed decomposition in the dung pat (Atkeson et al., 1934). Passage through the digestive tract of cattle has been shown to remove all or part of a thin layer of seed coat which should increase decomposition of seeds in dung and explain why some species like Illinois bundleflower germinate in the laboratory but not in dung pats (Simao Neto et al., 1987).

Despite conflicting evidence, some argue that dung pats may provide an appropriate microsite for seedling survival (Ocumpaugh et al., 1996; Archer and Pyke, 1991). The potential benefits of the dung pat microsite include high fertility, high moisture retention capacity, short-term reduction of competition with pre-existing vegetation, and short-term grazing avoidance. The results of this study indicate that dung deposition may improve seedling establishment for some species. For instance, perennial ryegrass seedlings that emerged in dung pats appeared more robust with more tillers and greater biomass than seedlings of the broadcast seeded treatment as observed with switchgrass (Ocumpaugh et al., 1996). Nevertheless, the lack of germination of Illinois bundleflower which survived digestion and readily germinated in the laboratory but failed to emerge in dung suggest that the dung pat microenvironment may reduce the likelihood of emergence of some species.

IMPLICATIONS

From the observations of this study, fecal seeding perennial ryegrass in late fall or early winter in the semi-arid southwest should produce better results than any other species or time. Producers could feed seeds to cattle the morning of the day that they were to be moved into a pasture and have seeds being deposited in substantial amounts for 3 days given that seeds typically pass for 4 days after ingestion (Burton and Andrews, 1948; Yamada and Kawaguchi, 1972; Ozer, 1979; Willms et al., 1995).

Even though perennial ryegrass was the most likely candidate from this study for fecal-seeding, traditional broadcast-seeding may be more economically feasible. Thirty seven percent of perennial ryegrass seeds survived digestion with 75% of those germinating in the lab. Thus, only 28% of the perennial ryegrass seeds fed could be expected to survive and germinate. Conversely, 98% of nonfed seeds germinated in the laboratory. When traditional microsite preparation is applicable, broadcast-seeding may result in higher recruitment of cool-season forages in the semi-arid southwest.

LITERATURE CITED

Akbar, G., C. A. Call, and R. D. Wiedmeier. 1995. Cattle dungpat microenvironmental effects on germination and establishment of crested wheatgrass. Arid Soil Res. Rehab. 9:409-422.

Archer, S. and D. A. Pyke. 1991. Plant-animal interactions affecting plant establishment and persistence on revegetated rangeland. J. Range Manage. 44:558-565.

Atkeson, F. W., H. W. Hulbert, and T. R. Warren. 1934. Effect of bovine digestion and of manure storage on the viability of weed seeds. J. Am. Soc. Agron. 26:390-397.

Booth, D. T. And M. R. Haferkamp. 1995. Morphology and seedling establishment. pp. 239-291. In : D.S. Bedunah and R. E. Sosebee (editors). Wildland Plants: Physiology Ecology and Developmental Morphology. Society for Range management, Denver.

Burton, G. W. and J. S. Andrews. 1948. Recovery and viability of seeds of certain southern grasses and lespedeza passed through bovine digestive tract. J. Agri. Res. 76:95-103.

Call, C. A. and B. A. Roundy. 1991. Perspectives and processes in revegetation of arid and semi arid rangeland. J. Range Manage. 44:543549.

Dore, W. G., and L. C. Raymond. 1942. Viable seeds in pasture soil and manure. Sci. Agri. 23:69-79.

Gomez, K. A. and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research. pp. 187-207. John Wiley and Sons, New York.

Grubb, P. J. 1977. The maintenance of species-richness in plant communities: The importance of the regeneration niche. Biol. Rev. 52:107-145.

Harmon, G. W., and F. D. Keim. 1934. The percentage and viability of weed seeds recovered in the feces of farm animals and their longevity in buried manure. J. Amer. Soc. Agron. 26:762-767.

Harper, J. L., J. T. Williams, and G. R. Sager. 1965. The behavior of seeds in the soil. I. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. J. Ecol. 53:273-286.

Harper, J. L. 1977. Population biology of plants. Acedemic Press, London.

Heady, H. F. 1954. Viable seed recovered from fecal pellets of sheep and deer. J. Range Manage. 7:259-261.

Hicks, C. R. 1993. Fundamental Concepts in the Design of Experiments. pp. 201. Saunders College Publishing, New York.

Janzen, D. H. 1981. *Enterolbium cyclocarpum* seed passage rate and survival in horses, Costa Rica Pleistocene seed dispersal agents. Ecol. 62:593-601.

Janzen, D. H. 1984. Dispersal of small seeds by big herbivores: Foliage is the fruit. Amer. Natur. 123:338-353.

Lehrer, W. P., and E. W. Tisdale. 1956. Effect of sheep and rabbit digestion on the viability of some range plant seeds. J. Range Manage. 9:118-122.

NRC. 1984. Nutrient Requirements of Beef Cattle. National Academy Press, Washington D.C.

Ocumpaugh, W. R., S. Archer, and J. W. Stuth. 1996. Switchgrass recruitment from broadcast seed vs. seed fed to cattle. J. Range Manage. 49:368-371.

Ortmann, J., W.H. Schacht, J. Stubbendieck. 1999. The "foliage is the fruit" hypothesis: complex adaptations in buffalograss (*Buchloe dactyloides*). Amer. Midl. Natur. 140:252-263.

Ozer, Z. 1979. The influence of passage through sheep on the seeds of meadow plants. Weed Res. 19:247-254.

Peinetti, R., M. Pereyra, A. Kin, and A. Sosa. 1993. Effects of cattle ingestion on viability and germination rate of calden (*Prosopis caldenia*) seeds. J. Range Manage. 46:383-386.

Quinn, J. A., D. P. Mowrey, S. M. Emanuele, and R. D. B. Whalley. 1994. The "foliage is the fruit" hypothesis: *Buchloe dactyloides* (Poaceae) and the shortgrass prairie of north America. Am. J. Botany. 81:1545-1554.

Simao Neto, M., R. M. Jones, and D. Ratcliff. 1987. Recovery of pasture seed ingested by ruminants. 1. Seed of six tropical pasture species fed to cattle, sheep and goats. Aust. J. Exp. Agri. 27:239-246.

Simao Neto, M., and R. M. Jones. 1987. Recovery of pasture seed ingested by ruminants. 2. Digestion of seed *in sacco* and *in vitro.* Aust. J. Exp. Agri. 27:247-51.

Tilley, J.M.A, and R.A. Terry. 1963. A two-stage technique for the in vitro digestion of forage crops. J. Br. Grassl. Soc. 18:104-106.

Valentine, J. F. 1989. Why range seedings fail, p. 269-270. *In:* Range Development and Improvements. Academic Press, inc, San Diego.

Wallander, R. T., B. E. Olson, and J. R. Lacey. 1995. Spotted knapweed seed viability after passage through sheep and mule deer. J. Range Manage. 48:145-149.

Westoby, M. 1980. Elements of a theory of vegetation dynamics in arid rangelands. Israel. J. Bot. 28:169-194.

Wicklow, D. T., R. Kumar, and J. E. Lloyd. 1984. Germination of blue grama seeds buried by dung beetles (Coleoptera: Scarabaeidae). Environmental Entomology. 13: 878-881.

Willms, W. D., S. N. Acharya, and L.M. Rode. 1995. Feasibility of using cattle to disperse cicer milkvetch (*Astragalus cicer* L.) seed in pastures. J. Anim. Sci. 75:173-175.

Winkel, V. K., B. A. Roundy, and D. K. Blough. 1991. Effects of seedbed preparation and cattle trampling on seedling emergence. J. Range Manage. 44:171-175.

Yamada, T., and T. Kawaguchi. 1972. Dissemination of pasture plants by livestock. 2. Recovery, viability and emergence of some pasture plant seeds passed through the digestive tract of dairy cow. J. Anim. Sci. 37:1062-1074.

Young, J. A. 1988. Seedbeds as selective factors in the species composition of rangeland communities, p. 171-188. *In:* P.T. Tueller (ed.), Vegetation Science and Applications for Rangeland Analysis and Management. Kuwer Academic Publ., The Netherlands.

Electric Power Deregulation: Potential Impacts on Irrigated Crop Production in the Texas High Plains

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ABSTRACT

Deregulation of the electric power industry has the potential to broaden the electric power markets in Texas by providing consumers with the ability to purchase their electric power needs from more than one supplier. Yet, not all segments of the consuming public may benefit from deregulation, in particular the agricultural industry in the Texas High Plains (THP), which is a major consumer of electricity for irrigation during the peak summer consumption period. The objectives of this study were to estimate the impacts on irrigated crop production in the THP from increasing electric power rates, and determine the associated impacts on the THP regional economy from changes in agricultural production. Nineteen county-level linear programming models (LP) were used to estimate the effects of increased electric rates on crop production. Key findings indicated that regional economic impacts from increasing electricity rates appear to be minor, yet farm level impacts could have a greater relative effect.

KEY WORDS electricity, deregulation, economic evaluation

Deregulation of the electric power industry in Texas has potential benefits for electricity consumers. The deregulation and restructuring of the electric utility industry is viewed as a positive progression that will broaden the electric power market for consumers and allow for comparative shopping. Consumers in the aggregate may benefit from deregulation,[2] however the distribution of benefits may be quite diverse across the various consuming segments of the market, such as residential, commercial, industrial and agricultural.

Who will be the winners and losers under deregulation? Several studies have indicated that industrial and commercial customers stand to be the big winners under retail deregulation (Chernoff and Sanchez, 1998; Chilton et al., 1997). Large industrial and commercial

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[2] As will be discussed, "re-regulation" may be the more appropriate term. States that have "deregulated" thus far, have placed limits/conditions on what utility companies can do with some electric rates.

customers who have high, consistent load factors and the ability to shift loads will be able to exert significant market power. Residential and small commercial customers may initially benefit from deregulation if rate reductions are mandated. Rural customers in low-cost states may face rate increases (Chernoff and Sanchez, 1998).

Irrigated agriculture is an important consumer of electric power in the Texas High Plains (THP). Electricity for irrigation represented approximately 38% of the total annual electricity usage over the period 1993-1998 for eleven rural electric cooperatives which serve much of the THP region (Golden Spread Electric Cooperative, 1999). However, this irrigation demand for electricity entails significant seasonal variations because irrigation customers consume the majority of their power over the crop growing season, the peak summer consumption period.

The use of electricity as an irrigation fuel has been increasing across the THP in recent years. This shift to electricity as a power source has resulted from reduced irrigation well yields which have encouraged the instillation of submersible pumps and the increased use of center pivot sprinkler irrigation systems. It is estimated that 55% of the irrigated acres in the THP use electricity as the source of power. The use of electricity for irrigation varies across the region, with electricity use estimated at 61% of irrigated acres in the southern sub-region and 53% of irrigated acres in the northern sub-region (Wolgamott, 1998).

Agricultural production, principally irrigated production, is an important component of the THP regional economy. The potential impact of electric power deregulation on agricultural production in the region and the resulting effects on the regional economy are important issues. Therefore, the objective of this study was to estimate the potential impacts of increasing electric rates on the THP regional economy. Specifically, the objectives were to (1) estimate the impacts on irrigated crop production in the THP from increasing electric power rates, and (2) determine the associated impacts on the THP regional economy from changes in agricultural production value.

This study was conducted for a defined region of 19 counties in the THP (Figure 1). The region was divided into northern and southern sub-regions in order to account for differences in cropping patterns across the region. The northern sub-region consisted of Armstrong, Bailey, Briscoe, Castro, Cochran, Deaf Smith, Floyd, Hale, Lamb, Parmer, Randall and Swisher Counties. The southern sub-region consisted of Crosby, Garza, Hockley, Lubbock, Lynn, Terry and Yoakum Counties. The selection of the study region was determined by the number of irrigated acres within these counties as well as the diversity in crop production. Wheat, corn, grain sorghum and cotton are the major crops produced within the study region.

Regional Agricultural Economy

Irrigated agricultural production is an integral component of the economy of the THP. Irrigated production of the four major field crops (corn, grain sorghum, wheat and cotton) within the study region contributed $1.06 billion directly to the regional economy in 1996 (Texas Agricultural Statistics Service). Crop production in the study region represented 60% of the state's cotton production, 37% of the state's corn production, 26% of the state's grain sorghum production, and 19% of the state's wheat production (Texas Agricultural Statistics Service). The three-year average planted acreages of the four major field crops in the study region are shown in Table 1. Of the 4.857 million acres, 53% were irrigated while 47% were dryland. As depicted in Table 2, 59% of the 2.910 million acres composing the northern sub-region were irrigated. Table 3 shows the allocation of acres within the southern sub-region, with 43% of the planted crop acreage

Figure 1. The Study Region.

Table 1. Regional Crop Acres (3-Year Average 1994-1996).

Crop	Irrigated	Dryland	Total
	(1,000 Acres)		
Cotton	1,537.7	980.8	2,518.5
Corn	467.5	-0-	467.5
Grain Sorghum	234.7	475.4	710.1
Wheat	327.0	833.9	1,160.9
Total	2,566.9	2,290.1	4,857.0

Table 2. Northern Sub-Region Crop Acres (3-Year Average 1994-1996).

Crop	Irrigated	Dryland	Total
	(1,000 Acres)		
Cotton	751.5	198.5	950.0
Corn	464.0	-0-	464.0
Grain Sorghum	197.8	264.9	462.7
Wheat	311.0	722.7	1,033.7
Total	1,724.3	1,186.1	2,910.4

Table 3. Southern Sub-Region Crop Acres (3-Year Average 1994-1996).

Crop	Irrigated	Dryland	Total
		(1,000 Acres)	
Cotton	786.2	782.3	1,568.5
Corn	3.5	-0-	3.5
Grain Sorghum	36.9	210.6	247.5
Wheat	15.5	111.2	126.7
Total	842.1	1,104.1	1,946.2

in irrigated production. Cotton dominates regional production with 52% of the total crop acres planted to cotton. In 1996, the region contributed 60% and of the state's total upland cotton production and 14% of total U.S. upland cotton production. In the study region, 62% of the cotton acreage is found in the southern sub-region, equally dispersed between both irrigated and dryland production practices.

While cotton is the primary crop planted in the southern sub-region, feed grain production (corn and grain sorghum) is located principally in the northern sub-region. In this region, 71% of the 926,700 acres of feed grains are irrigated. Feed grain production from the irrigated corn and grain sorghum produced in the region has contributed to the establishment of the region as the leading cattle feeding area in the nation. In 1996, fed cattle marketings in the study region totaled 3.108 million head, representing 57% of the state's total fed cattle marketings with a total value of $2.0 billion (Texas Agricultural Statistics Service). Several major packing plants are located in the study region with annual slaughter capacity in excess of 2.33 million head (Southwestern Public Service, 1998).

Agribusiness in the THP is composed of many interdependent components that sustain and enhance economic growth for the region. In addition to the commodity production sectors within the economy, a major element of this system is the agribusiness infrastructure. This infrastructure includes grain elevators, cotton gins, cattle feedlots, farm machinery and equipment dealers, trucking firms, production input suppliers (seed, fertilizer, chemicals), meat packing plants, cotton oilseed processing plants and textile mills. The agribusiness sector contributes to the production, marketing, processing and transporting of the agricultural products produced in the region and plays a primary role in the contribution of economic value to the regional economy.

Several other industries in the U.S. have been "deregulated" in recent years, such as natural gas, telecommunications, banking and airlines. Industries that have been deregulated in the past bring many issues of this policy change to the surface. For instance, rather than pure deregulation, changes within the regulation system occur. Most often, the impacts of the changes are not distributed uniformly across the nation. In particular, rural areas experience different impacts as compared to urban areas where the volume of transactions is large enough to enhance a workable competitive market. Finally, results from an ideal competitive situation often do not occur across a single national market as firms find ways to exploit market power and establish barriers to entry (Freshwater et al., 1997). Freshwater et al. notes that, by and large, deregulation of these industries has netted positive results, although the distribution of benefits has not been uniform.

MATERIALS AND METHODS

The estimation of the impacts of possible increases in electric rates for irrigation customers on agricultural production and the regional economy involved two types of analytical tools. Linear programming (LP) models were used to estimate acreage changes and levels of production of the four major crops at various electric rates. IMPLAN (an input-output model) was used to estimate the regional economic impacts given the estimated shifts in production patterns (MIG, Inc., 1995).

Estimating crop acreage changes was accomplished by using county level LP models that were constructed to take into account the variation in the hydrological characteristics of the aquifer and crop production patterns across the region. The LP models used county-specific information on pumping depth, saturated thickness of the aquifer, acres of each crop (corn, grain sorghum, wheat and cotton), crop yields, acres for each condition of irrigation (furrow, sprinkler, dryland), acres for each type of irrigation fuel and other quantitative variables, including electric rates. The estimated proportion of irrigated acres where electricity was the irrigation fuel used was held constant in the models, as it was beyond the scope of this study to predict how fuel source choices would change in the future in response to electric rate increases. Consequently, electric rate increases did not impact all irrigated acres within a county; only the proportion that used electricity as a source of power was impacted.

The estimated farm level production value for each crop was obtained by multiplying the estimated acres of each crop within a county by the average county yield and projected crop prices. Estimates of the production value were found for six levels of electric rates. The county estimates of farm level production value for each crop were aggregated for the study region and compared to a baseline scenario that represented the current electric rate structure. Changes in the total farm level production value for each crop were entered into IMPLAN to obtain the estimated regional economic impacts.

Model and Assumptions

Models were run for various electricity rates which represent the current rate as well as six scenarios at increased rates. The electric rates used in the LP models were 7.3¢, 8.0¢, 8.75¢, 9.5¢, 11.0¢, 12.8¢ and 14.6¢/ kWh which represent the current electric rate and increases of 10%, 20%, 30%, 50%, 75% and 100%, respectively. The current rate was calculated to be 7.3¢/kWh, which represented an average of irrigation service rates across the region and included an allowance for demand charges in the rate structure (Wolgamott, 1998). The model solutions were estimated using increased electric rates because rates in the THP are low relative to the rest of the state and may not be expected to decrease significantly under deregulation.

The initial crop acreages used in the models were an average of the 1994-1996 crop years (Texas Agricultural Statistics Service). Yield estimates for each crop were the nine-year average (1988-1996) county yield (Texas Agricultural Statistics Service). Crop prices were the average of projected crop prices for 1998-2007 from the Food and Agricultural Policy Research Institute with the cotton price adjusted to the THP (FAPRI, 1998). The irrigation acreages under both furrow and sprinkler technologies were calculated using a survey of center pivots and acres under sprinkler irrigation conducted in 1996 (New, 1996).

Several assumptions were made that affect the model formulation. Acres of each crop were maintained across all electric rates with the exception of corn, which was allowed to shift to grain sorghum because dryland corn is not produced in the region. This constraint was included in the models because production relationships relating crop production to applied irrigation water were not readily available for the region given the time frame for the project. The inclusion of these relationships possibly would have allowed the transition of crop acres to lower irrigation application rates within a specific crop activity. Model solutions estimated without this constraint went to almost total cotton production, even under the current electric rate structure, due to the relative profitability of cotton to the other crops and the lower water requirement of cotton. Therefore, the restriction on shifts between crops was included in the models. Irrigation technology shifts were allowed between furrow, sprinkler and dryland. The cost of natural gas rates was held constant at $2.99/mcf with no acreage increases allowed for natural gas as the irrigation pumping fuel.

Estimation of Production

The LP models used to derive crop acreages under the various electric rate scenarios maximized returns to management and risk. The crop production costs used in the models included the variable cost of production inputs (Texas Agricultural Extension Service, 1998), estimated irrigation cost under each irrigation system, a depreciation cost for machinery and equipment (including the irrigation system) and a land charge. Electric costs for irrigation as a percent of total production costs ranged from 8% to 36% depending on the crop, irrigation technology and county. An initial model was estimated using average acreages for each crop and irrigation condition at the current electric rate. This model represented the current state of crop production for each county and was used as the baseline for comparison purposes.

A set of models was estimated allowing for the optimization of irrigation conditions at the various rate scenarios. Each model could shift crop acres between irrigation system technologies or dryland production in order to maximize the return to management and risk. By comparing the results at the increased electric rate scenarios to the baseline model, the impacts on crop acres due to changes in electricity rates were estimated.

IMPLAN Application

The changes in the value of production for each electric rate scenario were evaluated using IMPLAN (MIG Inc., 1995). A regional input-output model was constructed for the study region using the 1995 database (MIG Inc., 1995). Input-output analysis makes the assumption that interindustry transactions plus final demand equals the total economic activity in an economy. IMPLAN gives estimates of economic impacts given changes in final demand. These final demand changes were derived from the changes in the production value of respective economic sectors. It should be noted that total economic activity in an economy, as estimated by IMPLAN, is based on the gross sales or production values of the sectors within the economy.

The changes in production value for each crop derived from the various electric rate scenarios represent changes in final demand for the relevant economic sector. The economic sectors within the model affected by the changes in crop production value were the cotton sector, feed grain sector (corn and grain sorghum) and food grain sector (wheat). The IMPLAN database does not break each crop production sector into irrigated or dryland, therefore, the irrigated a dryland production values were aggregated. The estimated changes in each crop's production value under each electric rate scenario were evaluated to give estimated total regional economic impacts. The impacts are specified as direct, indirect and induced. The direct effect represents the change in production value

Table 4. Regional Acreages in Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(1,000 acres)						
Dryland	2,276.46	2,276.46	2,403.30	2,408.36	2,479.39	2,479.39	2,590.08
Irrigated	2,567.47	2,567.47	2,440.63	2,435.56	2,364.53	2,364.53	2,253.85
Furrow	1,001.37	1,001.37	934.42	929.35	858.32	858.32	822.03
Sprinkler	1,566.10	1,566.10	1,506.21	1,506.21	1,506.21	1,506.21	1,431.82

Table 5. Northern Sub-Regional Acreages in Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(1,000 acres)						
Dryland	1,183.67	1,183.67	1,222.62	1,227.68	1,298.72	1,298.72	1,350.50
Irrigated	1,724.78	1,724.78	1,685.83	1,680.77	1,609.74	1,609.74	1,557.95
Furrow	724.99	724.99	686.04	680.98	609.95	609.95	592.42
Sprinkler	999.79	999.79	999.79	999.79	999.79	999.79	965.53

Table 6. Southern Sub-Regional Acreages in Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(1,000 acres)						
Dryland	1,092.79	1,092.79	1,180.68	1,180.68	1,180.68	1,180.68	1,239.58
Irrigated	842.69	842.69	754.80	754.80	754.80	754.80	695.90
Furrow	276.38	276.38	248.38	248.37	248.37	248.37	229.61
Sprinkler	566.31	566.31	506.42	506.42	506.42	506.42	466.29

for a given sector. The indirect effect represents the response of all other sectors to the change in final demand in a given sector due to the iteration of industries purchasing from other industries. The induced effect represents the response of all sectors caused by the expenditures of new household income generated by the direct and indirect effects for changes in final demand for a given sector. The total economic impact is the sum of the direct, indirect and induced effects.

RESULTS AND DISCUSSION

Production Changes

The effects of increasing electric rates on crop acres under dryland and irrigated conditions and the type of irrigation technology used in crop production are summarized in Tables 4 through 6. Shown in these tables are the acres of irrigated and dryland crop production and the acres under furrow and sprinkler technologies. The 10% electric rate increase had no effect on the level of irrigated acres. Electric rate increases of 20% to

Table 7. Regional Production Value of Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(million $)						
Cotton	814	814	802	801	793	793	787
Corn	184	184	184	184	182	182	166
Sorghum	77	77	77	77	78	78	81
Wheat	103	103	103	103	103	103	103
Total	1,178	1,178	1,166	1,165	1,156	1,156	1,137
Change from Baseline	—	0	−12	−13	−22	−22	−41

Table 8. Northern Sub-Regional Production Value of Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(million $)						
Cotton	362	362	357	356	348	348	348
Corn	183	183	183	183	181	181	165
Sorghum	59	59	59	59	60	60	63
Wheat	94	94	94	94	94	94	94
Total	698	698	693	692	683	683	670
Change from Baseline	—	0	−5	−6	−15	−15	−28

100% resulted in a decrease in irrigated acres and an increase in dryland acres at the regional and sub-regional levels. A 30% electric rate increase resulted in a 5% (131,910 acre) decrease in irrigated acres regionally, 67% of which occurred in the southern sub-region. At the 50% electric rate increase, irrigated acres decreased by 8% regionally (202,940 acres) with no additional decrease in the southern sub-region and a 115,040 acre decrease in the northern sub-region. In the southern sub-region, the impacts were constant from the 20% through the 75% electric rate increase levels. In the northern sub-region, additional adjustments in irrigated acres occurred at the 50% and 75% electric rate increase scenarios. Irrigated acres declined further in the northern and southern sub-regions under the 100% electric rate increase scenario.

As electric rates increased, the irrigation technologies used in the production process changed. Regionally, the level of furrow irrigated acres decreased by 7% and 14% at the 30% and 50% electric rate increases, respectively. Of the 72,180 acre regional decrease in furrow irrigated acres at the 30% electric rate increase, 61% (43,940 acres) were in the northern sub-region. Acres under sprinkler technologies declined marginally across the electric rate scenarios. At the 30% and 50% electric rate increases, sprinkler acres declined by 4% across the region.

The production value of crops for the region and sub-regions are shown in Tables 7 through 9. Under the baseline scenario, the total value of crop production in the region was estimated at $1.178 billion. Cotton production contributed 69% of the region's total crop production value with feed grains (corn and grain sorghum) and wheat contributing 22% and 9% of the crop production value, respectively.

As electric rates increased, it was estimated that at the 30% electric rate increase scenario the regional production value of crops would be expected to decline by $13

Table 9. Southern Sub-Regional Production Value of Crops Under Alternative Electric Rate Increase Scenarios.

	Baseline	10%	20%	30%	50%	75%	100%
	(million $)						
Cotton	452	452	445	445	445	445	439
Corn	1	1	1	1	1	1	1
Sorghum	18	18	18	18	18	18	18
Wheat	9	9	9	9	9	9	9
Total	480	480	473	473	473	473	467
Change from Baseline	—	0	−7	−7	−7	−7	−13

Table 10. Regional Economic Impacts Under Various Electric Rate Scenarios.

	10%	20%	30%	50%	75%	100%
	(million $)					
Direct	0	−12.000	−13.000	−22.000	−22.000	−41.000
Indirect	0	−6.144	−6.657	−11.199	−11.199	−20.066
Induced	0	−2.318	−2.512	−4.219	−4.219	−7.448
Total	0	−20.463	−22.169	−37.418	−37.418	−68.544

million, all coming from cotton production. The northern and southern sub-regions showed a $6 million and $7 million decrease in cotton value, respectively. At the 50% electric rate increase scenario, the total regional decrease in crop production value was estimated at $22 million. Cotton production represented $21 million of this decrease while feed grain production represented $1 million. Corn production decreased by $2 million while grain sorghum production increased by $1 million. The impact on crop production value did not change through the 75% electric rate increase scenario. At a 100% electric rate increase, crop production value decreased by $41 million regionally. Cotton represented 66% of the decrease ($27 million) while corn production value declined by $18 million, and grain sorghum value increased by $4 million.

In the southern sub-region, the impact of increased electric rates was felt at the 20% electric rate increase scenario and was constant up to the 75% electric rate increase. The impacts were reflected only in cotton production. In the northern sub-region, the impact of increased electric rates was reflected across a greater range of rate changes. Cotton was the major crop affected as electric rates increased up to the 50% electric rate increase scenario. As rates increased beyond the 30% electric rate increase, corn production was affected. There was an increase in grain sorghum production at the higher electric rate levels as grain sorghum was substituted for irrigated corn production. Under all electric rate scenarios analyzed wheat production was not affected given that it was primarily a dryland crop.

Aggregate Economic Impacts

Direct regional impacts on the economy from increased electric rates are the changes in production value shown in Table 7. The total annual regional economic impacts of increased electric rates are shown in Table 10. Estimates are shown for the direct, indirect, and induced economic impacts of changes in the production value of the crops. At the 30% electric rate increase scenario, the total regional economic impact was estimated to be a decrease in economic activity of $22.2 million. Of this, $13.0 million came from a reduction in crop production value, and $9.17 million came from the impacts on other sectors of the regional economy. At the 50% electric rate increase scenario, the negative regional economic impacts increased to $37.4 million with economic impacts beyond the reduction in crop values of $15.4 million. The regional economic impacts of the 100% electric rate increase scenario was estimated to be a decrease in economic activity of $68.5 million.

Farm Level Impacts of Increased Electric Rates

The farm level impacts of increased electric rates differ from the aggregate impacts as measured by the regional crop production values and economic impacts using the IMPLAN model. The farm level impacts of increased electricity rates varied across counties and crops due to differing crop yield levels, pumping lifts and saturated thickness of the aquifer. Hale County was selected to illustrate farm level impacts on cotton profitability as electric rates increased. Hale County is located in the northern sub-region of the study area and has 408,033 acres in production of the four crops considered in this study. The cropping mix is 55% cotton, 18% corn, 10% grain sorghum and 17% wheat. Irrigated acres total 338,066, of which 56% are furrow irrigated and 44% are under sprinkler irrigation. Acres with electricity as the power source make up 40% of total irrigated acres.

Using results from the initial baseline model for Hale County, a weighted average per acre net return to management and risk for irrigated cotton was derived (weighted by acres under furrow and sprinkler irrigation methods using electricity and natural gas). At the baseline electric rate scenario, the weighted average net return was $28.01 per acre. The weighted average net return declined to $21.95 per acre under the 30% electric rate increase scenario. This represents a 22% decrease in net return per acre for irrigated cotton. If only the acres using electricity as the power source were considered, net return per acre was found to be 40% lower under the 30% electric rate increase scenario as compared to the baseline scenario. Results using the 50% electric rate increase scenario indicated that per acre net return decreased 36% and 67%, respectively, for total irrigated cotton acres and acres irrigated using electricity as the power source.

SUMMARY AND CONCLUSIONS

The primary objectives of this study included the estimation of potential impacts of increased electric rates on irrigated agricultural production in the THP and the resulting economic impacts on the region's economy. The results of this study showed the expected shifts in irrigated crop production as electric rates increased. The range of electric rate scenarios used in the models was from the baseline level of 7.3¢/kWh up to 14.6 ¢/kWh which represents a 100% increase. Due to current electric rates in the THP being low relative to rates throughout Texas, changes in the THP rates may be anticipated. While the changes in rates cannot be accurately estimated because of many undetermined conditions, some groups in the industry believe that a 30% increase (from an average of 7.3¢/kWh to 9.5¢/kWh) is realistic (Wolgamott, 1998).

The results indicated that an increase of 10% in electric rates would have no impact on the levels of crop production within the study region. As electric rates increased by 20% and 30%, cotton production levels were impacted primarily in the southern sub-region. The reduction in the value of cotton production under the 20% and 30% electric rate increases ranged from $12 to $13 million. This reduction in cotton production value represented only a 1.5% decline in total cotton value for the region.

The results regarding crop production value can be segmented as follows: the 10% electric rate increase had no impact on crop production value; the 20% and 30% electric rate increase reduced crop production value by $12 to $13 million, respectively; the 50% and 75% electric rate increases reduced the crop production value by $22 million; and the 100% electric rate increase had a $41 million negative impact on crop production value. The impact of electric rate increases was found to primarily affect cotton production. Wheat production was not affected under any of the electric rate scenarios, while grain sorghum production would be expected to increase under the higher rate scenarios as corn production acreage shifts to grain sorghum.

The regional economic impacts estimated with IMPLAN followed the trends in crop production value. The loss in regional economic activity at the 20% and 30% electric rate increase scenarios was $20 to $22 million, respectively, while at the 50% and 75% electric rate increase scenarios regional economic activity would be expected to be reduced by $37 million. The regional negative impact at the 100% electric rate increase was $68 million. The magnitude of the loss in economic activity across the electric rate scenarios is minor when compared to a total regional economy of $21 billion (MIG, Inc., 1995). The regional economic impacts may be further separated into the impacts on individual sectors of the economy. Using the results from the 30% increase in electric rates, the total negative economic impact was estimated at $22.2 million of which $13 million was directly from reduced crop production value, $6.7 million was from indirect impacts on other sectors of the economy and $2.5 million was from induced impacts on households within the economy. Of the $6.7 million in indirect negative impacts, the economic sectors most affected included: agricultural, forestry and fishery services—$1.5 million; wholesale trade—$1.1 million; and real estate—$1.7 million. Induced impacts totaled $2.5 million, with economic sectors most affected being: owner occupied dwellings—$0.25 million; hospitals—$0.15 million; doctors and dentist—$0.15 million; eating and drinking—$0.15 million; and banking - $0.11 million. Given that the southern sub-region had the greatest proportion of the reduced crop production value, the sector affects may be weighted more toward the southern sub-region.

The economic impacts estimated using the IMPLAN input-output model are driven off of aggregate production values from each sector of the economy. Therefore, estimates of the impacts on the regional economy were related to regional changes in the gross values of crop production. While the negative regional economic impacts are relatively small compared to the regional economy, the impacts on individual farms are more significant. For example, in Hale County the 22% reduction in per acre net return for irrigated cotton could significantly affect individual farming operations. In particular, those farms using electricity as the only irrigation fuel would be expected to experience a 40% reduction in net returns for irrigated cotton. For farmers who are dependent on electricity for irrigation, structural changes in their operations would be necessary. The option of converting to natural gas as an energy source may be limited for many farmers due to availability and the cost of building pipelines and replacing pumps. While the negative impact of increased electric rates on the regional economy is not expected to be severe, the impact on current farm families' incomes is likely to be greater, especially if electricity is the primary energy source for the farm.

The results of this study show that electric rate increases associated with deregulation could have a negative impact on the economy of the THP and individual farms where electricity is the primary source of irrigation fuel. The regional economic impacts appear to be minor, while the farm level impacts could have a greater relative effect. However, a broad spectrum of possible responses exists. There are economic, technological, and managerial approaches to dealing with possible electric rate increases that could ease the transition to a fully deregulated electric power market.

REFERENCES

Chernoff, Harry, and Gabriel Sanchez. 1998. The Impact of Industry Restructuring on Electricity Prices. Catalog #F60198. American Gas Association. Arlington, VA.

Chilton, John B., Ronald P. Wilder, and Douglas P. Woodward. 1997. Electricity Deregulation in South Carolina: An Economic Analysis. SCANA Corporation. May 1997.

FAPRI. 1998. Food and Agricultural Policy Research Institute U.S. Agricultural Outlook. Staff Report 1-98. Iowa State University, University of Missouri-Columbia: Food and Agricultural Policy Research Institute. January 1998.

Freshwater, D., Stephan Goetz, Scott Samson, Jeffrey Stone, Tulin Johansson, and Monica Greer, 1997. The Consequences of Changing Electricity Regulations for Rural Communities in Kentucky. National Rural Electric Cooperative Association: University of Kentucky, College of Agriculture. December 1997.

Golden Spread Electric Cooperative, Inc. 1999. 1998 Annual Report. Golden Spread Electric Cooperative, Inc. Amarillo, TX.

MIG, Inc. 1995. IMPLAN-1995. MIG, Inc. Stillwater, MN.

New, Leon. 1997. Center Pivot and Acres Count. Irrigation Committee of the High Plains Ogallala Regional Water Management Planning Team. Unpublished raw data.

Southwestern Public Service Company. 1998. Cattle-Feeding Capital of the World. Southwestern Public Service Company. Amarillo, TX.

Texas Agricultural Extension Service. 1998. Texas Crop and Livestock Enterprise Budgets—Texas High Plains. Bulletin B-1241. Texas Agricultural Extension Service. College Station, TX.

Texas Agricultural Statistics Service. various issues. Texas Agricultural Statistics. USDA, National Agricultural Statistics Service. Austin, TX.

Wolgamott, Monte. 1998. Personal communication. South Plains Electric Cooperative, Inc. Lubbock, TX.

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Effect of Soil Fertility and Cultural Practices on Burr Yield of Buffalograss

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ABSTRACT

Successful production of buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] burrs is one of the greatest limitations to increased use of this native species as either a turfgrass or forage crop. The objective of this research was to determine the impact of soil fertility, planting rate, planting date, and harvest date on burr yields of buffalograss. Trials were conducted near Bronco, TX on a Portales fine sandy loam soil (fine-loamy, mixed superactive thermic Aridic Calciustolls) and at Lubbock, TX on an Amarillo fine sandy soil (fine-loamy, mixed thermic Aridic Paleustalfs). Under conditions where buffalograss had less than 47 in of available soil moisture, the application of 60 to 80 lbs N acre^{-1}, 20 to 40 lbs P_2O_5 acre^{-1}, and micronutrients did not enhance burr production. At lower levels of available moisture, soil nutrients did not appear to be a limiting factor. Cultivar, planting date, planting rate, and type of seed used for establishment had minimal impact on burr yield. Buffalograss appeared to be well adapted to a dual burr harvest regime in which the initial harvest was made in July, and the final harvest was made after the first frost.

KEYWORDS: Buchole dactyloides (Nutt.) Engelm., cultivar evaluation, planting rates, planting date, harvest date

Buffalograss [*Buchole dactyloides* (Nutt.) Engelm.] is a warm-season, long-lived, drought tolerant grass that forms a dense sod (Wenger, 1941). Because it is native to the Great Plains of North America, it is very tolerant to heat, drought, and pests that limit many turfgrass species introduced into this region (Hitchcock, 1936; Savage, 1934). These traits, combined with its slow growth rate, need for minimal levels of fertilization, and ability to withstand moderate traffic, have increased the use of buffalograss as a turfgrass (Leuthold, 1982; Riordan, 1991). Successful establishment of buffalograss by planting burrs has historically been difficult and expensive (Launchbaugh and Owensby, 1970; Hauser, 1986; Savage, 1934; Wu et al., 1989). Since buffalograss is dioecious, only female plants bear the seed-containing burrs which further limits yields. However, direct planting remains the most practical and cost effective means to establish large areas of buffalograss (Wu et al., 1989).

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Ahring and Todd (1977) extracted a water soluble compound from buffalograss burrs that reduced germination (Hauser, 1986). Removing the seeds from the burr eliminates this type of inhibition. Svoboda (1991) studied different types of burr decortication and compared the germination and establishment of seed with treated and untreated burrs. Burrs soaked in potassium nitrate had higher germination and establishment rates than nontreated burrs but were equivalent to seeds which had been removed from the burrs.

Successful stand establishment can also limit burr yields in this species. Since buffalograss seeds will not germinate at temperatures below 60°F, planting is often delayed until late spring (Leuthold, 1982). Wenger (1941) reported that planting from 10 to 20 April provided the highest plant establishment in undisturbed soils in Kansas. Planting prior to 15 May gave adequate establishment on fallow and cultivated soils, but successful stand establishment was achieved with all planting dates prior to 15 June. In addition, Gaitan-Gaitan et al. (1998) reported that planting seeds before mid-July gave optimum stand establishment at Lubbock, TX. The impact of initial stand establishment on burr yield in subsequent years has not been determined. The objectives of these studies were to determine impact of soil fertilization, planting rate, planting dates, and harvest dates on burr production in buffalograss in the lower Great Plains. This information could help growers produce economic yield of buffalograss burrs and seed.

MATERIALS AND METHODS

Soil Fertility

Three soil fertility trials were conducted in 1993 and 1994 on established stands of buffalograss near Bronco, TX (approximately 3 miles west of Plains, TX) on a Portales fine sandy loam soil (Fine-loamy, mixed superactive thermic Aridic calciustolls). The test site was at an altitude of 3788 ft and was located at 32° 15′ N latitude and 103° 03′ W longitude. The 1993 trials were conducted on established stands of the cultivar 'Texoka' (Voigt et al., 1975), and the 1994 trials on the cultivar 'Comanche' (Davis et al., 1978). Both of these cultivars have similar areas of adaptation. Six stratified soil samples from the top 36 in (0-6, 0-12, 12-24, 24-36 in) of the soil profile were taken across the plot area in both 1993 and 1994 prior to applying fertilizer treatments (Table 1). The samples from each soil depth were composited prior to laboratory analyses. Soil samples were taken 2 Feb. 1993 and 4 Feb. 1994. The 1993 samples were analyzed by the Texas A&M University Soil Laboratory and the 1994 samples by the High Plains Agricultural Laboratories, Inc. at Lubbock, TX for soil pH, nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), sodium (Na), sulfur (S), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), and boron (B).

Nitrogen × Phosphorus Trial. Five rates of N and $P_2 0_5$ (0, 20, 40, 60, and 80 lbs/acre) in all possible combinations were applied to plots 6 ft wide and 24 ft long. Nitrogen was applied as urea (46-0-0) and P as triple superphosphate (0-46-0). Fertility treatments were preweighed for each plot and scattered by hand to ensure uniform distribution on 12 Mar. 1993 and 11 Mar. 1994. Fertilizer treatments were watered immediately after planting to minimize potential volatilization of the urea. Irrigation was provided by overhead sprinkler with a total of 41 and 20 in of water applied in

Table 1. Initial soil pH and nutrient status of buffalograss fields at Bronco, TX, where soil fertility trials on buffalograss burr yields were conducted.

	1993				1994			
	Soil depth, in				Soil depth, in			
Index	0-6	0-12	12-24	24-36	0-6	0-12	12-24	24-36
ph	8.7	8.7	8.6	8.9	8.5	8.2	8.0	8.2
Nitrogen (ppm)	1	1	1	1	14	7	7	12
Phosphorous (ppm)	169	118	21	5	12	13	12	12
Potassium (ppm)	571	508	539	256	203	166	105	90
Calcium (ppm)	8571	8571	8571	8571	2410	2500	2400	2200
Magnesium (ppm)	827	827	827	827	220	228	244	500
Zn (ppm)	0.2	0.3	0.1	0.1	0.3	0.2	0.2	0.2
Fe (ppm)	3.5	5.0	3.8	8.5	3.0	3.0	3.0	2.0
Mn (ppm)	3.0	3.0	0.9	0.3	3.0	2.0	2.0	.01
Cu (ppm)	0.4	0.4	0.3	0.1	0.4	0.4	0.4	0.4
Na (ppm)	115	158	498	139	70	152	171	143
Boron (ppm)	—	—	—	—	0.7	0.3	0.6	0.4

the 1993 and 1994 growing seasons, respectively. Total precipitation was 10 in and 11 in for 1993 and 1994.

Plots were harvested 9 Nov. to 4 Dec. of 1993 and 11 Nov. to 15 Dec. of 1994 using a rotary lawn mower with a rear bagging system. A swath 20 in wide and 23 ft long was cut 0.4 in above the soil surface from each plot and placed in individual polyweave sacks. The harvested area was then vacuumed and the recovered residue added to the clippings. Harvested clippings were dried for 5 d at 86°F in a forced air oven. Burrs were separated with a small plot thresher and a clipper seed cleaner to provide estimates of total seed yield.

This trial was arranged in a split plot, randomized complete block design with four blocks. The five N rates were assigned to main plots: (30 ft × 24 ft) and the five P rates to subplots (6 × 24 ft) to minimize the impact of N fertilizer movement between plots. Data from each year of the study were analyzed separately using analysis of variance. Fisher's Protected Least Significance Test was used to separate means (SAS, 1989).

Nitrogen Rate × Split Applications Trial. Five total rates of N (0, 20, 40, 60, and 80 lbs/acre) were applied in one, two, or three applications to buffalograss using the procedures described for the previous trial. The single application was applied on a single date (12 Mar. 1993 and 11 Mar. 1994). Fertilizer treatments for the double (split) application was placed on the plots on 12 Mar. and 20 Apr. 1993, and 11 Mar. and 20 Apr. 1994. Fertilizer treatments for the triple (split) applications were placed on the plots on 12 Mar., 20 Apr., and 13 May of 1993; and 11 Mar., 20 Apr., and 12 May of 1994. Fertilizer treatments were preweighed for each plot and scattered by hand to ensure uniform distribution. Fertilizer treatments were watered immediately after planting to minimize potential volatilization of the urea.

A randomized complete block design with four blocks was used. Data from individual years were subject to separate analysis of variance. Means for all analysis were separated with Fisher's Protected Least Significant Difference test (SAS, 1989).

Micronutrient Trial. Four micronutrients (Mn, Fe, Zn, and B) were applied as foliar sprays on 10 May 1993 and 12 May 1994 to buffalograss using the procedure described for the N × P trial. Chelated Mn Sulfonate was applied at two rates (0.21 lbs Mn/acre + 0.16 lbs S/acre and 0.41 lbs Mn/acre + 0.32 lbs S/acre). Chelated Zn Chloride was applied at two rates (0.13 lbs Zn acre^{-1} and 0.24 lbs Zn acre^{-1}). Chelated Fe Sulfonate was applied at two rates (0.19 lbs Fe/acre + 0.10 lbs S/acre and 0.38 lbs Fe/acre + 0.19 lbs S/acre). Boron was applied as mixed borate at the rate of 8.3×10^{-4} lbs B/acre. All micronutrients were applied by a hand sprayer after dissolved in solution equivalent to 40 gal H_2O/acre to ensure uniform coverage. The entire plot area in which the micronutrients were applied was uniformly treated with 36 lbs N/acre as urea on 12 Mar. 1993 and 11 Mar. 1994. This trial was conducted as a randomized complete block design with four blocks. Data from each year of the study were analyzed using analyses of variance and means were separated with Fisher's Protected Least Significant Difference test (SAS, 1989).

Cultural Practices

Additional trials were conducted in 1993 and 1994 at Lubbock, TX on an Amarillo fine sandy soil (fine-loamy, mixed thermic Aridic Paleustalfs). The test site was at an altitude of 3290 ft and was located at 33° 35′ N latitude and 101° 58′ W longitude. Buffalograss was fertilized with 20 lbs N acre^{-1} as ammonia sulfate (21:0:0:24) on 11 May of 1993 and 10 May of 1994. Additional nutrients were not added. During the establishment year, these plots were evaluated for seedling establishment and turf quality (Gaitan-Gaitan et al., 1998; 1999). Treatments were evaluated for their impact on burr production during the second year of establishment.

Planting Rate Study. Burrs from a 1991 lot of 'Comanche' (Davis et al., 1978) were dehulled by Frontier Hybrids (Abernathy, TX) in early 1992 to provide the seed used in both years of this study. Burrs of the same seed lot were commercially treated with a 0.5% potassium nitrate solution for 24 h prior to the initiation of the study in 1992 (Wenger, 1941). Both treated burrs and seed were stored at room temperature (72 to 81°F).

Planting rates of 626, 939, 1253, and 1566 burrs or seeds/yd^2 were used to establish the plots used in this study. This seed lot required 0.26, 0.39, 0.52, and 0.67 oz/yd^2 of burrs and 0.04, 0.06, 0.08, and 0.10 oz. per yd^2 of seeds to provide rates equivalent to 626, 939, 1253, and 1566/yd^2. These planting rates assumed only one seed per burr would establish.

The studies were planted 17 June 1992 and 17 May 1993. Burrs and seed were scattered by hand to ensure even distribution and immediately covered with approximately 0.24 in of sand to reduce desiccation. A micro set sprinkler system applied approximately 2.0 in of water immediately after planting and an additional 0.5 in of water every 3 d during the first 14 d of the study. During weeks 3 and 4 of the study, the irrigation rate was decreased to 0.5 in every 4 d. This irrigation schedule provided adequate moisture to ensure optimum germination and establishment for the initial 4 wks after planting. Subsequent irrigations during the remainder of the establishment year were scheduled on the basis of estimated evaporation as determined by published estimates provided by the Texas A&M Center at Lubbock, TX.

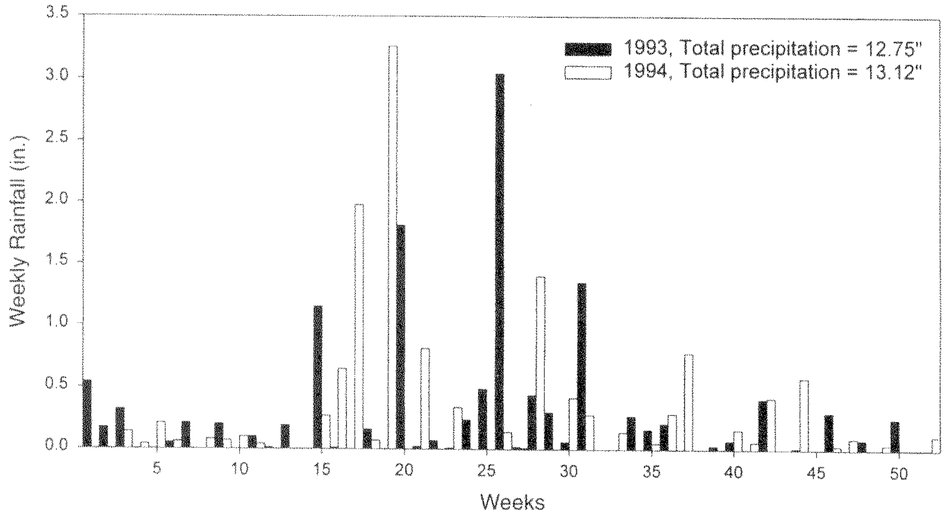

Figure 1. Rainfall distribution at Lubbock, TX during 1993 and 1994.

During the winter following establishment, the plots were mowed to a height of 2 in above the soil surface to remove accumulated thatch to stimulate burr production. During the seed production year, plots were irrigated twice each week to replace soil moisture lost through estimated evapotranspiration. An additional 20 in of irrigation water were applied in 1993 and 27 in 1994. Rainfall at this site was 127 in in 1993 and 13 in in 1994 (Fig. 1).

Treatments were planted in a randomized complete block design with a split-plot treatment arrangement and five blocks. The main plots were seed types (burrs or seed), and the four planting rates were subplots. Main plots were 43.2 ft^2 in 1992 and 96.8 ft^2 in 1993 and 1994. Subplots were 10.8 ft^2 in 1992 and 24.2 ft^2 in 1993 and 1994. Data were analyzed using analyses of variance and means separated by Fisher's Protected Least Significant Difference Test at the 0.05 level of probability (SAS, 1989).

Planting Date Study. This study was conducted using procedures described for the planting rate study with the following exceptions: Seven planting dates evaluated in this study ranged from mid-June (Day of Year 165) to mid-September (Day of Year 250) in 1992 and 1993. The experiment was conducted as a randomized complete block design with a split-split plot arrangement of treatments and five blocks. The seven planting dates were assigned to main plots, the two seed types (burrs and seed) were assigned to subplots, and cultivars (Comanche and Texoka) to sub-subplots. Data were analyzed using analyses of variance and mean separations were performed using Fisher's Protected Least Significant Differences Test at the 0.05 level of probability.

Date of Harvest Study. This study was conducted using procedures described for the planting rate study except all plots were seeded in early spring of 1993. The experiment was conducted as a randomized complete block design with four blocks and a split plot arrangement of treatments. Cultivars (Commanche and Texoka) were assigned to main plots (96.8 ft^2) and harvest dates were assigned to subplots (24.2 ft^2). Harvest dates were 1 July 1994, 15 July 1994, 27 July 1994; and 11 January 1995. Data were analyzed using analyses of variance and mean separations were performed using Fisher's Protected Least Significant Differences Test at the 0.05 level of probability.

RESULTS AND DISCUSSION

Soil Fertility

Initial soil analyses conducted at both Bronco, TX test sites showed the soil had a high pH of 8.6 to 8.9 in 1993 and 8.0 to 8.5 in 1994 (Table 1). Both sites had low levels of residual N and most micronutrients based on soil tests. The 1994 site had very low levels of available P. These soil analyses suggest that the application of nutrients should have improved the yields of most cereal and forage crops. The low burr yields observed in 1994 trials were probably the result of an extreme drought and limited irrigation at the site which provided only 31.0 in of total moisture compared to 60.6 in of total moisture in 1993 (Fig. 1).

Nitrogen × Phosphorus Trial. In 1993 and 1994, there was no N × P interaction in burr yield (Table 2). The main effect of P did not influence burr yield in either year of these trials, but the addition of N increased burr yield in 1993. Under dry conditions such as in 1994, soil nutrients did not appear to limit burr production. Under conditions where moisture is not limiting, growers would probably obtain increases in burr yield with applications of 20 to 40 lbs of N/acre.

Nitrogen Rate × Split Applications Trial. In 1993, average burr yield of buffalograss increased from 198 lbs/acre with no N application to 356 lbs/acre with 80 lbs of N $acre^{-1}$ (Table 3). The increase in burr yield with increasing N rates was less dramatic in 1994 when moisture stress limited burr production. Splitting N application in one, two, or three applications had no measurable impact on burr yield. This could be expected under the dry conditions under which these trials were conducted, when growth was limited by moisture availability. Once again, applications of 60 to 80 lbs of N/acre would probably increase burr yield in environments where moisture did not limit burr production.

Micronutrient Trial. In 1993, there was no significant response in burr yield to the foliar application of micronutrients even with the high soil pH's (8.0 to 8.9) measured at this site (Table 4). Under the dry conditions of 1994, a slight but statistically significant response in burr yields to application of micronutrients was observed. Because this response was highly variable, no consistent recommendation on micronutrient fertility could be made based on these limited data.

Table 2. Effect of nitrogen (N) and phosphorous (P) fertilization on buffalograss burr yield at Bronco, TX in 1993 and 1994.

	lbs N/acre					
lbs P_2O_5/acre	0	20	40	60	80	Avg
1993			lbs/acre			
0	238	236	368	353	394	**318 a**[†]
20	249	347	380	347	380	**341 a**
40	295	312	322	416	380	**345 a**
60	300	336	322	347	286	**318 a**
80	348	314	409	317	436	**365 a**
Avg	**286 c**[†]	**309 bc**	**360 ab**	**356 ab**	**375 a**	
CV = 27.2%						
1994			lbs/acre			
0	96	96	71	130	100	**99 a**[†]
20	87	88	85	94	119	**95 a**
40	87	91	100	90	122	**98 a**
60	73	86	139	121	105	**105 a**
80	108	127	111	123	104	**113 a**
Avg	**90 a**[†]	**98 a**	**101 a**	**112 a**	**110 a**	
CV = 34.7%						

[†] Means of average N or P rates not followed by the same letter differ at 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Cultural Practices

Planting Rate Study. During the initial year of establishment, buffalograss usually does not produce significant burr yields. Consequently, burr yields were not determined until the second year of establishment. No differences in burr yields were measured among seeding rates or between plots established with either burrs or seed. No interaction was present among these factors during either 1993 or 1994 (Table 5). These data indicate that establishment of buffalograss for burr production can be achieved across a wide range of seeding rates using both burrs and seed removed from the burrs. The stolons of this warm-season grass, with appropriate irrigation and weed control, quickly produce uniform stands. Higher burr yields were observed in 1994 than in 1993 probably reflect the additional irrigation water applied in 1994.

Planting Date Study. No differences in burr yield were detected between planting dates (1993); cultivars (1993 and 1994); planting burrs vs. seed (1993 and 1994); and the interactions of these factors (Table 6). The mid-September planting date in the 1994 harvested trial had lower burr yields than all earlier planting dates. All other factors did not impact burr yield. These results indicate that buffalograss fields grown for burr production could be established as late as midsummer using either burrs or seed. This would facilitate rapid seed increase of improved varieties of buffalograss.

Table 3. Effect of split applications of nitrogen (N) on burr yield of buffalograss at Bronco, TX in 1993 and 1994.

Total N applied	Number of applictions	Burr weight 1993	Burr weight 1994
—lbs/acre—	—No.—	—lbs/acre—	
0	**0**	**198 de**†	**74 b**†
20	1	264 cde	113 ab
	2	237 cde	126 a
	3	176 e	94 ab
	Avg	**226**	**111**
40	1	244 cde	117 ab
	2	224 cde	105 ab
	3	265 cde	111 ab
	Avg	**244**	**111**
60	1	294 bcd	106 ab
	2	265 cde	102 ab
	3	405 a	115 ab
	Avg	**322**	**108**
80	1	369 ab	116 ab
	2	316 abc	100 ab
	3	384 ab	113 ab
	Avg	**356**	**110**
CV		25.5%	33.7%

† Means not followed by the same letter differ at 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Table 4. Effect of foliar-applied micronutrients and sulfur on burr yield of buffalograss at Bronco, TX in 1993 and 1994.

Nutrients	Application rate	Burr weight 1993	Burr weight 1994
	-- lbs/acre --	------------- lbs/acre -------------	
Manganese/Sulfur	0.41/0.32	121 a†	56 cd†
Iron/Sulfur	0.19/0.10	125 a	113 a
Iron/Sulfur	0.38/0.19	123 a	64 bcd
Manganese/Sulfur	0.21/0.16	112 a	63 bcd
Zinc	0.13	109 a	95 ab
Boron	0.83	109 a	92 abc
Control	0.00	91 a	43 d
Zn	0.24	84 a	117 a
CV		29.5%	43.0%

† Means not followed by the same letter differ at 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Table 5. Burr yield of Comanche buffalograss established the previous year at four seeding rates of burrs or seed at Lubbock, TX in 1993 and 1994.

	Burr yield	
Treatment	1993	1994
	lbs/acre	
Seeding Rate:		
Burrs or Seed yd^2		
626	257 a	481 a[†]
939	249 a	473 a
1253	245 a	454 a
1566	194 a	592 a
Seed Treatment:		
Burrs	283 a	465 a[†]
Seed	187 a	485 a
Interactions:		
Rate x Treatment	ns	ns

[†] Means within a treatment column not followed by the same letter differ at the 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Table 6. Burr yield of buffalograss established the previous year at seven planting dates, two cultivars, and two seed treatments at Lubbock, TX in 1993 and 1994.

	Burr yield	
Treatment	1993	1994
	lbs/acre	
Planting Date:		
Mid-June	214 a	472 a[†]
Late June	288 a	540 a
Mid-July	228 a	552 a
Late July	245 a	489 a
Mid-August	203 a	472 a
Late August	172 a	445 a
Mid-September	185 a	259 b
Cultivar:		
Comanche	230 a[†]	477 a[†]
Texoka	209 a	447 a
Seed Treatment:		
Burr	207 a[†]	443 a[†]
Deburred	231 a	480 a
Coefficient of Variation	32.4%	33.4%

[†] Means within a treatment column not followed by the same letter differ at the 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Table 7. Total and percent burr yield of post frost (PF) harvest of Comanche and Texoka buffalograss at four dates with dual and single harvest regimes at Lubbock, TX in 1994.

Treatment	Total burr yield	Final harvest
	---- lbs/acre -----	-------%-------
Cultivar:		
Comanche	581 a†	48 a†
Texoka	443 b	47 a†
Harvest Dates:		
1 July / PF	447 a†	
	28 a†	
15 July / PF	591 a	33 a
27 July / PF	551 a	31 a
PF	459 a	100 b
Interactions:		
Cultivar × Harvest Date	ns	ns
CV%	29.5%	60.4%

† Means within a treatment column not followed by the same letter differ at the 0.05 level of probability by Fisher's Protected Least Significant Difference Test.

Date of Harvest Study. In the 1994 growing season, Texoka produced slightly lower total burr yields than Comanche (Table 7). The four harvest dates and the cultivar × harvest date were not significantly different. The percentage of seed recovered in the final harvest of the three dual harvest date regimes ranged from 28 to 33% indicating that a large proportion of the burrs of buffalograss was produced in the early summer. The burrs harvested at the three midsummer dates appeared to be physiologically mature, but no attempt was made to determine seed quality of the dual harvest regime. Based on this study, it would appear that buffalograss burrs can be grown under a wide range of harvest regimes.

CONCLUSION

These studies attempted to optimize production of buffalograss burrs on the Texas High Plains. They indicated that soil fertility requirements of buffalograss are highly dependent upon available soil moisture. Under dry conditions, the addition of soil nutrients did not significantly increase burr yield. In conditions where total available moisture was less than 47 in, burr production had a positive response from applications of 60 to 80 lbs of N/acre and 20 to 40 lbs of P_2O_5/acre. These studies did not provide adequate information to provide recommendations in sulfur or micronutrients. The factors of planting burrs vs. seed, planting date, planting rate, and cultivar had a minimal impact on burr yield of buffalograss in the year following establishment. Based on these studies, it appears that buffalograss is adapted to a dual harvest regime. Under this type of harvest management, almost 70% of the total burr yield was obtained in the initial mid-July harvest. In some situations, it might be more profitable to use the fall growth of buffalograss on burr production fields for forage instead of as a second burr crop.

Future research should concentrate on better defining the interaction of soil moisture and soil nutrition on burr yield of buffalograss. It would also be important to better define the impact of different harvest regimes on germination and emergence of the harvested burrs and the seed they contain.

REFERENCES

Ahring, R.M., and G.W. Todd. 1977. The burr enclosure of the caryopses of buffalograss as a factor affecting germination. Agron. J. 69:15-17.

Davis, W.H., C.A. Robinson, and D. Robinson. 1978. Announcing 'Comanche' hybrid buffalograss (*Buchloe dactyloides*). Robinson Seed Company. Plainview, TX 79072. 1 p.

Gaitan-Gaitan, F., D. L. Auld, and C. B. McKenney. 1998. Effect of burrs vs. caryopses and planting date on establishment of seeded buffalograss in the Southern Great Plains. Crop Science 38:353-357.

Gaitan-Gaitan, F., C. B. McKenney, and D. L. Auld. 1999. Planting rate and caryopses effect on establishment of buffalograss on the Southern Great Plains. J. Turfgrass Management 3:1-11.

Hauser, V.L. 1986. Emergence of several grasses from pregerminated seed and some soil water effects. Agron. J. 78:206-210.

Hitchcock, A.S. 1936. The genera of grasses of the United States. USDA Bull. 772. Beltsville, MD.

Launchbaugh, J.L., and C.E. Owensby. 1970. Seeding rate and first year stand relationships for six native grasses. J. Range Manage. 23:414-417.

Leuthold, L.D. 1982. Buffalograss lawns. Horticulture Facts. Kansas State Univ. Cooperative Extension Service. Manhattan, KS. 4 p.

Riordan, T. 1991. Buffalograss. Grounds Maint. 26(2):12-14.

SAS Institute, Inc. 1989. SAS/STAS User's Guide, Version 6, Fourth Ed. SAS Institute, Inc. Cary, NC.

Savage, D.A. 1934. Methods of re-establishing buffalograss on cultivated land in the Great Plains. U.S. Dept. Agric. Circ. 328. Beltsville, MD. 20 p.

Svoboda, J.F. 1991. Seedling germination and establishment of buffalograss caryopses vs. burrs. M.S. Thesis. University of Nebraska. Lincoln, NE. 96 p.

Voigt, P.W., W.R. Kneebone, J.R. Harlan, and R.H. Ahring. 1975. Registration of Texoka buffalograss. Crop Sci. 15:885.

Wenger, L.E. 1941. Soaking buffalograss (*Buchloe dactyloides*) seed to improve its germination. J. Amer. Soc. Agron. 33:135-141.

Wu, L., D.R. Huff, and M.A. Harivandi. 1989. Buffalograss as a low maintenance turf. California Agric. 43(2):23-25.

Economic Impacts of Plant Biotechnology in the Northern Plains Region of Texas

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ABSTRACT

The impacts of expected advances in crop biotechnology in the Northern Plains Region of Texas are estimated by optimizing the risk/return trade-off for representative farms. Historical yield distributions are used to derive baseline optimal solutions for the representative farms. Expected advances in crop biotechnology are incorporated into the representative farm models using yield distributions from a panel of biological experts. The results indicate that such advances could significantly increase producers' revenues and generally decrease the associated risks.

KEYWORDS: biotechnology, risk premium

Biotechnology, in its most general form, encompasses a wide range of techniques that use biological knowledge to modify living organisms. These techniques range from simple and well documented to complex and state-of-the-art. The more sophisticated techniques identified with genetic engineering have become a novelty of interest to the American public. Media reports routinely use the word *biotechnology* in reference to genetic engineering, so modern use of the term in the United States is generally associated with the newer technologies closely related to genetic engineering and recombinant DNA. As a result, the current interest in the possible impacts of biotechnology on production agriculture results from the discovery of new ways to manipulate and transfer genes from one organism to another. Modification of the genetic scheme of plants has been the focus of a long and growing list of crop production research strategies. Biotechnological approaches can lead to transgenic plants that can optimize the exploitation of specific environments.

As world economies and international trade become increasingly market-driven, the question of *'Which biotechnologies should be developed with limited resources?'* becomes increasingly determined by market forces. Based upon market needs, genetically modified products are developed and used by producers. Because of development costs, new products are not likely to be brought to the market before the status of consumer and producer acceptance has been, at least, partially established. Consumer acceptance hinges on perceived social and economic costs and benefits to society. Producer support of new technologies generally depends on consumer acceptance and the economic feasibility of production (Caswell, Fuglie, and Klotz, 1994).

The flexibility of genetic approaches permits researchers to address many problems in agricultural crop production. Biotechnology can directly affect producers by influencing

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yields, quality characteristics, or production costs. Each of these effects can be influenced by either changing their expected levels or by reducing the uncertainty associated with realizing the expected level. A firm engaged in agricultural production is governed by general economic principles common to all types of firms and industries. Because the definition of profit is the difference between revenue and costs, maximization of profit entails the joint optimization of revenue and costs. Producers must simultaneously decide the optimal level of revenue to maximize profit while minimizing the associated costs required to generate that level of revenue. Given that uncertainty cannot be eliminated from the producer's decisions, the objective of the producer becomes maximization of the *expected* level of profit. Such an objective is achieved through optimization of the expected level of yields that optimizes the expected level of revenue. Because of the simultaneous decisions on revenue and costs required to attain maximum profit, uncertainty about the revenue received for the crop affects the expected level of profit through uncertainty of revenues and costs. Thus, the producer's objective becomes the maximization of expected utility of profit through optimization of expected yields and revenue, given the uncertainly associated with production of the crop.

Costs of crop production are jointly determined with expected revenue. As a result, the producer wishing to achieve the maximum profit minimizes costs of production with respect to the expected level of revenue. Therefore, a producer has control of three factors to bring profit closer to its maximum: increase the expected level of yields, reduce the risk involved, or lower production costs. Because the objective is obtaining maximum utility of profit, a producer is faced with the problem of always striving to improve at least one of these three factors.

The Northern Plains Region of Texas (NPRT) is an important area for crop production in the United States. Much of the NPRT, the segment in which most regional crop production takes place, lies in a zone classified as semiarid. To assess the feasibility of continued research on plant stress reduction through genetic engineering in the NPRT, a need exists to evaluate the economic impacts of genetically engineered crop varieties on the profitability of agricultural operations in the region. The objective of this study is to estimate and analyze the impacts on farm profitability and enterprise selection of expected biotechnological advances in crops grown in the NPRT.

LITERATURE REVIEW

Limited research exists on the potential physical impacts of genetically engineered plants. However, literature addressing such ideas is becoming increasingly available. The lack of research into the physical impacts of biotechnology probably results from the modest number of innovations sufficiently developed to support quantitative impact studies. Genetically engineered variations, such as Bt cotton and greenbug tolerant wheat could increase agricultural productivity. Some biotechnologies have been developed and are in current use, either commercially or in wide scale testing. Rummel et al. (1994) evaluated genetically engineered cotton plants coded with the Bt gene for resistance to bollworms in the Texas Southern High Plains, an area included in the NPRT. Plants with the Bt gene sustained less bollworm injury to squares and green bolls than two highly adapted commercial cultivars. The economic feasibility of such Bt technology in cotton grown on the Texas Southern High Plains will determine the degree of adoption by producers. Some knowledge of the economic impacts to the area is necessary to help to determine whether to allocate a sizeable investment to further development of the technology.

Tauer and Love (1989) measured the potential economic impact of using herbicide-resistant corn varieties in the United States. The study examined the impacts on production, acreages, costs, prices, and producer and consumer surplus. Overall, they found that the expected yield increases would be small and likely to lead to small changes in regional acreages and income. The results of this study suggest that the gains from herbicide resistance in corn will probably result from technologies that are cost reducing rather than yield enhancing. This conclusion emphasizes the distinction between the two types of technologies. Because the immediate impacts expected in corn from herbicide tolerance are significant, the short to medium term aggregate impacts of biotechnology in corn could be expected to be mostly cost reducing instead of yield enhancing. Therefore, an estimation of the impacts of short to medium term yield enhancing biotechnologies in corn, such as those in this study, could be considered as a minor part of the total impact.

Halbrendt and Blase (1989) used a multi-equation model to estimate the impact of biological nitrogen fixation technology on U.S. nitrogen fertilizer demand and planted corn acreage. They considered three levels of reduced fertilizer application due to biological nitrogen fixation technology. They concluded that a decrease in nitrogen fertilizer demand and a reduction in corn acreage planted would be the result of lower production costs. Like the work of Tauer and Love (1989), this study suggests that gains from biotechnology in corn will take the form of cost-reducing technologies and not yield-enhancing technologies. Biological nitrogen fixation in corn is concluded to lower levels of nitrogen fertilizer application, thereby lowering production costs. Combining the near-term expectations for biological nitrogen fixation in corn with herbicide tolerance, short-term expectations for biotechnology in corn could lean even further toward cost reducing technologies.

Tauer (1989) estimated the economic impact of future biological nitrogen fixation technologies using AGSIM, an econometric simulation model of United States agriculture. He modeled five scenarios that represented five possible states after biotechnological innovation. He concluded that biological nitrogen fixation technologies could have a high value to society. Tauer estimated the benefits that might be attributed to biological nitrogen fixation technology if nitrogen fertilizer application were eliminated on the major crops in the United States to be almost $4.5 billion. Tauer indicated that crop plant biotechnology is likely to have substantial economic impacts to producers and to the larger society.

Chiou, Chen, and Capps (1993) developed a structural qualitative choice model to estimate the impact of genetic improvements in cotton fiber quality resulting from inserting Bt-toxin genes into cotton plants. They developed two simulation scenarios using projections of staple length and strength improvements to estimate potential economic gains. They found that enhancements in fiber characteristics could change cotton prices. Thus, these improvements could affect the profitability of cotton production. Price changes resulting from quality improvements would have an effect on the revenue received by cotton producers.

Significant influences in agricultural production decisions are: (1) the level of risk inherent in the enterprise, and (2) the attitude of the decision maker toward the inherent risks. The risk attitudes, or risk preference, of a decision maker are difficult to quantify. Protracted debate continues about the appropriate technique for quantifying individual risk preferences. Smith and Mandac (1995) focused on the use of fertilizer in rice production to find whether empirical objective distributions can be taken as reasonable approximations of farmers' risk perceptions. They concluded that properly estimated objective distributions could be used to approximate upper limits of the effects of producer risk aversion on farmers' allocative decisions.

The issue of technology adoption, if, when, and why a firm decides to exploit a new technology, involves the analysis and evaluation of factors affecting the decision to adopt a new technology such as the usefulness and cost of the innovation and the risk associated with the innovation. Szmedra, Wetzstein, and McClendon (1990) developed a dynamic theoretical framework to estimate the degree of technology adoption, full or partial. They found that varying adoption rates among producers may be explained by differing levels of existing technology and the producer's level of risk preference.

Anderson and Hazell (1994) confirm that the empirical evidence on the importance of risk in adoption decisions is not conclusive. They point to studies by Roumasset (1976) and Walker (1981) to refute risk's role in technology adoption decisions. Likewise, they refer to Moscardi and de Janvry (1977), O'Mara (1983), Gerhart (1975), Anderson and Hamal (1983), Binswanger et al. (1982), and Krause et al. (1990) to support the role of risk in technology adoption. They conclude that the contrasting results may be due to the sophistication of the relationship between crop yield risks and the variability of farm income.

METHODS, PROCEDURES, AND MODEL FORMULATION

Upland cotton, grain sorghum, winter wheat, and corn are the primary field crops produced in the NPRT, a 55-county area in Northwest Texas. Most of the production of these four crops in Texas takes place in the NPRT. Cotton production for 1996 in the NPRT was 3.3 million bales, making up 18% of total national cotton production. Regional production of grain sorghum was 52 million bushels, representing 11% of grain sorghum production in the United States. Of the 1.5 billion bushels of all wheat produced in the nation, the NPRT produced 41 million bushels. NPRT production of corn in 1996 was 156 million bushels, representing approximately 2% of corn production in the United States (USDA, various).

Representative farms were used to evaluate the effects of yield-altering biotechnologies on profitability and enterprise selection of farm entities. These farms were used to determine optimal levels of production and net returns for whole farms composed of risky crop enterprises before and after expected biotechnological shifts in the crop production functions. The NPRT was disaggregated into four subregions. The subregions are the Northern High Plains, the Transition, the Southern High Plains, and the Northern Low Plains subregions. Four representative farms, one for each subregion, were developed (Figure 1).

Two sets of quadratic programming models were developed for each representative farm. The two sets of models differ in two ways. First, the models in one set contained constraints on the number of acres planted to each crop enterprise. These acreage constraints were designed to emulate the effects of federal agricultural programs that govern crop plantings. No such constraints were included in the models of the alternate set. This dissimilarity allowed analysis of the impacts of historical commodity price supports versus the current trend toward elimination of agricultural subsidies. Second, the models in one set used historical crop yields for analysis of profitability and enterprise selection. Expected crop yields, due to biotechnological advances, were used in the alternate set of models. A detailed discussion of the two sets of models follows.

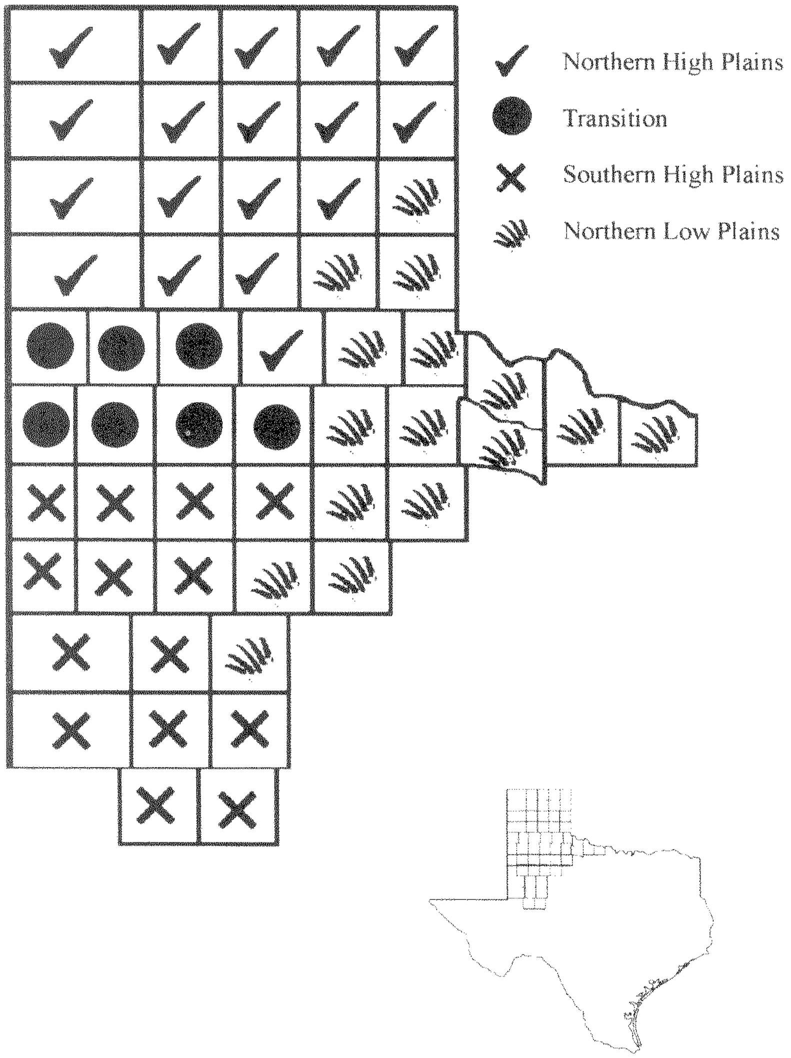

Figure 1. Subregions of the Northern Plains Region of Texas.

One set of models, called the baseline set (BASELINE), was developed to simulate current typical crop production decisions of producers in the representative subregion. Crop enterprise acreages were held constant and historical crop yields were used in the BASELINE set. A second set of models, the biotechnology set (BIOTECH), was developed to account for the expected changes in crop yields brought about by biotechnology. Assumed in the BIOTECH set is that crop enterprise acreages are not fixed, but producers are allowed to select enterprise acreages, and the expected crop yields and the variation from expected crop yields are altered because of biotechnological advances.

Asymmetric quadratic programming was used to allow for stochasticity of net revenues, resulting from crop yield and output price variability, to be maximized subject to production constraints. Parameters, applicable to the representative farms before the introduction of biotechnology-enhanced crops, were used in the BASELINE set. The BASELINE set was designed to model the current regulatory and production conditions facing producers. Parameters applicable to the representative farms after the introduction of biotechnology-enhanced crops were used in the BIOTECH set. New expected crop yield distributions resulting from biotechnological advances were used in the BIOTECH set. Clearly, the selection of the crop yield distributions for each set is important. The crop yield distributions used in the BASELINE set represent actual crop yield series, while the expected crop yield distributions used in the BIOTECH set were elicited from an expert panel. Because of the stochasticity of the crop yields and therefore crop net returns, in both representative farm model sets, a measure estimating the level of producer risk aversion was necessary.

The information required to develop the representative farm models consisted of farm size, available crop enterprises, federal farm program details, crop yield statistics, cattle grazing fees, costs of production, and producer risk preferences. Sizes in acres and available crop enterprises of representative farms were determined using data from the 1992 Census of Agriculture

Federal farm program provisions were integrated into the representative farm models to capture the effects of farm subsidies. The models included federal price supports as they existed up through the 1995 crop season. Federal program payments are incorporated into the representative models by increasing or having no effect on total revenue, depending upon whether the target price is above the national market price. The models allow for program payments to accrue to representative producers when the market price of a commodity falls below the mandated target price. The target prices used for cotton, sorghum, wheat, and corn were \$0.73/lb., \$2.61/bu., \$4.00/bu., and \$2.75/bu., respectively. The national market price for each commodity used in the representative models was the five-year arithmetic mean of the actual national market price for the 1989-1993 period. The program yields maintained on each representative farm were determined by soliciting a subjective judgement of the county average from Farm Service Administration employees in a sampling of the counties in each subregion.

As born out in the Federal Agricultural Improvement and Reform Act (FAIR) of 1996, however, the contemporary political climate is amenable to reducing agricultural subsidies. Because of the structure of declining program payments called for in the FAIR Act, the uncertainty regarding the federal agricultural program after the cessation of the FAIR Act in 2002, and the effect of the FAIR Act on commodity prices, the 1990 program provisions were judged sufficiently appropriate for the representative models. Therefore, a simplified rendering of the structure of farm price supports from the Food, Agriculture, Conservation, and Trade Act of 1990 was used in the representative farm models.

Wheat production in each of the representative subregions is generally a multiproduct enterprise generating grain and cattle grazing. Therefore, revenue from cattle grazing is included in the representative farm models. Wheat was assumed to be grazed for 4.5 months by cattle initially weighing 450 pounds at a fee of \$3.50/cwt/month. Stocking rates were assumed to be one acre of wheat pasture per calf for irrigated wheat and 3.5 acres of wheat pasture per calf for dryland wheat. Gross revenue from grazing totaled \$60.75/acre for irrigated wheat and \$17.36/acre for dryland wheat. The calculation for wheat grazing revenue is typical of such contractual arrangements in the region.

Production costs were subtracted from gross revenues to derive crop net returns per acre for the representative farms. Production costs, variable and fixed costs, were taken from Texas Crop Enterprise Budgets (Texas Agricultural Extension Service, 1995). Budget entries from the Panhandle, the South Plains, and the Rolling Plains districts were combined to match as closely as possible the production costs of the representative subregions.

Because of the focus of this study being the application of biotechnology as output enhancing, the crop yield distributions exemplified in the models are the fundamental elements that drive the analysis. Because the study emphasizes the analysis of *future* impacts from crop plant biotechnology, the crop yield distributions used in the BIOTECH set take the designation of *expected* crop yield distributions.

The modeling of the representative farms was designed to analyze enterprise selection on the representative farms given the two combinations of regulatory and production conditions described in the two model sets. That is, part of the modeling solution should provide optimal crop enterprise acreages for each crop enterprise available to a representative farm. Therefore, solution of the models requires information on expected crop yields, expected variation from expected levels of crop yields, and expected relationships between yields of each crop.

Determination of the crop yield distributions of the Baseline set for each representative subregion was made by considering the historical crop yield series of each county in a representative subregion. A geographically weighted average in which the average across counties gave equal weight to each county in the representative subregion, was selected. The advantage of this method is that the average crop yields for all the crops in the model apply to each county in the representative subregion.

The crop yield distributions used in the BASELINE set are founded upon an historical period of twenty-two growing seasons from 1972 through 1993. The historical crop yield series were taken from USDA Crop County Statistics. The crop yield levels used in the BASELINE set were the continuations of the crop yield trends present in the historical data. The trends in the historical crop yield data were found using ordinary least squares regression. Two regression functional forms were investigated for each crop in each representative subregion. The crop yield series were examined for confirmation of a linear trend and a quadratic trend. The regression equation providing the best fitting trend for each crop yield series was selected and used to form an expected crop yield level.

The variations from expected levels of crop yields and relationships between yields of each crop were needed for the BASELINE set. Calculation of such variations and relationships within and among crop yield series required that technological trends be removed from the crop yield series. A method for detrending each crop yield series was used and is later discussed in detail. For each crop yield series, the variation from the expected level was calculated as the expected variance of the detrended crop yield series. Likewise, for each crop yield series, the relationship between the yields of each crop were calculated as the expected covariance of the detrended crop yield series with each of the other detrended crop yield series present on the representative farm. The variance and covariance of the crop yield series were descriptive of the detrended crop yield series because the accuracy of such descriptive statistics taken on the actual crop yield series would suffer from the technological trends in the series.

The detrended crop yield series were calculated in a two-step approach. First, the regression deviations were calculated for each crop yield series as the difference between the actual crop yield observation and the regression or predicted crop yield observation. Second, the deviations were added to the expected crop yield levels to generate detrended crop yield series with an expected value equal to the expected crop yield level. The variance and covariances were then taken from the detrended crop yield series.

The BIOTECH set used crop yield distributions altered to reveal the impacts of output enhancing biotechnology. Solution of the models of the BIOTECH set required information on expected crop yields, expected variation from expected levels of crop yields, and expected relationships between yields of each crop, similar to the BASELINE set. However, the expected crop yields and expected variation were elicited from an expert panel. Once obtained, the expected crop yield levels and the variance of crop yield levels were incorporated into the models of the BIOTECH set. The covariances between crop yields of crops in the representative subregion are assumed to remain unchanged from the BASELINE set.

As mentioned above, the expected crop yields and expected variation were elicited from an expert panel. The expert panel was made up of 13 scientists from biological and agricultural fields who are directly involved in some aspect of crop plant biotechnology research. The purpose of the panel within the context of the broader research project was discussed with each panel member. Through these discussions, a time horizon of 20 years was established for the BIOTECH modeling sets. That is, the expectations obtained from the panel members are for a twenty-year horizon. The panel interview was conducted in 1996, therefore, based upon the twenty-year time horizon, expectations produced from the panel are for the year 2016.

Overall, panel members were not comfortable separating the crop yield impacts directly resulting from biotechnology from the total crop yield impacts expected to take place within the twenty year horizon. Therefore, panel members were asked to return their expectations about total crop yields. Most of the difference between current crop yields and future crop yields was agreed by panel members to result from biotechnology

The Triangular Distribution Procedure (Young, 1983) was used to subjectively elicit expectations of crop yield distributions. Each panel member was asked to specify the *most likely*, *maximum*, and *minimum* expected crop yields for each crop in each representative subregion. Once the three estimates were obtained, mean crop yields and the variance of crop yields for each panel member were calculated. Once elicited and transformed into expected crop yields and variances, the individual expectations of the panel members were aggregated to provide a single expectation of crop yields and variance of crop yields for each crop in each representative subregion (Middleton, 1996). The mean and standard deviation of current and future expected crop yields are found in Table 1.

Because of the stochasticity of the crop yields in the representative farm models, a measure estimating the level of producer risk aversion was necessary in the modeling. The modeling technique used a standardized risk measurement to introduce producer risk preferences into the models. The risk aversion coefficient, denoted by λ or RAC, is equal to the Arrow-Pratt absolute risk aversion coefficient divided by two. The RAC is used in the modeling to express producer risk preferences. A wide array of risk aversion levels was tested for each representative farm to establish a range in which the RAC of subregional crop producers would be expected to lie. The bounds of the range of coefficients were determined by an iterative process of refining the bounds and running the BASELINE model set until the appropriate bounds were identified.

The set of production constraints and opportunities faced by producers in each subregion can be broadly defined and, hence, differ among subregions. Therefore, because producers' attitudes have adapted to the local conditions that help determine the profitability of available enterprises, the bounds on the range of producer risk aversion are different for each representative subregion. The range of producer risk aversion was equally divided to produce nine risk aversion coefficients (RAC), the set of which remains unchanged for each representative subregion. For each subregional model set, nine models were developed, varying only the level of risk aversion. Therefore, for the representative farm

Table 1. Current expected crop yields compared with future (twenty-year) expected crop yields elicited from expert panel.

Northern High Plains		Northern High Plains		Transition		Southern High Plains		Northern Low Plains	
		Current	Future	Current	Future	Current	Future	Current	Future
		expected yield in units per acre							
Irrigated Cotton	**M**EAN	—	—	593.77	662.36	694.36	742.35	558.95	633.40
(lb/ac)	**S**TD	—	—	108.81	71.59	81.17	74.40	93.44	66.98
Dryland Cotton	**M**EAN	—	—	342.29	371.89	330.18	365.33	343.71	376.24
(lb/ac)	**S**TD	—	—	85.44	46.75	88.95	44.11	69.66	38.49
Irrigated Sorghum	**M**EAN	101.65	109.76	94.76	104.77	69.82	77.69	—	—
(bu/ac)	**S**TD	7.00	12.47	7.67	11.20	7.61	7.18	— N—	
Dryland Sorghum	**M**EAN	49.83	54.53	49.31	54.55	36.02	42.41	40.41	46.28
(bu/ac)	**S**TD	7.07	6.56	9.43	7.12	7.40	5.81	4.68	5.67
Irrigated Wheat	**M**EAN	48.66	54.98	49.35	55.96	—	—	—	—
(bu/ac)	**S**TD	9.79	7.41	10.29	7.66	—	—	—	—
Dryland Wheat	**M**EAN	23.77	27.16	22.84	26.42	20.72	23.51	23.59	25.72
(bu/ac)	**S**TD	6.05	4.38	5.71	4.26	4.88	3.52	5.09	3.58
Corn	**M**EAN	164.50	177.96	160.72	176.56	—	—	—	—
(bu/ac)	**S**TD	13.76	15.30	10.54	14.78	—	—	—	—

in each subregion, two sets of models (BASELINE and BIOTECH), both consisting of nine models with differing RACs, were solved

The asymmetric quadratic programming models were of the general form:

$$\text{(1)} \qquad Max\ Z = C'X - \lambda X'\Sigma X$$

$$\text{(2)} \qquad subject\ to:\ AX \leq b,$$

$$\text{(3)} \qquad X \geq 0.$$

Where Z represents expected net returns discounted for the producer's risk premium, C is the vector of net return coefficients, λ is the risk aversion coefficient, Σ is the variance-covariance matrix of net returns associated with the various enterprises, X is the vector of enterprises, A is the matrix of technical coefficients of the constraints, and b is the vector of constraint values. The first term on the right-hand side of the objective function, $C'X$, represents the product of the vector of net return coefficients and the vector of decision variables (i.e., levels of enterprise acreages). This product is the expected net return for the representative farm. The second term on the right-hand side of the objective function, $\lambda X'\Sigma X$, is equal to the risk premium. The risk premium can be separated into the risk aversion coefficient, λ, and the variance of net returns, $X'\Sigma X$. To simplify the discussion of the model solutions, Z is defined as the expected net returns discounted for the producer's risk preference (ENRD), $C'X$ is referred to as the expected net return (ENR), $X'\Sigma X$ is defined as the variance of net returns (VNR), λ is referred to as the risk aversion coefficient (RAC), and $\lambda X'\Sigma X$ is the risk premium (RP).

RESULTS

The representative farm models were formulated to maximize total ENRD from crop production given production constraints on available irrigation water, labor, land and capital investment, financial parameters, economic relationships, and institutional regulations. The decision variables were the acreages of cropland allocated to production of each crop enterprise. For each of the four representative subregions (Northern High Plains, Transition, Southern High Plains, and Northern Low Plains), two set of models (BASELINE and BIOTECH) were estimated. The results are presented in Tables 2 to 5.

As expected in all of the BASELINE sets, because the crop enterprise acreages are fixed on the representative farm, the producer's level of risk aversion makes no difference in the enterprise selection. Therefore, within a model set for each of the nine models having different RACs, the ENR is identical. However, the ENRDs and the risk premiums vary according to the level of risk aversion

For each subregion, the BASELINE set is designed to mimic current producer decisions and is based on current crop yield distributions, federal price subsidies, and acreage regulations. The BIOTECH set is designed to mimic future producer decisions based on the expected crop yield distributions and the expected regulatory atmosphere of no agricultural producer subsidies or acreage regulations. Therefore, a comparison of the results from the two sets of models provides insight into the impacts of biotechnology on producer decisions and net returns (Tables 2 to 5). A detailed discussion of the results for each subregion is available from the authors, therefore in the interest of brevity only a discussion of the overall results is presented here

Changes in enterprise selection on the representative farms from the BASELINE set to the BIOTECH set provide an idea of possible acreage shifts into and out of each

Table 2. Optimal solutions and associated enterprise levels for the Northern High Plains subregion representative models.

	RAC								
	0.00e+00	1.38e−05	2.75e−05	4.13e−05	5.50e−05	6.88e−05	8.25e−05	9.63e−05	1.10e−04
ENR					dollars				
BASELINE	24,277	24,277	24,277	24,277	24,277	24,277	24,277	24,277	24,277
BIOTECH	60,367	60,367	60,367	55,039	51,891	50,003	48,744	47,844	47,140
RP									
BASELINE	0	1,817	3,634	5,451	7,268	9,084	10,901	12,718	14,317
BIOTECH	0	5,062	10,123	8,729	7,976	7,834	8,016	8,377	8,851
Total Cropland					acres				
BASELINE	739	739	739	739	739	739	739	739	739
BIOTECH	739	739	739	739	739	739	739	739	739
Irrigated Sorghum									
BASELINE	103	103	103	103	103	103	103	103	103
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	101	101	101	101	101	101	101	101	101
BIOTECH	239	239	239	373	453	500	532	555	572
Irrigated Wheat									
BASELINE	171	171	171	171	171	171	171	171	171
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	244	244	244	244	244	244	244	244	244
BIOTECH	0	0	0	0	0	0	0	0	0
Corn									
BASELINE	120	120	120	120	120	120	120	120	120
BIOTECH	500	500	500	366	286	239	207	184	167

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 3. Optimal solutions and associated enterprise levels for the Transition subregion representative models.

	RAC								
	0.00e+00	1.00e−05	2.00e−05	3.00e−05	4.00e−05	5.00e−05	6.00e−05	7.00e−05	8.00e−05
ENR					dollars				
BASELINE	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636	37,636
BIOTECH	80,666	80,457	80,453	80,452	78,912	73,510	69,909	67,336	65,407
RP									
BASELINE	0	4,676	9,352	14,028	18,704	23,380	28,056	32,732	37,408
BIOTECH	0	4,805	9,604	14,404	17,621	15,949	15,178	14,920	14,985
Total Cropland					acres				
BASELINE	858	858	858	858	858	858	858	858	858
BIOTECH	858	858	858	858	858	858	858	858	858
Irrigated Cotton									
BASELINE	264	264	264	264	264	264	264	264	264
BIOTECH	0	251	256	257	249	218	198	183	172
Dryland Cotton									
BASELINE	60	60	60	60	60	60	60	60	60
BIOTECH	0	0	0	0	0	0	0	0	0
Irrigated Sorghum									
BASELINE	91	91	91	91	91	91	91	91	91
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	65	65	65	65	65	65	65	65	65
BIOTECH	158	158	158	158	191	308	385	441	482
Irrigated Wheat									
BASELINE	77	77	77	77	77	77	77	77	77
BIOTECH	0	0	0	0	0	0	0	0	0

Table 3. *(Continued)*

Dryland Wheat									
BASELINE	91	91	91	91	91	91	91	91	91
BIOTECH	0	0	0	0	0	0	0	0	0
Corn									
BASELINE	210	210	210	210	210	210	210	210	210
BIOTECH	700	449	444	443	418	332	275	234	204

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 4. Optimal solutions and associated enterprise levels for the Southern High Plains subregion representative models.

	RAC								
	0.00e+00	1.88e−06	3.75e−06	5.63e−06	7.50e−06	9.38e−06	1.13e−05	1.31e−05	1.50e−05
ENR					dollars				
BASELINE	40,831	40,831	40,831	40,831	40,831	40,831	40,831	40,831	40,831
BIOTECH	79,972	79,972	79,972	79,972	79,972	79,972	79,972	79,972	79,972
RP									
BASELINE	0	2,217	4,433	6,650	8,867	11,084	13,300	15,517	17,734
BIOTECH	0	1,952	3,904	5,857	7,809	9,761	11,713	13,665	15,618
Total Cropland					acres				
BASELINE	921	921	921	921	921	921	921	921	921
BIOTECH	921	921	921	921	921	921	921	921	921
Irrigated Cotton									
BASELINE	318	318	318	318	318	318	318	318	318
BIOTECH	400	400	400	400	400	400	400	400	400
Dryland Cotton									
BASELINE	419	419	419	419	419	419	419	419	419
BIOTECH	521	521	521	521	521	521	521	521	521
Irrigated Sorghum									
BASELINE	50	50	50	50	50	50	50	50	50
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Sorghum									
BASELINE	112	112	112	112	112	112	112	112	112
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	22	22	22	22	22	22	22	22	22
BIOTECH	0	0	0	0	0	0	0	0	0

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

Table 5. Optimal solutions and associated enterprise levels for the Northern Low Plains subregion representative models.

	RAC								
	0.00e+00	1.63e−05	3.25e−05	4.88e−05	6.50e−05	8.13e−05	9.75e−05	1.14e−05	1.30e−05
					dollars				
ENR									
BASELINE	26,906	26,906	26,906	26,906	26,906	26,906	26,906	26,906	26,906
BIOTECH	65,094	65,094	65,094	65,094	65,094	65,094	65,094	65,094	65,094
RP									
BASELINE	0	3,211	6,422	9,633	12,844	16,055	19,266	22,477	25,688
BIOTECH	0	3,507	7,013	10,520	14,026	17,533	21,039	24,546	28,052
					acres				
Total Cropland									
BASELINE	566	566	566	566	566	566	566	566	566
BIOTECH	566	566	566	566	566	566	566	566	566
Irrigated Cotton									
BASELINE	22	22	22	22	22	22	22	22	22
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Cotton									
BASELINE	258	258	258	258	258	258	258	258	258
BIOTECH	566	566	566	566	566	566	566	566	566
Dryland Sorghum									
BASELINE	20	20	20	20	20	20	20	20	20
BIOTECH	0	0	0	0	0	0	0	0	0
Dryland Wheat									
BASELINE	266	266	266	266	266	266	266	266	266
BIOTECH	0	0	0	0	0	0	0	0	0

RAC = Risk Aversion Coefficient; ENR = Expected Net Return; RP = Risk Premium

subregion because of biotechnology developments. Acres of irrigated cotton continue around 250 acres in the Transition farm, decrease from 22 acres to zero acres in the Northern Low Plains farm, but increase about 25% in the Southern High Plains farm from around 320 acres to 400 acres. Irrigated cotton acreage would continue higher on the Southern High Plains farm if it were not constrained by irrigation water availability. Acres of dryland cotton fall from 60 acres to zero acres in the Transition farm, however, acreage increases about 100 acres and 300 acres in the Southern High Plains and Northern Low Plains farms, respectively.

Irrigated sorghum production goes to zero on all farms, removing irrigated sorghum from production in the entire NPRT. However, dryland sorghum acreage increases about 350 acres in the Northern High Plains farm and 135 acres in the Transition farm. Decreases of about 110 acres in the Southern High Plains farm and about 20 acres in the Northern Low Plains farm result in an aggregate increase of about 120 percent or 355 acres of dryland sorghum in the NPRT. Irrigated wheat production in the Northern High Plains and Transition farms goes from 171 acres and 77 acres, respectively, to zero. Likewise, dryland wheat production declines to zero on all four farms in the NPRT. On the Northern High Plains, the Transition, the Southern High Plains, and the Northern Low Plains farms, 244 acres, 91 acres, 22 acres, and 266 acres, respectively, are lost in dryland wheat production. Corn acreage increases on the Northern High Plains farm from 120 acres to 300 acres and on the Transition farm from 210 acres to 400 acres. In both cases, the less risk averse producer increases corn acreage up to the point of constraining irrigation water.

CONCLUSIONS

This study attempts to bring together both theoretical and empirical methods of economic analysis to address the crop productivity impacts of plant stress and biotechnology, as they affect the decision-making behavior of economic agents. The empirical models developed here are for four representative farms in four distinct representative areas of the NPRT. Changes in the specification of the characteristics of the representative farms would be expected to cause changes with respect to the optimal solutions. However, the models developed here are flexible enough to accommodate additional characteristics and/or constraints that may be found in other regions where biotechnology would be expected to have significant impacts on agricultural production. Also, the models constructed here represent a general depiction of the farming conditions in each subregion of the NPRT, and thus, the results should remain robust across different farms in each particular subregion.

The results show that marked increases in producers' expected net returns and in the expected levels of payoff that account for producers' risk preferences are anticipated to accompany advances in crop biotechnology. Likewise, for the higher levels of risk aversion, developments in crop biotechnology are expected to reduce producers' risk premiums for each subregion except the Northern Low Plains subregion, where risk premiums increase slightly. At lower levels of risk aversion, risk premiums are expected to, at worst, also increase slightly. Therefore, biotechnological advances can be expected to reduce the proportion of expected net returns represented by the risk premiums for each subregion. These results have consequential and timely implications.

Producers, historically relying on federal farm programs for some protection against uncertainty, may face the reduction or elimination of farm program payments. The current political climate surrounding the federal farm support program calls for decreased program payments to producers. Total withdrawal of agricultural subsidization by the federal government may become a reality early in the twenty-first century. Under such conditions, many farmers will be forced to seek alternative risk management strategies. Expected biotechnological progress such as was examined in this study could allow farmers to realize added benefits from risk management. Depending upon the time frame of actual elimination of farm subsidies and the urgency to find a risk management tool to replace the subsidies, realization of such benefits could speed the rate of adoption of biotechnologically enhanced crops.

It is likely that expected net returns will increase because of biotechnology. The increases estimated in this study provide some idea of the expected benefits that can be anticipated. Such an estimate allows the calculation of the maximum *rent* that farmers would be willing to pay for such technology. An estimation of the *rent* could aid companies and institutions in developing investment analyses and so, budgeting of research funding for biotech products.

Based on the results of the representative farm models, expected biotechnology developments will entice producers in the region to change their enterprise selections. Such changes in enterprise selection will precipitate shifts in the typical quantities of crops grown between subregions and even into and out of the region. Keep in mind that these shifts are expected to take place gradually over an extended period of time and therefore, might not be impeded by the rigidities of a shorter time period.

Overall, biotechnology will encourage increased production of dryland sorghum and cotton at the expense of wheat and irrigated sorghum acreages. The representative models typically indicate that acres of irrigated crops will tend to decrease as advances in crop biotechnology are adopted, especially for producers at higher levels of risk aversion. Such a decrease in irrigated acreage may coincide with increased demand for water for uses other than agriculture. As a result of the increased non-agricultural demand, the cost of irrigation water could increase and further decrease its use in the crop production systems. The difference in the relative changes in irrigated versus dryland crop acreages expresses an awareness that dryland crop yields stand to benefit most from biotechnology.

The flexibility of the representative models developed here could be altered to discern the impacts of biotech innovations that differ from those expected by the expert panel members. The impacts of specific shorter-term biotech products could be incorporated into the models to determine the effect on crop production in the region. Or, the consequences of shifting funding priority from research in one crop to another could also be analyzed. Likewise, the flexibility of the models allows not only for analysis of yield changing technologies, but also, for relatively simple introduction of cost changing biotechnologies.

REFERENCES

Anderson, J.R., and K.B. Hamal. 1983. Risk and Rice Technology in Nepal. Indian J. Agric. Econ. 38:217-222.

Anderson, J.R., and P.B.R. Hazell. 1994. Risk Considerations in the Design and Transfer of Agricultural Technology. *In:* J.R. Anderson (ed.). Agricultural Technology: Policy Issues for the International Community. C·A·B International, Univ. Press, Cambridge.

Binswanger, H.P., D. Jha, T. Balaramaiah, and D.A. Sillers. 1982. The Impact of Attitudes Towards Risk on Agricultural Decisions in Rural India. Discussion Paper ARU 4, Agriculture and Rural Development Department, World Bank, Washington, D.C.

Caswell, M.F., K.O. Fuglie, and C.A. Klotz. 1994. Agricultural Biotechnology: An Economic Perspective. USDA, ERS. AER No. 687.

Chiou, G.T., D.T. Chen, and O.Capps, Jr. 1993. A Structural Investigation of Biotechnological Impacts on Cotton Quality and Returns. Am. J. Agric. Econ. 75:467-478.

Gerhart, J. 1975. The Diffusion of Hybrid Maize in West Kenya, CIMMYT, Mexico, D.F.

Halbrendt, C., and M. Blase. 1989. Potential Impact of Biological Nitrogen Fixation: The Case of Corn. N. Cen. J. Agric. Econ. 11:145-156.

Krause, M.A., R.R. Deuseon, T.G. Baker, P.V. Preckel, J. Lowenberg-DeBoer, K.C. Reddy, and K. Maliki. 1990. Risk Sharing Versus Low-cost Credit Systems for International Development. Am. J. Agric. Econ. 72:911-922.

Middleton, M.R. 1996. The Economics of Plant Stress Reduction Through Biotechnology: An Application to the Northern Plains Region of Texas. M.S. Thesis. Texas Tech Univ., Lubbock, TX.

Moscardi, E.R. and A. de Janvry. 1977. Attitudes Toward Risk Among Peasants: An Econometric Approach. Am. J. Agric. Econ. 59:710-716.

O'Mara, G. 1983. p. 235-241. The Microeconomics of Technique Adoption by Smallholding Mexican Farmers. *In:* R.D. Norton and L. Solis M. (eds.) The Book of CHAC: Programming Studies for Mexican Agriculture. Johns Hopkins Univ. Press, Baltimore.

Roumasset, J.A. 1976. Rice and Risk: Decision Making Among Low Income Farmers. North-Holland, Amsterdam.

Rummel, D.R., M.D. Arnold, J.R. Gannaway, D.F. Owen, S.C. Carroll, and W.R. Deaton. 1994. Evaluation of Bt Cottons Resistant to Injury from Bollworm: Implications for Pest Management in the Texas Southern High Plains. Southwestern Ento. 19:199-207.

Smith, J., and A.M. Mandac. 1995. Subjective Versus Objective Yield Distributions as Measures of Production Risk. Am. J. Agric. Econ. 77:152-161.

Szmedra, P.I., M.E. Wetzstein, and R.W. McClendon. 1990. Partial Adoption of Divisible Technologies in Agriculture. J. Agric. Econ. Res. 42:20-26.

Tauer, L.W. 1989. Economic Impact of Future Biological Nitrogen Fixation Technologies on United States Agriculture. Plant and Soil, 119:261-270.

Tauer, L.W., and M.J. Love. 1989. The Potential Economic Impact of Herbicide-Resistant Corn in the USA. J. Prod. Agric. 2:202-207.

Texas Agricultural Extension Service. 1995. Texas Crop Enterprise Budgets, Projected for 1995. Tx. A&M Univ. Sys., College Station, TX.

United States Department of Agriculture. Various Issues. Crops County Statistics. NASS, Washington D.C.

Walker, T.S. 1981. Risk and Adoption of Hybrid Maize in El Salvador. Food Res. Inst. Studies. 18:59-88.

Young, D.L. 1983. A Practical Procedure for Eliciting Subjective Probability Distributions, *In:* Symposium: Introduction to Risk Measures from the Behavioral Sciences. AAEA Annual Meeting, Purdue Univ., W. Lafayette, IN.

Evaluating Temperature Constraints for Municipal Biosolids Application to a Desert Grassland Soil

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ABSTRACT

Arid and semiarid regions of Texas and the United States are becoming locations of choice for year-round application of municipal biosolids (sewage sludge) to minimize application-time lost to cold or wet conditions. We determined carbon losses from surface applied municipal biosolids (1.8 lbs wet biosolids ft^{-2}) to a clay loam soil in sealed, forced-air chambers for 29 days after application. Experimental conditions, three temperatures (41, 73 or 100°F) and two initial soil-water contents (5 or 15 % water), were similar to those experienced at a commercial application site near Sierra Blanca, Texas. All treatments had an initial, nonmicrobial degassing peak. From 4 hours through day 2, carbon loss as measured by CO_2 evolution increased significantly ($P < 0.05$) with temperature. By day 29, 0.41, 0.55 and 0.73 % of carbon was lost for the 41, 73 or 100°F treatments, respectively. Carbon loss from the 41°F temperature treatments and temperature differences in carbon loss were significant only through day 2. We conclude, therefore, that biosolids may be applied throughout the year without restricting temperature or water parameters beyond the current USEPA or Texas Natural Resource Conservation Commission regulations.

KEYWORDS: Municipal biosolids, Desert grassland, Sewage sludge.

Current U.S. Environmental Protection Agency policies and regulations encourage beneficial use of waste substances such as biosolids (municipal sewage sludge) (U.S. Environmental Protection Agency, 1995). These regulations state that biosolids cannot be applied to a "site that is flooded, frozen, or snow-covered. . .or that enters a wetland or waters of the United States" (U.S. Environmental Protection Agency, 1993). This policy favors application of biosolids in warm southwestern U.S. desert areas (Aguilar and Loftin, 1994; White et al., 1997). One such commercial application site is located near Sierra Blanca, Texas. At this location 3 dry tons of biosolids per acre are applied, annually (Mooney 1992).

Concerns have been raised as to temperature effects at time of application on plant utilization and degradation of surface-applied municipal biosolids in the desert. Benton and Wester (1998) reported tobosagrass (*Hilaria mutica*) and alkali sacaton (*Sporobolus*

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airoides) respond more to dormant-season application of biosolids than growing-season application at Sierra Blanca, Texas in the first growing season. Loftin (1995) reports that grassland response to biosolids application is dependent upon water availability. Staley and Konopka (1985) report the rate of microbial decomposition depends on the physical, chemical and biological characteristics of the habitat. Sommers et al. (1981) list these factors to be temperature, O_2 supply, water potential, pH, inorganic nutrients and C:N ratio of the material along with management factors.

Although it may be assumed that decomposition requires microorganisms, the rate of decomposition may not be directly related to increasing microbial populations. Macalady et al. (1998) stated that CO_2 evolution rate is not necessarily influenced by microbial growth. Microbial habitats are unlikely to be in a steady state (Staley and Konopka 1985). Instead, habitats occur as a series of transient states due to the fluctuations in the chemical and physical environment.

Climate preeminently influences biotic and abiotic decomposition of organic matter in the Chihuahuan Desert (Moorhead and Reynolds, 1991). Moorhead and Reynolds (1989) stated that abiotic factors account for 50-75% of the total annual degradation of creosotebush (*Larrea tridentata*) surface litter in the northern Chihuahuan Desert. Miller and Pepper (1988) suggested that high pH levels, high temperature and low moisture would be advantageous to soil microbes under desert conditions. In addition, a fast growth rate to take advantage of ephemeral conditions would favor microbial growth in these environments. Other microbial advantages to cope with limited nutrient supplies would be the ability to utilize a wide range of nutrients for carbon, energy, and nitrogen sources.

Anderson and Domsch (1975) reported that litter decomposition for mixed microbial populations with complex substrates can be determined quantitatively by measurement of total respiration. Huffman et al. (1996) reported CO_2 evolution peaks at day 5 with wheat (*Triticum aestivum*) residue that was high in cellulose. The initial peak observed by Huffman et al. (1996) would be expected to occur more quickly with biosolids, because cellulose is more resistant to decomposition than many of the components of biosolids. Similar CO_2 evolution peaks have been shown in other studies for ryegrass (Jenkinson, 1966) and soils (Heilmann and Beese, 1992) over a shorter time scale. Therefore, the exact timing of this initial CO_2 evolution peak was likely to depend on soil type and environmental conditions prevalent at the time of the study.

Current interests in beneficial applications in the Texas and southwestern U.S. deserts suggest a need for specific information regarding the influence of temperature and soil-water content on the fate of surface-applied biosolids. The objective of this project was to evaluate the influences of temperature and initial soil water on the loss of carbon from surface applied biosolids to a desert grassland soil. Specific objectives were to (1) quantify the CO_2 evolution from surface-applied biosolids as a function of temperature and soil water, and (2) determine the influence of temperature and soil water on microbial population numbers in biosolids and soil.

MATERIALS AND METHODS

Soil used in this study was from a commercial application site in a Chihuahuan Desert grassland near Sierra Blanca, Texas that received New York, New York domestic biosolids. Temperature chambers contained two soil and one control chamber, which were 10 inch long × 6 inch wide × 7 inch high. A 6.6-lb soil sample from the top 2 inches of a calcareous clay loam (fine, mixed, thermic superactive Vertic Paleargids) was placed into each soil chamber. On the "inlet" side of each temperature chamber, ambient air was pumped by diaphragm pumps set to deliver a flow rate of 0.0175 $ft^3\ hr^{-1}$. Bacterial air vents (No. 4210, Gelman Sciences, Ann Arbor, MI) were installed in-line between the pumps and the sample chambers. Individual CO_2 samples could be obtained on the "outlet" side without opening the temperature chamber.

Temperature chambers were operated at 41, 73 and 100°F to simulate winter, spring/fall or summer application temperatures. Copper/constantan thermocouples connected to a data logger (Campbell Scientific CR-5A Digital Recorder, Logan, UT) monitored soil-air interface temperatures. Water content was monitored four times per day using Time Domain Reflectometry (TDR-Trase system, Soil moisture Equipment Co., Santa Barbara, CA). Carbon dioxide samples were evaluated in an infrared CO_2 analyzer (Beckman Model 865, equipped with a Hewlett-Packard 3390A Integrator, Avondale, PA). The analyzer was calibrated with a 515 ppm CO_2 gas standard. Integrated sample values were compared to a calibration curve peak height to obtain CO_2 concentrations from each sample. Chambers were allowed to equilibrate within the temperature chambers for a period of 5 to 7 days. Sufficient water was added to bring gravimetric soil water levels to 5% (~permanent wilting point) and 15% (~field capacity).

After stabilization, nylon mesh fabric (390 × 390 mesh per $inch^2$) was placed over the entire soil surface. Approximately 0.77lbs of the biosolids (~1.8 lbs per ft^2) were applied evenly across the soil surface/mesh fabric of each soil chamber. Biosolids averaged 72% water on a wet basis with 2.08% carbon on a dry basis. CO_2 samples were taken immediately after biosolids application and daily thereafter for a total of 28 days.

Soil and biosolids subsamples were taken for microbial population size determination initially and at day 29. All samples were stored at -4°F until replicate plating could begin. The microbial population enumeration procedure for soils (Wollum, 1982) was extended to biosolids. Wollum (1982) reported shaking times of 10 min. for soils. Post-experimental biosolids subsamples, however, were often dried into hydrophobic "clumps." Pretrial studies indicated a 20-min. shaking time improved the disaggregation of these clumps.

Soil and biosolids were plated using dilutions ranging from 10^{-3} to 10^{-8}. Dilutions were made as needed with no more than five dilutions being necessary for any subsample. Aliquots of 0.06 in^3 were drawn from each dilution and spread onto Triptic Soy Agar plates using a bent glass spreader. Subsample plates were incubated at the temperature at which the sample was treated during the experiment. The temperature chambers used in the experiment were subsequently used as incubators for plating. All plates were incubated for 48 hours and microbial colonies counted using a Quebec counter. The CO_2 evolution and plating experiments were replicated three times. Data were analyzed using Analysis of Variance procedures and significances evaluated at the 5% level using Duncan's new multiple range test.

DISCUSSION OF RESULTS

Soils and biosolids used in this study were collected from a commercial application site. Experimental temperatures and initial soil-water contents were similar to those encountered at that location. The actual temperature chamber design precluded maintaining soil water at a constant level. For both the 73°F-wet and 100°F-wet treatments, soil water decreased throughout the experiment, presumably as a result of evaporation (Fig.

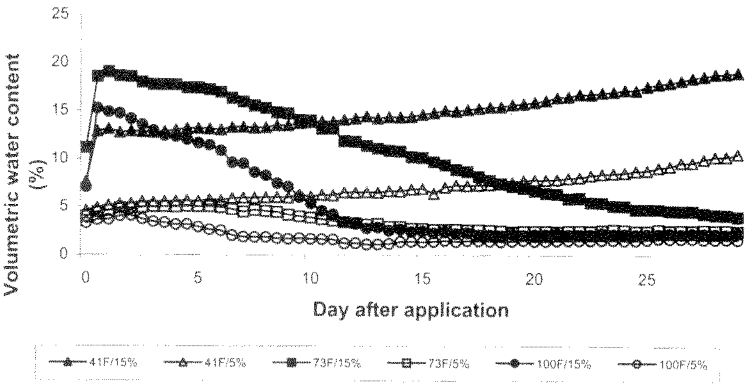

Figure 1. Volumetric soil-water content for each temperature-water content treatment as a function of time.

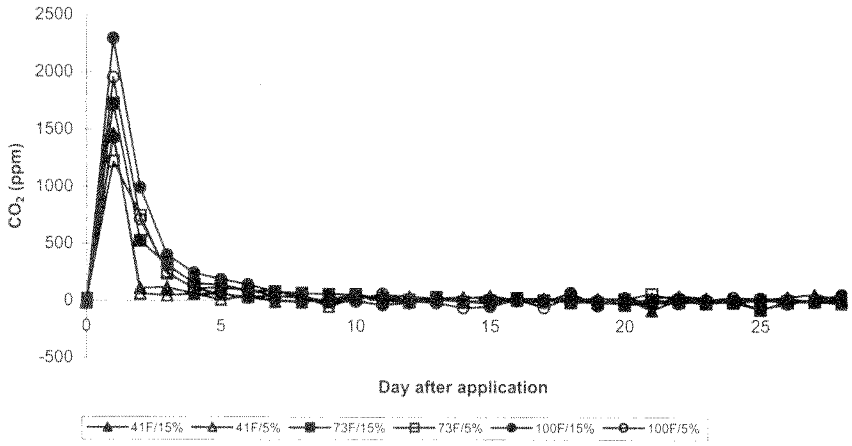

Figure 2. Daily CO_2 evolution for each temperature-water content treatment as a function of time.

1). Soil water increased in both the 41°F-wet soil treatment and the 41°F-dry soil treatment presumably due to condensation within the chambers. The 100°F-dry and 73°F-dry treatment water contents were relatively constant (± 2% water) throughout the experiment. Thus, in the context of the entire 29 day study, initial water contents were not independent variables, but were dependent upon temperature. Cumulative CO_2 evolution from this experiment as a function of initial water content could not be statistically compared across treatments due to changes in soil water.

Daily CO_2 evolution values, however, were compared since soil water was assumed not to change during the daily sampling period of approximately 30 min. Immediately after biosolids application, all treatments showed an increase of CO_2 above preapplication levels (Fig. 2). There were no temperature or water treatment effects at this sampling time. While these first experimental CO_2 samples were taken immediately after application, it was unlikely that biosolids had reached either 41°F or the 100°F. Thus, initial biosolids CO_2 evolution occurred with the biosolids at or near ambient temperature (73°F). Theoretically, initial CO_2 evolution should increase with increasing temperature.

Four hours after application, biosolids temperatures were assumed to be the same as the soil. At this time (Fig. 2), the 100°F treatment had significantly greater CO_2 evolution (2180 ppm CO_2 above background) than either the 73°F or 41°F treatments (1270 and 1500 ppm CO_2 above background, respectively). On day 1, CO_2 evolution values for the 73°F treatment were not significantly different from either the 41°F or 100°F treatments. By day 2, CO_2 evolution values for the 41°F treatment were significantly less than either the 73°F or 100°F treatments. Through day 2, CO_2 evolution differences were significantly ($P < 0.05$) related to temperature alone. From day 2 through the remaining 29 days of the study, there were no significant daily temperature effects on carbon loss. The CO_2 peaks for all temperatures decreased quickly to levels near background (<100 ppm CO_2 above background) by day 5 (Fig. 2). CO_2 evolution data may be inconclusive since only one series of CO_2 samples was taken per day. Increased sampling was impractical due to time and budgetary constraints.

Cumulative CO_2 evolution could not be statistically compared across different water treatments due to changes in soil-water contents. Actual CO_2 evolution amounts, however, indicate a greater loss of CO_2 as the temperature increased. The wet initial soil treatments evolved more CO_2 than the dry initial soil treatments. Quantities of CO_2 evolved for the 41, 73 and 100°F temperatures of the wet treatments were 30.9, 43.4 and 61.4 mg CO_2 lost during the 29 d experiment, respectively. Quantities of CO_2 evolved for the 41, 73 and 100°F temperatures of the dry treatments were 30.2, 38.0 and 48.1 mg CO_2 lost during the 29-day experiment, respectively. The average carbon lost across both initial water treatments were 8.34, 11.1 and 14.9 mg carbon lost during the 29 day experiment at the 41, 73 and 100°F temperatures, respectively. These values are 0.41, 0.55 and 0.73 % of carbon applied for the 41, 73 and 100°F temperature treatments, respectively. Again, with the confounding of the water treatments, these results cannot be statistically compared.

All temperature and water treatments lost carbon as indicated by CO_2 evolution. Biosolids CO_2 evolution likely occurred as a result of two distinct phenomena: (1) the physical degassing of the biosolids and (2) microbial decomposition of the biosolids. We believe that physical degassing of the biosolids is responsible for the initial CO_2 evolution peak in the cold temperature treatments. Although we were unable to separate physical and microbial phenomena, Jenkinson (1966) demonstrated that, in fumigated soils, this initial peak was primarily due to the decomposition of lysed microbial cells. The materials used in this experiment were not fumigated (autoclaving the biosolids resulted in visually altered material), but biosolids may be assumed to consist largely of components similar to those of lysed cells (U.S. Environmental Protection Agency, 1983). Huffman et al. (1996) reported a similar initial peak in a study investigating wheat residue application. Macalady et al. (1998) stated that CO_2 evolution is based on microbial populations and not necessarily influenced by microbial growth.

Soil and biosolids microbial populations differed in pre-application and post-application numbers. Replicated plating results indicated no soil or biosolids microbial colony forming units for either the pre-application or post-application cold treatments (Table 1). Initial soil microbial numbers were significantly less at 41°F than for the warmer temperatures while initial biosolids microbial population numbers were not significant with respect to temperature. Final soil microbial numbers were significantly different with respect to temperature with microbial population numbers increasing with temperature.

Table 1. Initial and final (29d) microbial population numbers for the soil and biosolids as a function of temperature (Initial only) and temperature and initial soil-water content.

	Temperature			ANOVA results
Parameter	41°F	73°F	100°F	Pr>F
	CFU × 10^6 g^{-1}			
Initial soil	0.0a*	1.45b	1.10b	0.0017
Initial biosolids	0.0a	1.06a	1.20a	0.5148
Final soil	0.01	3.308b	7.578c	0.0001
Final biosolids	0.0a	142.3a	591.9b	0.0057

*Similar letters within rows are not significantly different using Duncan's new range test.

The 41°F microbial population numbers were not significantly different from the 73°F population, but both differed significantly from the 100°F population numbers. Although the 73°F microbial population numbers were less than the 100°F numbers (142.3 × 10^6 colony forming units per gram (CFU g^{-1}) vs. 591.9 × 10^6 CFU g^{-1}), replication to replication variability in both the 73°F and 100°F treatment numbers precluded significant differences.

Replicated plating data support the concept that CO_2 evolution, after the initial phase of degassing, was due to microbial metabolic activity. As experimental temperatures increased, microbial population numbers for both biosolids and soil increased. Increased microbial populations in biosolids may be just that—aerobic microbes indigenous to the biosolids that are increasing in population number as a result of the application process (i.e., removed from anaerobic shipping containers used to transport the biosolids and applied to an oxygen-rich environment). Soil microbial numbers may increase not as a direct result of biosolids addition, but result indirectly from an influx of nutrients in the solution leached from the biosolids to the soil.

CONCLUSIONS

Temperature at which biosolids are surface applied to the soil influences total carbon loss. The CO_2 peak obtained immediately after biosolids application was not influenced by temperature or water. This peak was consistent with peaks reported by Jenkinson (1966) and Huffman et al. (1996). Carbon loss increased significantly as temperature increased from 4 h after application through day 2. Beyond day 2, carbon loss was not significantly related to temperature levels. Average carbon lost across both initial water treatments were 0.41, 0.55, and 0.73% of the carbon applied during the 29-day experiment at the 41, 73 and 100°F temperatures, respectively. Since temperature differences in carbon loss were significant only for 2 days, and there was carbon loss even for the 41°F temperature treatment, we concluded that biosolids may be applied throughout the year without restricting temperature or water parameters beyond the current USEPA or Texas Natural Resources Conservation Commission regulations.

REFERENCES

Aguilar, R. and S.R. Loftin. 1994. Rangeland restoration with treated municipal sewage sludge. *In* Sewage sludge: Land utilization and the environment. C.E. Clapp, Larson, W.E. and Dowdy, R.H. (eds). SSSA. Madison, WI, pp. 205-207.

Anderson, J.P.E. and K.H. Domsch. 1975. Measurement of bacterial and fungal contributions to respiration of selected agricultural and forest soils. Can. J. Micro. 21: 314-322.

Benton, M.W. and D.B. Wester. 1998. Biosolids effects on tobosagrass and alkali sacaton in a Chihuahuan Desert grassland. J. Environ. Qual. 27: 199-208.

Heilmann, B. and F. Beese. 1992. Miniaturized method to measure carbon dioxide production and biomass of soil microorganisms. Soil Sci. Soc. Am. J. 56: 596-98.

Huffman, S.A., C.V. Cole and N.A. Scott. 1996. Soil texture and residue addition effects on soil phosphorus transformations. Soil Sci. Soc. Am. J. 60: 1095-1101.

Jenkinson, D.S. 1966. Studies on the decomposition of plant material in soil. II. Partial sterilization of soil and the soil biomass. J. Soil Sci. 17: 280-302.

Loftin, S. R. 1995. Global climate change, land management, and biosolids application to semiarid grasslands. *In* General Technical Report for the Rocky Mountain Forest and Range Experiment Station. U. S. Forest Service. Fort Collins, CO, 262:119-122.

Macalady, J.L., M.E. Fuller and K.M. Scow. 1998. Effects of metam sodium fumigation on soil microbial activity and community structure. J Environ. Qual. 27: 54-63.

Miller, M.S. and I.L. Pepper. 1988. Survival of a fast-growing strain of lupine rhizobia in Sonoran Desert soils. Soil Biol. Biochem. 20: 323-327.

Mooney, L. 1992. Beneficial use program for New York city's sludge. BioCycle 33(8):72-73.

Moorhead, D.L. and J.F. Reynolds. 1989. Mechanisms of surface litter mass loss in the northern Chihuahuan desert: A reinterpretation. J. Arid Environ. 16: 157-163.

Moorhead, D.L. and J.F. Reynolds. 1991. A general model of litter decomposition in the northern Chihuahuan Desert. Ecol. Model. 59: 197-219.

Sommers, L.E., C.M. Gilmour, R.E. Wildung and S.M. Beck. 1981. The effect of water potential on decomposition processes in soils. *In* Water potential relations in soil microbiology. J.F. Parr, Gardner, W.R. and Elliot, L.F. (eds). SSSA, Madison, WI, pp. 97-117.

Staley, J.T. and A. Konopka. 1985. Measurement of in situ activities of nonphotosynthetic microorganisms in aquatic and terrestrial habitats. Ann. Rev. Micro. 39: 321-346.

U.S. Environmental Protection Agency. 1983. Process design manual for land application of municipal sludge. U.S. Government Printing Office, Washington, DC: USEPA Report 625/1-83-016.

U.S. Environmental Protection Agency. 1993. Standards for the use or disposal of sewage sludge. U.S. Government Printing Office, Washington, DC: Federal Register 58(32):9336.

U.S. Environmental Protection Agency. 1995. Process design manual for land application of sewage sludge and domestic septage. U.S. Government Printing Office, Washington, DC: USEPA Report 625/R-95/001.

West, A.W., G.P. Sparling and W.D. Grant. 1986. Correlation between four methods to estimate total microbial biomass in stored, air-dried and glucose-amended soils. Soil Biol. Biochem. 18: 569-576.

White, C.S., S.R. Loftin and R. Aguilar. 1997. Application of biosolids to degraded semiarid rangeland: Nine-year response. J. Environ. Qual. 26: 1663-1671.

Wollum, A.G. 1982. Cultural methods for soil microorganisms. *In* Methods of Soil Analysis, Part 2, 2nd Ed. A.L. Page, Miller, R.H., and Keeney, D.R. (eds). SSSA, Madison, WI, pp. 781-814.

The Cost of Red Imported Fire Ant Infestation: The Case of the Texas Cattle Industry

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ABSTRACT

The spatial economic impacts of the red imported fire ant (RIFA) on the Texas cattle industry were estimated using regression analysis. Data from a survey of Texas cattle producers were used in conjunction with Agricultural Census data to estimate economic impacts statewide, and on a per county and per acre basis. The statewide economic impacts on the cattle industry were estimated to be approximately $255 million annually. A 95% confidence interval was also calculated, having a lower bound of $28 million and an upper bound of $573 million. Estimates were also calculated for each county to evaluate the spatial properties of RIFA impacts. Per county estimates highlight those counties with relatively large damages associated with RIFA. Per acre damages highlight "hot spots" of RIFA infestation within the state.

KEYWORDS: RIFA, Economic Impacts, Texas Cattle Industry.

The red imported fire ant (RIFA), *Solenopsis invicta* Buren, was introduced into the United States approximately 70 years ago. It is believed that RIFA entered the United States through Mobile, Alabama during the 1930s from South America. From Alabama it has spread and infested Texas, Louisiana, Mississippi, Arkansas, Georgia, Florida, and North and South Carolina. Approximately 275 million acres were estimated to be infested with RIFA in the United States in 1996 (Barr and Drees, 1996) and it continues to infest surrounding states at a steady rate. RIFA was first observed in Texas in 1953 (Culpepper, 1953). Since that time RIFA has continued to spread south and west in the state. Figure 1 depicts the geographical spread of RIFA in the state over time. In 1989, RIFA's infestation range in Texas was estimated to be approximately 50 million acres, representing about 29 percent of the state (Cockendolper and Phillips, 1989). As of 1996, Barr and Drees (1996) estimate that RIFA's infestation range in the state is at 56 million acres of pasture and rangeland, a 10 percent increase over the 1989 estimate.

Temperature and moisture limit the distribution of RIFA because of its dependence on these factors for mound building and foraging. Therefore, RIFA's main direction of expansion has been towards the southern and western parts of Texas in diverse environments. Currently, RIFA infests portions of the state that possess annual rainfall averages ranging from 52 inches in southeast Texas to 24 inches along the entire western edge of

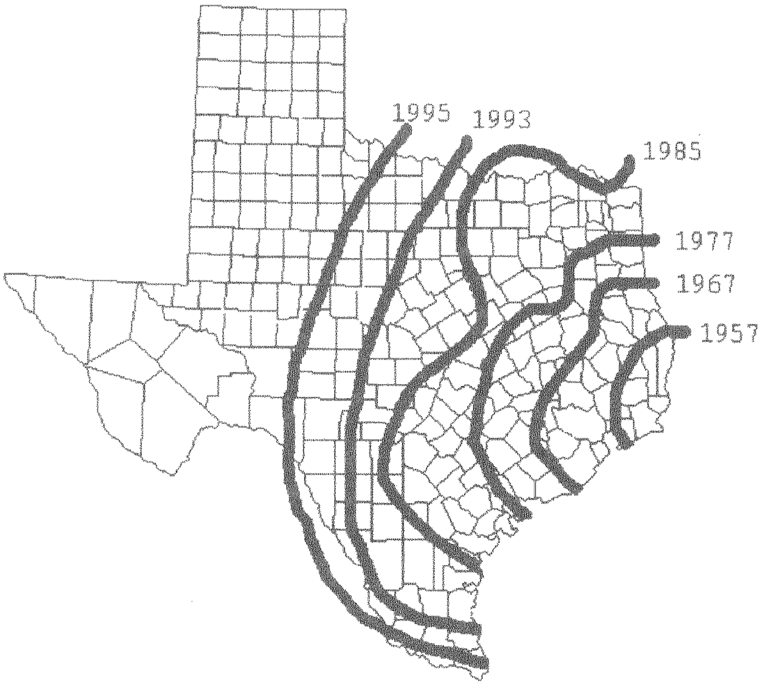

Figure 1. RIFA Infestation and Historical Spread

the infested area. Soils range from sand to heavy clay, and frost-free seasons range from over 300 to less than 225 days per year. Vegetation ranges from pine and hardwood forests in the east, to open prairie and semi-arid rangeland along the southern and western edges of the state (Barr and Drees, 1994).

Given RIFA's ability to successfully adapt to various environments, it has become a significant urban and rural economic pest. Many of RIFA's damages to agricultural crops and livestock production, human health, electrical equipment and urban landscape are well documented. Glancey, Coley, and Killebrew (1979) reported a 63.4 percent loss in potential corn yield due to RIFA. Lonfgren and Adams (1981) reported losses of 14.5 percent of soybean yield because of RIFA. Adams (1983) estimated a 50 percent loss in eggplant yields. Smitttle, et. al. (1988) estimated damages to young citrus trees to be $750 per hectare. A study by Brinkley (1989) estimated RIFA's annual damages in terms of medical expenses, wildlife losses, electrical equipment related expenses and negative impacts on golf courses in Texas to be $52.8 million dollars annually. Using this information, Ervin et. al. (1990) conducted a benefit-cost analysis for controlling RIFA in Texas. They determined that RIFA could be considered an economically damaging pest.

It is estimated that current losses due to RIFA in the state are significantly higher than in the past. Control costs of RIFA, structural repairs, human medical expenses, and other costs are estimated to be $93.2 million dollars annually in urban areas of Texas (Frisbie, 1997). A survey of cattle producers was conducted in 1995 to estimate the economic impact of RIFA on cattle production. Estimates based on that survey placed losses to the cattle industry in Texas at about $67 million dollars annually (Barr and

Drees, 1996). An overall estimate of the current annual economic loss due to RIFA on all economic sectors in Texas is $300 million dollars (Frisbie, 1997).

Livestock production in the state of Texas is a significant industry in the state's economy. It accounts for over $7 billion annually and contributes more than 50 percent of the total estimated value of agricultural production in the state (USDA, 1996).

Given that RIFA continues to spread and that its spreading is a function of climatic and geographical factors, it is desirable to develop methods and procedures to estimate possible ex-ante impacts of its infestation. In particular, the objective of this study is to revisit Barr and Drees' estimated impacts of RIFA on the Texas cattle industry based on climatic and geographical factors, and focus on the spatial impacts of RIFA on the cattle industry in Texas.

METHODS AND PROCEDURES

Data from the cattle producers' survey conducted by Barr and Drees (1996) were used to re-analyze the economic impact of RIFA on the Texas cattle industry on a spatial basis. Barr and Drees' information was used to estimate RIFA damages as a function of the number of cattle per operation, size of operation, location, and spatial weather characteristics.

Total loss with respect to cattle injuries as well as damages to hay production for those who produce their own feed was used as the dependent variable in the regression model estimated. Several independent variables were considered. Some of the independent variables that were suspected of affecting total loss were: climatic related factors, geographical location, number of cattle, number of acres, and length of time a particular region had been infested with RIFA. The survey provided data for the county in which the respondent lived, and the number of acres and cattle on their ranches. The other independent variables were introduced by using dummy variables.

Several qualitative variables were examined using dummy variables as both intercept and slope shifting variables. These included variables for the amount of annual rainfall, the annual number of frost-free days, and the amount of time RIFA has been in the area. The rainfall variable was chosen because RIFA population tends to thrive in areas with greater amounts of rainfall. This variable was determined by the amount of rainfall that each respondent's county received during an average year. The variables included less than 20 inches, 20-34 inches, 35-48 inches and 49 inches or more of rainfall per year.

Another variable considered was related to the number of frost-free days per year for particular counties. This variable was included because the greater the number of frost-free days usually result in higher RIFA populations. This variable was used as a dummy variable to separate counties into two categories: those with less than 290 frost-free days and those with more than 290 frost-free days.

The last dummy variable dealt with the rate at which RIFA has spread over the state of Texas. RIFA was first observed in Texas in 1953, but it is believed to have been established in 1957. RIFA has continued to spread south and west through the state as shown in Figure 1. Each respondent was assigned to a group based on their geographical location in that map. Because of the small number of respondents in the first two groups (1957 and 1967), these two areas were combined into Group 1. Group 2 corresponded to the areas infested between 1967 and 1977. Group 3 corresponded to the areas infested between 1977 and 1985. Group 4 corresponded to the areas infested between 1985 and 1993. And Group 5 corresponded to the areas located west of the areas infested by 1995.

After establishing these dummy variables, a considerable number of alternative regressions using several combinations of the independent variables were ran. Several functional forms such as linear, quadratic, and semi-log were considered. These regressions were ran to determine which functional form provided the best fit of the data. Using the best model would allow the prediction of RIFA damages on a per county basis. That is, given a county in a certain geographical location in the state, a total cost or damage estimate can be determined for that county depending on the average number of cattle operations, and the number of cattle and acres per cattle operation in that county.

The model that best fit the data took the following functional form:

$$TC = f(G1, G2, G3, Cat, Cat^2, G1Acre, G2Acre, FFD1),$$

where: TC represents the total damage to cattle and hay production caused by RIFA; G1 to G3 are dummy variables based on the length of RIFA establishment; Cat represents the number of cattle per operation; Cat^2 represents the number of cattle per operation squared; G1Acre is a slope shifting dummy variable relating Group 1 of infestation and the number of acres per operation; G2Acre is another slope shifting dummy variable for Group 2; and FFD1 is the first category of frost-free days. There were a total of 1,415 observations in the data set used.

Once a regression equation depicting the total cost of RIFA to cattle and hay production was determined, this equation was used to extrapolate the RIFA impact on a per county basis. The procedures used to accomplish this included the use of 1992 census data to derive the average number of acres per cattle operation on a per county basis (Agriculture Census, 1992). This information along with the geographical and climatic characteristics of a particular county, were substituted in the regression equation to derive a per cattle operation RIFA damage estimate. After this was done, these levels of damages were multiplied by the number of cattle operations in a particular county to determine the total damage on a per county basis.

RESULTS

As mentioned previously, several functional forms and combinations of the variables relating to RIFA damages and number of acres per operation, number of cattle per operation, dummy variables for the spread of RIFA, dummy variables for annual rainfall, and dummy variables for the number of annual frost-free days were examined. The estimated model was:

$$\begin{array}{l} TC = 933.800 + 1023.300 * R1 + 1092.700 * R2 + 1639.200 * R3 + 2.3068 * CAT - \\ \qquad (2.1818) + (2.6047) \qquad (3.9088) \qquad (6.2515) \qquad (5.9400) \\ \quad 0.000299 * CAT^2 + 0.8998 * R1ACRE + 0.50803 * R2ACRE - 778.640 * FFD1 \\ \quad (-6.2228) \qquad (3.1944) \qquad (4.9591) \qquad (-1.9064), \end{array}$$

where the variables are defined as before, and the numbers in parenthesis below the coefficients depict their associated t-values. All estimated coefficients had the expected signs and were significant at the 95 percent confidence level, except for the dummy variable for the number of frost-free days, which was significant at the 90 percent confidence level. The coefficient for the dummy variable of region one has a positive sign, indicating a direct relationship with RIFA damage. The same is true about the coefficients for the dummy variables for regions two and three. In short, the regional location was a significant determinant of total RIFA damage. The coefficient for the number of cattle variable was found to have a direct relationship with RIFA damage. The number of cattle squared coefficient is negative, indicating an indirect relationship with RIFA damage. Thus, it is expected that after a certain number of cattle RIFA damage begins to decline. Specifically, it was found that the number of cattle before the damage begins to decline is approximately 3,950 cattle.

Region one multiplied by the number of acres was found to have a direct relationship with the dependent variable. This is a slope shifter dummy variable. As the number of acres change within this region, RIFA damages increase. Region two multiplied by the number of acres was found to also have a similar effect on expected RIFA damages, but at a slightly lower level.

The last independent variable included in the model was the dummy variable associated with the annual number of frost-free days. This variable was found to have a direct relationship with the dependent variable. That is, the fewer frost-free days at a given location, the lower the RIFA damages.

The coefficient of determination, or R^2, of the estimated equation was 0.0923. Due to the fact that the regression model uses cross-sectional data and that the variation in the dependent variable is large, this causes the model to have a low R^2. However, because the R^2 is lower than what would be desired, a confidence interval of the estimated damages on a per county basis was calculated at the 95% confidence level. This provides upper and lower bounds of damages.

Per County Damages

Using the estimated equation, census information, climatic, and geographic information, a point estimate of the aggregate annual damage of RIFA to the state's cattle industry was found to be $254.847 million. In Figure 2, the point estimate of damages is shown on a per county basis. As shown in that figure, the highest annual levels of RIFA damages on the cattle industry are expected to take place in 16 counties in which the levels of annual damages are estimated to be between $3 and $5.56 million. The county with the highest level of estimated damage was Lavaca, located in south central Texas. Generally speaking, the counties expected to experience the greatest losses are surrounded by counties that are expected to experience the second highest levels of damages, between $2 and $3 million per year, due to RIFA.

Given that the overall fit of the estimated equation, on which the above estimates of damages are based, is not as good as desired, the reliability of the estimate of damages discussed above is questionable. For this reason, in Figures 3 and 4 the lower bound and upper bound estimates of damages at the 95% confidence level are depicted, respectively. At the 95% confidence level, the lower bound of the annual aggregate estimate of RIFA damages on the Texas cattle industry is $27.870 million and the upper bound of the damage is $572.904 million. The spread of these bounds reflects the less than desirable goodness of fit of the overall equation. However, given the statistical significance of the variables included in the regression model, it is felt that, while the estimated levels of damages on a per county basis and for the state as a whole might not be as accurate as desired, the relative magnitude of the damages from county to county provide valuable insight in identifying counties in which RIFA damages are expected to be highest.

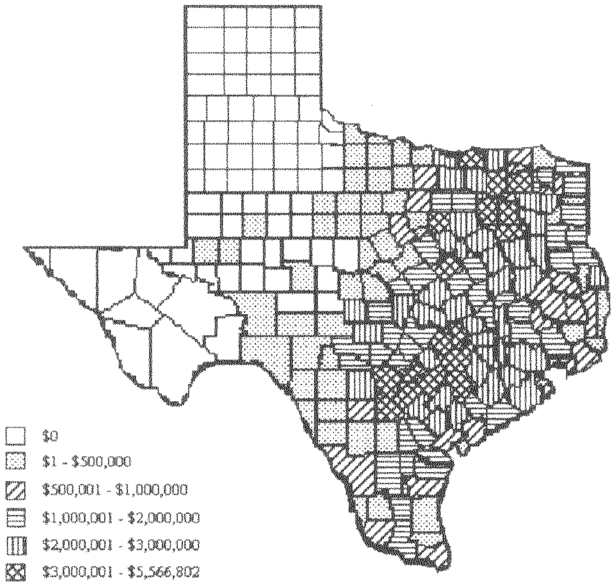

Figure 2. Spatial Economic Impacts of RIFA on the Texas Cattle Industry, 1995.

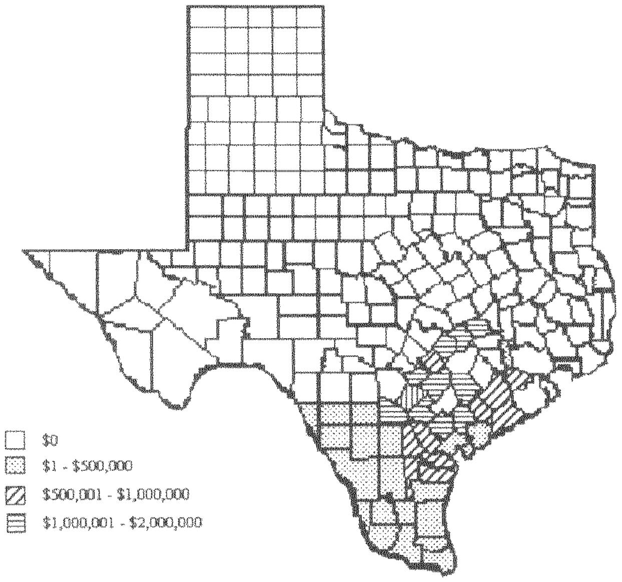

Figure 3. Spatial Economic Impacts of RIFA, 1995: 95% Confidence Level - Lower Bound.

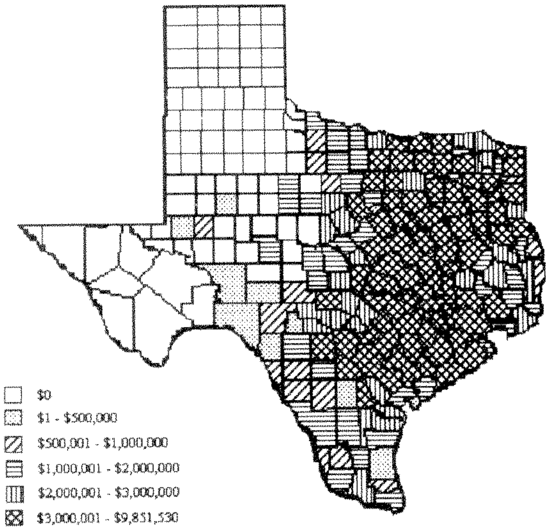

Figure 4. Spatial Economic Impacts of RIFA, 1995: 95% Confidence Level - Upper Bound.

Per Acre Damages

County-wide estimates are useful in determining which regions of the state are expected to be experience the highest levels of damages due to RIFA infestation. However, counties which include large urban areas generally do not have large damage estimates because of the small numbers of cattle within these counties. For this reason, RIFA damages were also estimated on a per acre basis.

Per acre damages were calculated in a similar fashion as the estimates on a per county basis. The estimated equation was used along with census data to determine the damage to the cattle industry on a per operation basis. This damage estimate was then divided by the operations' average size per county. Figure 5 presents the annual damages per acre, per county.

As can be seen in Figure 5, most of the counties that were considered "hot spots" for RIFA infestation on a per county basis, only have moderate damages on a per acre basis. Because these counties have more acres devoted to cattle production, the overall damage estimates are higher than other counties with higher per acre estimates. The highest per acre damage estimate was for Hunt County at $28.06 per year. The per acre damage estimates show those regions of the state which are being affected most by the presence of RIFA.

Again, because of the low R^2 of the estimated equation, 95% confidence intervals were calculated on a per acre basis. Figures 6 and 7 show the upper and lower bounds of the annual per acre damage estimates, respectively.

SUMMARY AND CONCLUSIONS

Given an interest in identifying the spatial impacts of RIFA on the Texas cattle industry, hypothesized relationships between RIFA damages, and characteristics and

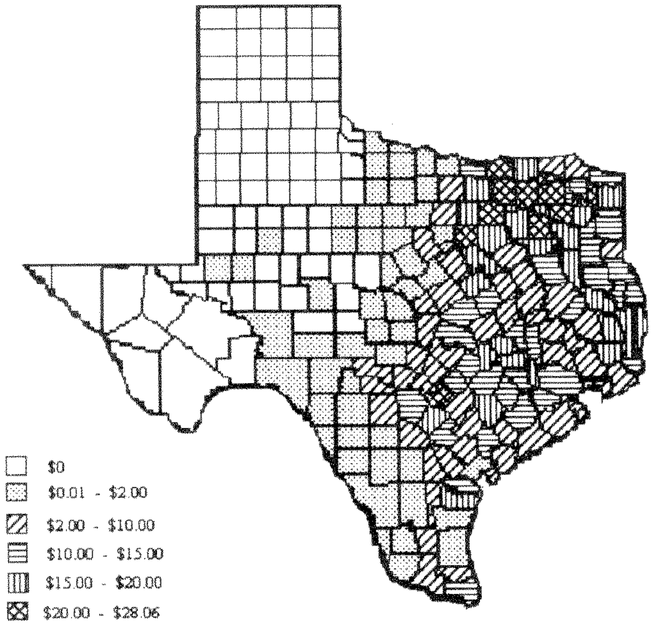

Figure 5. Spatial Per Acre Economic Impacts of RIFA, 1995.

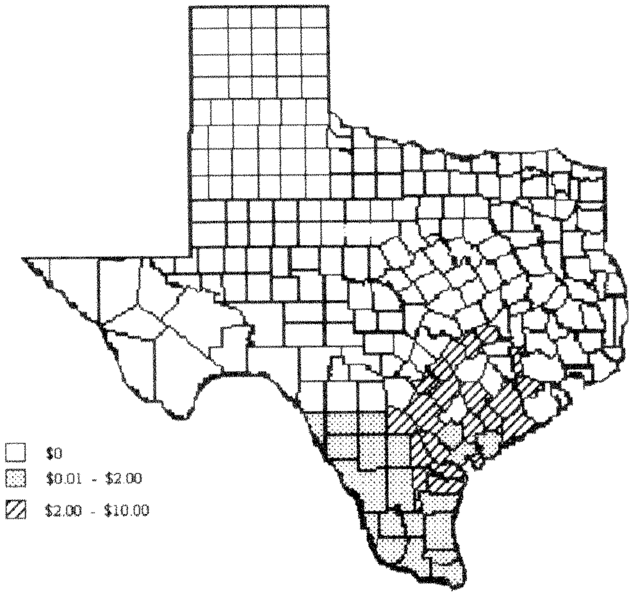

Figure 6. Spatial Per Acre Impacts of RIFA, 1995: 95% Confidence Level - Lower Bound.

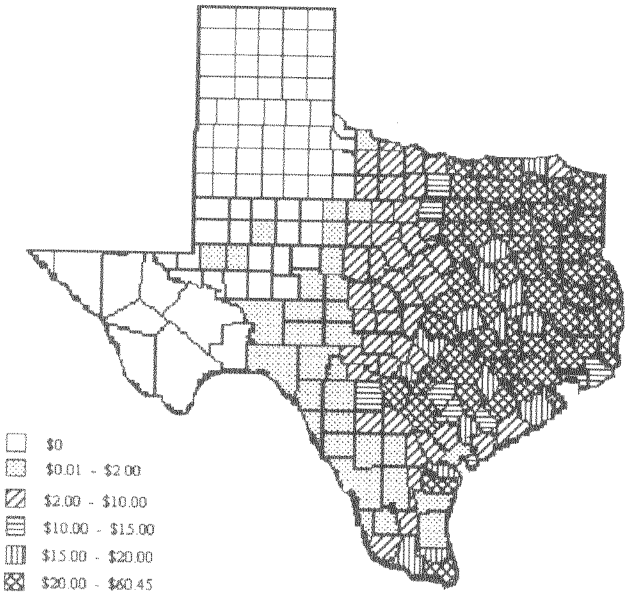

Figure 7. Spatial Per Acre Impacts of RIFA, 1995: 95% Confidence Level - Upper Bound.

location of cattle operations were tested using regression analysis. The data used in this study were a cross-sectional sample consisting of 1,415 survey responses from cattle producers regarding their personal costs of RIFA infestation on their cattle operations. These data came from a survey conducted by Barr and Drees in 1995. A model relating RIFA damages as a function of characteristics and location of cattle operations was estimated, and then used to derive annual county and state level estimates of RIFA damages on the Texas cattle industry.

Using the estimated equation, census information, climatic, and geographical information, a point estimate of the aggregate annual state damage of RIFA to the cattle industry was found to be $254.847 million. Given that the overall fit of the estimated equation on which this estimate of damages is based is not as good as would be desired, the reliability of the estimate of damages is questionable. For this reason, lower bound and upper bound estimates of damages at the 95% confidence level were derived. The lower bound of the annual aggregate estimate of RIFA damages on the Texas cattle industry was found to be $27.870 million, and the upper bound of the damage was found to be $572.904 million. The spread of these bounds reflects the less than desirable goodness of fit of the overall equation. However, given the statistical significance of the variables included in the regression model, it is felt that the relative magnitude of the damages from county to county provides valuable insight in identifying counties expected to experience significant RIFA damages.

Damage estimates were also determined on a per acre basis. Per acre damage estimates show those counties which may not have a high damage estimate for the county as a whole, but could be considered "hot spots" in RIFA infestation none the less.

It was difficult to come up with a statistically sound model that fit the data well, but significant variables affecting RIFA damages on the cattle industry were identified. The major obstacles in the statistical estimation were that the information represents a cross-sectional sample and that the variability of the RIFA damages reported from respondent to respondent was large. Overall, the statistical power of the estimated equation was not as good as would be desired, however some of the independent variables that have an impact on RIFA populations were found to be significant in explaining the economic damages of RIFA on the Texas cattle industry. It is felt that, given the way in which RIFA infestations and associated damages on the cattle industry take place, it would be difficult to improve on the estimation of the economic impacts of RIFA on the cattle industry derived in this study.

REFERENCES

Adams, C.T. 1983. Destruction of Eggplants in Marion County, Florida by Red Imported Fire Ant. Florida Entomologist, 66: 518-520.

Agriculture Census Data, 1992. http://govinfo.kerr.orst.edu.

Barr, C. L. and B.M. Drees, 1996. "Texas Cattle Producers' Survey: Impact of Red Imported Fire Ants on the Texas Cattle Industry. Final Report." Texas Agricultural Extension Service, The Texas A&M University System.

Barr, Charles L., and Bastiaan M. Drees, 1994. "Results from the Texas Veterinarian Survey: Impact of Red Imported Fire Ant on Animal Health" Proceedings of the 1994 Imported Fire Ant Conference.

Brinkley, C.K. 1989. Economic Impact of the Red Imported Fire Ant, Solenopisi invicta (Buren), in Texas. M.S. Thesis, Texas Tech University, Lubbock, Texas.

Cockendolpher, J.C., and S.A. Phillips, Jr. 1989. "Rate of Spread of the Red Imported Fire Ant, Solenopsis invicta (Hymenoptera: Formicidae)", in Texas. Southwestern Naturalist.

Culpepper, G.H. 1953. "Status of the Imported Fire Ant in Southern States in July 1953." Entomol. Plant Quar. USDA, Bur. Entomol. Plant Quar. E-867.

Ervin, R.T., C.K. Brinkley, D.E. Ethridge, E. Segarra, P. Zhang, and H.G. Thorvilson. 1990. "Economic Impact of Red Imported Fire Ant with Uncertainty Considerations." Working Paper, Department of Agricultural Economics, Texas Tech University, Lubbock, Texas.

Frisbie, R., 1997. "Texas Imported Fire Ant Control Management Plan Summary." World Wide Web posting at: http://fireant.tamu.edu/summary.htm.

Glancey, B.M., J.D. Coley, and F. Killebrew. 1979. "Damage to Corn by the Red Imported Fire Ant". Journal of the Georgia Entomological Society, 14: 198-201.

Lofgren, C.S., and C.T. Adams. 1981. "Reduced Yield of Soybeans in Fields Infested with Red Imported Fire Ants, Solenopsis invicta Buren". Florida Entomologist, 64: 199-202.

Smittle, B.J., C.T. Adams, W.A. Banks, and C.S. Logren. 1988. "Red Imported Fire Ant: Feeding on Radiolabeled Citrus Trees". Journal of Economic Entomology, 81: 1019-1021.

United States Department of Agriculture, Texas Agricultural Statistics Service, 1996. "Texas Agricultural Statistics."

Perceptions of Texas Agricultural Science Teachers Toward Granting Science Credit for Agricultural Science Courses

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ABSTRACT

As early as 1887, Agriculture was recognized as a science. Hammonds (1950), author of *Teaching Agriculture*, wrote, "The 'organized body of knowledge' we call the science of agriculture is deeply rooted in the sciences that contribute to agriculture. If we strip away from agriculture the portions of other sciences that bear upon it, we perhaps do not have left a science of agriculture. To teach agriculture is to recognize that it is a science."

Data published in a national study in 1993 indicates that 34% of agricultural science teachers are teaching courses that are receiving science credit (Dormody, 1993). In a later study, Dormody found that, during the 1989-90 school year, 67% of the nation's agricultural science teachers and 73% of the nation's science departments had shared resources.

Agricultural science teachers are separated from other teachers by the fact that they are responsible for much more than just classroom and laboratory instruction. They are called upon to serve the community as an educator and an agriculturalist. There are over 1,500 agricultural science teachers in Texas. These teachers often work year-around with students, assisting them with their Supervised Agriculture Experience Program (SAEP) projects. Furthermore, they advise the school's FFA chapter and are involved in leadership and career development events (Newcomb, et al.—1993). Due to the vast curricula offered in agricultural science at the secondary level, agricultural science teachers often are asked to teach subjects that may range from biological sciences to hunter safety (Texas Education Agency—1990).

If agricultural science teachers could open their programs by offering science credit, there is a tremendous potential for increased enrollment in the agricultural science programs. Moreover, offering additional options for students to complete science credits would be beneficial to students and administrators alike.

Schools could conceivably benefit economically as well. School districts with increased enrollment in their agricultural sciences program would stand to gain additional vocational funding from the state of Texas.

PURPOSE AND OBJECTIVES

The purpose of this study is to determine the perceptions and attitudes of Texas agricultural science teachers toward granting science credit for agriculture courses.

Specific objectives are as follows:

1. Determine Texas agriculture teachers' level of support for granting science credit for agricultural science courses.

2. Determine Texas agriculture teachers' perceptions of administrator and community support levels for granting science credit for agricultural science courses.
3. Determine possible effects of granting science credit for agricultural science courses, as perceived by Texas agriculture teachers.
4. Determine Texas agriculture teachers' level of support for various methods of granting science credit for agricultural science courses.
5. Determine Texas agriculture teachers' level of support for various methods of certifying teachers to offer science credit for agricultural science courses.
6. Determine Texas agricultural science teachers' post-secondary credit hours, grade point averages and required hours in biology, chemistry, earth sciences and physics.
7. Determine the extent to which Texas teachers currently teach agricultural science courses which are granted science credit, as well as to determine the teachers' perceptions as to which classes have the proper content and potential to be used for science credit.

METHODS AND PROCEDURES

Instrumentation

Instrumentation consisted of a modified questionnaire developed from a study in Arkansas (Johnson 1995) accompanied by a disclaimer. Questions on the instrument corresponded to the objectives of the study. The instrument also contained space for written comments concerning science credit for agricultural science courses.

Population

The population for this study included a sample of the 1,504 Texas agricultural science teachers. For budgeting purposes, stratified random sampling was used. Three hundred teachers were surveyed. Using the random numbers method, a sample of 30 teachers was selected randomly from ten strata within the state of Texas. The ten areas, used by the Texas FFA Association to divide the state, were used as the strata for the sample.

Data Collection

The 300 surveys were mailed to the randomly selected individuals. Due to budget restraints, self-addressed, stamped envelope was not provided. The individuals were given a deadline of one month after mailing to complete the survey. This length of time was allowed because the spring semester is the busiest time of the year for agricultural science teachers in Texas.

Analysis of Data

Data were analyzed using Corel Quattro Pro. Some statistical testing was done by hand, using formulas from *Elementary Survey Sampling* (Scheaffer, et al., 1996). All data

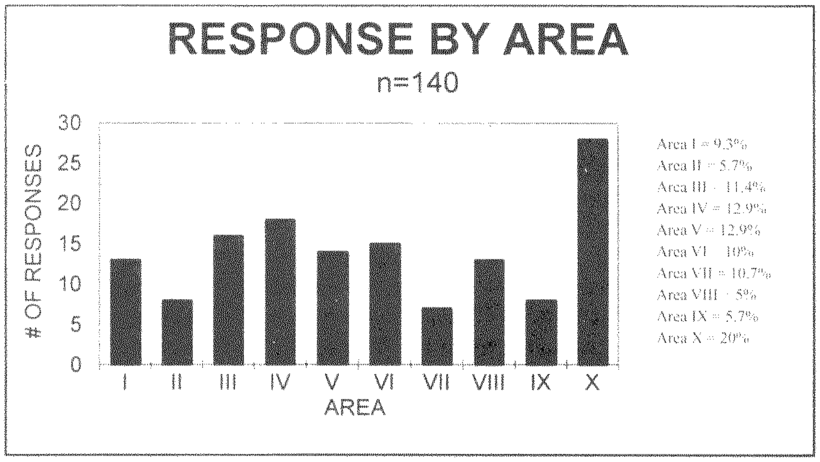

Figure 1. Response By Area

was entered into a Corel Quattro Pro spreadsheet. Various "@ Functions" were used to determine the number of different responses to each question, mean, standard deviation, mode, and median. Statistical differences were determined using a proportion estimate comparison formula from *Elementary Survey Sampling,* Chapter 4, section 4.60. All comparisons were done with 95% confidence. The results were reported as descriptive statistics and inferential statistics.

RESULTS

Demographics

The subjects were asked to provide their area, age, sex, school size, number of students in their agricultural science program, number of agricultural science teachers in the school, and number of science teachers in their school.

Response by area ranged from 23.3% to 93.3% (n=30 for each area). As seen in Figure 1, Area VII had 7 responses, while Area X had 28 responses. Twenty percent of the total responses (n=140) came from Area X, which includes most of South Texas. Area seven had only 5% of the total responses. (See Figure 1)

The numbers of male and female respondents were highly disproportional. Three subjects did not respond to this question (n=137). Out of the remaining 137 surveys, there were 116 (84.7%) males and 21 (15.3%) females.

The average age of the teachers (n=139) was 38.9, with a standard deviation of 9.216. The median and mode age was 38 and 51 respectively. The maximum age was 56, and the minimum age was 25.

The high schools in Texas are divided according to size, with 1A being the smallest and 5A being the largest. The majority of the responses (58.6%) came from teachers in 2A and 3A schools.

Most of the respondents had either 100—125 or 125—150 students in their agricultural sciences program. No respondents had less than 20 students in their program.

Table 1. Demographic Information About Survey Respondents (Including sex, size of school, and # of students in agricultural science program).

	n	Percent (%)
Sex (n=137)		
Males	116	84.7
Females	21	15.3
Size of School (n=140)		
1A	18	12.9
2A	43	30.7
3A	39	27.9
4A	21	15.0
5A	19	13.5
# of students in agricultural science programs (n=40)		
0-20	0	0
20-30	6	4.3
30-40	0	0
40-50	2	1.4
50-60	12	8.6
60-70	15	10.7
70-80	12	8.6
80-90	9	6.4
90-100	6	4.3
100-125	23	16.4
125-150	31	22.1
150-200	13	9.3
Over 200	11	7.9

The mean number of agricultural science teachers in each agricultural science program was 1.73, with a standard deviation of .62. The most frequently occurring number of teachers in a program was two.

The number of science teachers in each school varied greatly among the respondents. The mean number of science teachers was 6.7, with a standard deviation of 4.8. (See Tables 1 and 2)

Table 2. Demographic Information About Respondents (Including age, # of agricultural science teachers in the program, and # of science teachers in the school)

	n	X	SD	Med.	Mode
Age	139	38.98	9.22	38	51
# of ag. science *teachers in program*	140	1.73	0.62	2	2
# of science *teachers in school*	39	6.68	4.81	5	3

Levels of Support

Ninety two percent of the respondents supported granting science credit for agricultural science classes, with 55% answering "strongly agree," and 37% answering "agree." Seven percent were neutral and only two teachers (1%) were opposed.

Table 3. Perceived Support for Granting Science Credit for Agricultural Science Classes

Support From: (n = 140)	Strongly Agree %	Agree %	Neutral %	Disagree %	Strongly Disagree %
Building Admin.	38.0	33.6	15.7	11.3	1.4
Students	76.4	21.5	2.1	0	0
Guidance Counselors	35.7	35.7	16.4	10.8	1.4
Science Teachers	12.9	35.0	27.8	20.0	4.3
Parents	32.9	53.6	10.7	2.8	0

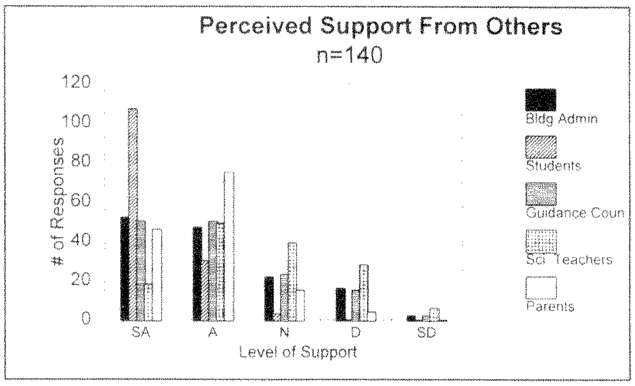

Figure 2. Bar Graph Comparing Perceived Support of Building Administrators, Students, Guidance Counselors, Science Teachers, and Parents. (SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree) agricultural science program.

The majority of the respondents also felt that their building administrators (vocational director, principal, etc.), students, counselors, parents, and science teachers would support granting science credit for agricultural science classes. Perceived support was highest for students and lowest for science teachers. (See Table 3 and Figure 2)

Effects of Granting Science Credit

As a group, the agricultural science teachers felt that granting science credit for agricultural science classes would have positive effects on their programs. Over ninety one percent (91.6%) of the teachers felt it would increase enrollment in their.

As shown in Table 4, most of the teachers felt that granting science credit would: (1) increase enrollment at all learning levels, (2) benefit students, (3) benefit the program, (4) increase student interest in agriculture, and (5) cause agricultural science teachers to work more closely with the science teachers.

While concerns about granting science credit do exist, Table 4 shows that a minority of agricultural science teachers disagree or strongly disagree with the concept. For example, 52.2% either disagreed or strongly disagreed when asked if granting science credit would

Table 4. Effects of Granting Science Credit for Agricultural Science Classes

Effect: (n = 140)	Strongly Agree %	Agree %	Neutral %	Disagree %	Strongly Disagree %
Granting science credit will:					
Increase enrollment in my program	35.6	56.0	5.6	2.8	0
Benefit students.	37.1	52.1	7.9	2.9	0
Enhance program's image.	44.3	38.6	11.4	5.7	0
Cause me to work more closely with science teachers.	31.4	56.0	7.1	5.7	0
Increase importance of ag. science program within school.	27.9	52.9	15.0	4.3	0
Increase student interest in ag. science.	29.3	51.4	12.1	7.1	0
Cause more high-ability students to enroll in ag. science.	22.9	35.7	25.0	16.4	0
Caure more low-ability students to enroll in ag. science	19.3	44.3	27.1	9.3	0
Require me to increase science content in ag. science courses.	17.2	56.4	12.1	14.3	0
Result in higher student achievement in science.	15.7	43.6	24.3	15.0	1.4
Cause ag. science courses to be thought of as "watered down" science courses	10.7	22.1	15.0	49.3	2.9
Prevent me from teaching important vocational skills.	14.3	11.4	3.6	67.9	2.9
Make me feel like a "second rate" science teacher.	8.6	10.7	12.9	57.1	10.7
Weaken my FFA chapter.	3.6	20.0	9.3	60.0	7.1

result in agricultural science classes being thought of as "watered down" science courses. Additionally, 67.9% of the respondents did not think it would make them feel like a "second rate" science teacher. Furthermore, only two respondents (1.4%) strongly disagreed with any of the positive effects.

Methods of Granting Science Credit

For this category, teachers were asked to rate their level of support for five different methods of granting science credit for agricultural science courses. Two of the methods

Table 5. Levels of Support for Methods of Granting Science Credit for Agricultural Science Classes (n = 140).

Method	Support %	Neutral %	Oppose %
Grant science credit for *any one of a specified group* of agricultural science courses, with changes made to enhance science content of courses.	64.3	16.4	19.3
Award science credit for *any one of several new* agricultural science courses, specifically designed to teach science applications in agriculture.	55.0	26.4	18.6
Grant science credit for *any one of a specified group* of agricultural science courses, with no changes in course content.	34.3	42.9	22.8
Grant science credit for *all agricultural science courses,* with changes made to enhance the science content of the courses.	10.7	30.7	58.6
Grant science credit for *all agricultural science courses,* with no changes in course content.	16.4	16.4	67.2

were supported by 55% or more of the teachers. These methods involved granting science credit to specific courses, with changes made in content, and granting science credit for new courses specifically designed to teach science applications in agriculture.

Over 42% of the respondents indicated that they were neutral concerning granting science credit for *any one of a specified group* of agricultural science courses, with no changes in course content (Table 5). Statistically, the proportion of those who were neutral (.42) is not significantly different from the proportion supporting this method. However, the proportion of those supporting this method was significantly different from the proportion of those opposed to this particular method (.23).

Methods of Certifying Teachers

The teachers were given four different methods of certifying agricultural science teachers to offer science credit for agriculture classes. The methods are as follows:

Method #1—Grant an endorsement in science to all teachers currently holding valid agricultural science certification.

Method #2 - Grant an endorsement in science to only teachers holding valid agricultural science certification, *and* completing a special science education in-service workshop.

Method #3—Grant an endorsement in science to only teachers holding valid agricultural science certification, *and* scoring above a designated level on a science achievement test.

Method #4—Grant an endorsement in science to only teachers currently holding valid certificates in both agricultural science *and* science.

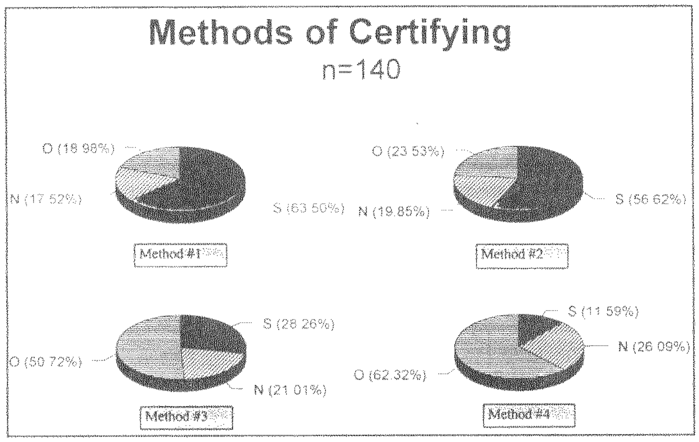

Figure 3. Pie Charts Comparing Levels of Support for the Four Methods of Certifying Agricultural Science Teachers to Offer Science Credit for Agricultural Science Courses. (S = Support, N = Neutral, O = Oppose) **Method numbers correspond with those listed in above.

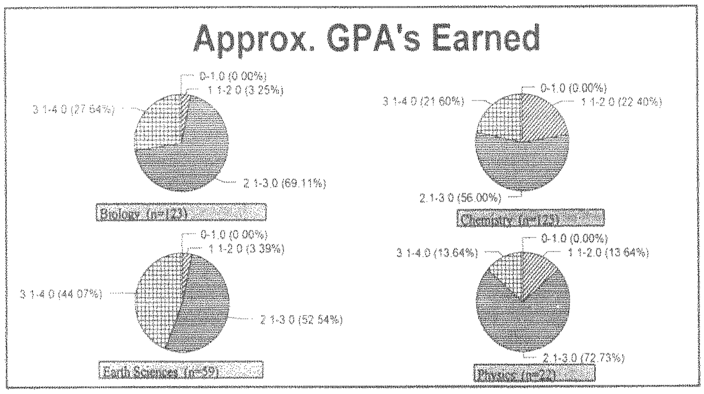

Figure 4. Approximate Grade Point Averages by Subject as Reported by Texas Agricultural Science Teachers (based on a 4.0 grading scale)

They were asked to rate their level of support for each method. The highest percentage (63.6%) of the teachers supported Method #1. Fifty five percent supported Method #2.

Statistically these proportions are not significantly different when compared using a 95% confidence interval. There is, however, a significant difference, with 95% confidence, between the proportion (.28) of those supporting Method #3, and the proportion (.11) of those supporting Method #4. (See Figure 3)

College-Level Science Course Work

The teachers were asked to provide the number of hours earned, approximate grade point average, and number of hours required on their degree plan for the following

Table 6. Post-Secondary Science Credit Hours Earned and Credit Hours Required on Degree Plan, As Reported by Texas Agricultural Science Teachers.

	Credit Hours Earned				Credit Hours Required			
Subject Area	n	X	SD	Mode	n	X	SD	Mode
Biology	135	11.7	7.36	8	110	9.58	5.30	6
Chemistry	135	8.78	3.93	8	116	7.80	3.50	8
Earth Sciences	130	3.30	4.60	0	126	2.60	3.89	0
Physics	140	1.09	2.61	0	137	0.27	1.15	0

subjects at the post-secondary level: Biology, Chemistry, Earth Sciences, and Physics. The number of responses varied greatly in this category.

As shown in Table 6, the mean number of hours completed in biology from 135 respondents was 11.70, while the mean number of hours required on the degree plan (n=110) was 9.58. In the chemistry category, the mean number of hours completed (n=135) was 8.78.

The teachers were given four ranges for approximate grade point average (0-1.0, 1.1-2.0, 2.1-3.0, and 3.1-4.0). The ranges are based on a 4.0 scale, with 0-1.0 in the F/D grade range, 1.1-2.0 in the D/C grade range, 2.1-3.0 in the C/B grade range, and 3.1-4.0 in the B/A grade range. Of the total responses for all four subjects (n=329), 61.4% were in the 2.1-3.0 range. None of the respondents reported having a grade point average below the 1.1-2.0 range.

Course With Proper Content to be Granted Science Credit

The teachers were asked to circle classes, from a list provided, which they felt had the proper content to be granted as science credit. They were asked to circle as many as they felt had the proper content. The list was as follows:

1. AgSc 101—Introduction to World Agricultural Science and Technology
2. AgSc 102—Applied Agricultural Science and Technology
3. AgSc 231—Animal and Plant Production
4. AgSc 261—Introduction to Horticultural Sciences
5. AgSc 281—Energy & Environmental Technology
6. AgSc 335—Applied Entomology
7. AgSc 332—Animal Science
8. AgSc 333—Plant & Soil Science
9. AgSc 334—Equine Science
10. AgSc 362—Horticultural Plant Production
11. AgSc 323—Agriculture Power Technology
12. Other ____________________

There were 131 responses to this item. The respondents circled a total of 614 courses. As shown in Table 7, 79.4% of the respondents felt that AgSc 332 (Animal Science) had the proper content to be counted as science credit, while only 16% of the respondents felt that AgSc 101 (Introduction to World Agricultural Science and Technology) had the proper content.

Table 7. Classes With Proper Content to be Counted Toward Science Credit, as Perceived by Texas Agricultural Science Teachers. **Corresponding names for the course numbers in this table can be found above.

Course	n	% of Total Responses (n=614)	% of Respondents (n=131)
AgSc 101	21	3.4	16.0
AgSc 102	35	5.7	26.7
AgSc 231	86	14.0	65.6
AgSc 261	56	9.1	42.7
AgSc 281	41	6.7	31.3
AgSc 335	45	7.3	34.4
AgSc 332	104	16.9	79.4
AgSc 333	75	12.2	57.3
AgSc 334	54	8.8	41.2
AgSc 362	56	9.1	42.7
AgSc 323	28	4.6	21.4
Other	13	2.1	9.9

Courses provided in the "other" category included: Forestry, Introduction to Agricultural Mechanics, Agricultural Structures Technology, Agricultural Metal Fabrication Technology, Advanced Animal Science, Biotechnology, Fruit, Nut & Vegetable Production, Wildlife & Recreation Management, and Aquaculture.

Courses Currently Being Granted Science Credit

The teachers were asked to circle any classes, from the same list as in the last section, which they are teaching that are currently being granted science credit. There were 135 responses to this item. Animal Science is being granted science credit in two of the teachers' schools, Equine Science in one school, and Horticultural Plant Production in one school. Others provided in the responses were Wildlife (n=2) and Recreation Management (n=2), and Aquaculture (n=1).

Comments

The respondents were also given an opportunity to write any comments concerning granting science credit for agricultural science courses. Some of the comments were as follows:

"I would like to give science credit for some of these courses because I believe it would enhance my program."

"I support this fully, and we are going to implement this in my school."

"I feel we need to leave agriculture where it is. I don't want to lose the identity of agriculture."

"This would increase the number of students enrolled in class, but could reduce the number of FFA members."

"My 1st thought is to let all ag. science teachers do this, 2nd thought is there are some that couldn't handle it, and we could get some bad feedback."

CONCLUSIONS AND LIMITATIONS

A more accurate study could be done with a higher response rate. The assumed reasons for the low response rate are lack of a self-addressed, stamped envelope in the survey, and the fact that the surveys were sent out during the 965454mpe odlkglfkgl;fdkgl;-dkgdl;kdg;ldl;busiest time of the year for Texas agricultural science teachers.

The response from those agricultural science teachers surveyed in Area X was extremely high in comparison to the other nine areas. This could be due to the teachers' close proximity to the university from which the survey came. This created an abnormal distribution among the ten areas, therefore possibly creating some bias.

With perceived support from guidance counselors, parents, administrators and students as well, these individuals, along with agricultural science teachers and science teachers should be involved in the process. Each group should be made aware of the advantages and disadvantages of granting science credit that would affect both students and teachers.

Although 63.6% of the teachers supported granting a science endorsement to all teachers holding a valid agricultural science certification, the best route would probably be to hold in-service workshops to enhance the science strength of the agricultural science teachers. Although teachers support granting science credit for agricultural science courses, there seems to be a lack of support for any extra education or effort on the part of the agricultural science teachers.

It would be in each teacher's best interest to take the Examination for the Certification of Educators in Texas (ExCet) in science and become certified, although there was little support for this method of certification.

With several agricultural science teachers already offering courses that are counted as science credit, a precedent could be created. If there are few negative effects on teachers and students, perhaps other school districts will follow the lead, and we will see more science credit being granted for agricultural science courses in the near future.

REFERENCES

Anderson, B.H. & Boddy, R. (1985). *The identification of science competencies included in the curriculum of secondary vocational education programs.* (ERIC Document Reproduction Service No. ED 259 219)

Budke, W. (1991, January). Agricultural science—Striving for excellence. *The Agricultural Education Magazine, 63* (7), 4,11.

Conners, J. and Elliot, J. (1995). The influence of agriscience and natural resources curriculum on students' science achievement scores. *Journal of Agricultural Education, 36* (3), 57-63.

Dormody, T.J. (1992). Exploring resource sharing between secondary school teachers of agricultural education and science departments nationally. *Journal of Agricultural Education*, (3) 23-31.

Dormody, T.J. (1993). Science credentialing and science credit in secondary agricultural education. *Journal of Agricultural Education, 34* (2), 63-70.

Hammonds, C. (1950). *Teaching Agriculture.* New York: McGraw-Hill .

Johnson, D.M. (1995, December). Arkansas agriculture teachers' opinions concerning science credit for agriculture. *Proceedings of the 22nd Annual National Agricultural Education Research Meeting, 22*, 129-140.

Johnson, D.M. & Newman, M.E. (1993). Perceptions of administrators, guidance counselors, and science teachers concerning pilot agriscience courses. *Journal of Agricultural Education, 34* (2), 46-54.

Newcomb, L., McCracken, J., & Warmbrod, J. (1993). *Methods of Teaching Agriculture*, 25-40.

Norris, R.J. & Briers, G.E. (1989). Perceptions of secondary agricultural science teachers toward proposed changes in agricultural curricula for Texas. *Journal of Agricultural Education, 30*, (1), 32-43, 59.

Scheaffer, R.L., Mendenhall, W., & Ott, R.L. (1996). *Elementary Survey Sampling Fifth Edition*, 95-106.

Texas Education Agency, (1990). *Basic curriculums for semester courses in agricultural science and technology.*

Texas Education Agency, Science Unit, (1996). *Science essential elements.*

Texas Education Agency, (1996). *Texas Teachers of Agricultural Science and Technology 1996-1997 Directory.*

Understanding Agriculture New Directions for Education. (1988). National Research Council. Washington, DC: National Academy Press.

Testing Leopold's Law of Dispersion on Cottontail Rabbits Occupying Shrubland-Grassland Ecotones

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ABSTRACT

Leopold's law of dispersion, commonly referred to as the principle of edge, is a long-held tenet of wildlife management. The law suggests that a direct linear relationship exists between the densities of edge-benefitted species and the quantity of edge. We tested three hypotheses derived from edge theory and used cottontail rabbits (Sylvilagus floridanus) as our animal model. Our hypotheses were: (1) an edge-benefitted species will exist in the absence of edge, (2) each species has an edge saturation value (maximum length of edge/area) where additional edge will not increase species density, and (3) there exists a distance from edge, defined as the radius of full use, beyond which a species' use of an area declines. Cottontail rabbits were found in the absence of edge only with shrubland habitat. Cottontails did not exhibit an edge saturation value. The radius of full use for cottontail rabbits was undefined and 3.1 yds in shrubland and grassland, respectively. Data collected in this study did not support current theories concerning the relationship between length of edge and species density.

KEY WORDS: Cottontail rabbit, ecotone edge, Law of Dispersion, *Sylvilagus floridanus*

Leopold's (1933:132) law of dispersion, sometimes referred to as the principle of edge, is often cited in wildlife management texts (Giles, 1978; Robinson and Bolen, 1984; Hunter, 1990), and is used extensively by wildlife managers (Laudenslayer, 1984). However, before a principle is accepted as a law, it must (1) originate as an hypothesis, (2) be upgraded to a theory after considerable evidence is collected in support of the general principle, and finally, (3) be accepted as law after withstanding rigorous testing in which the principle occurs with unvarying uniformity under the same conditions (Bronowski, (1973:240). This has not been the case with the law of dispersion. Although the concept of edge effect has received much attention in the scientific literature (see Reese and Ratti, 1988; Yahner, 1988 for reviews), no researcher, to our knowledge, has specifically collected data in an attempt to refute the law of dispersion. Edge theory has been accepted as fact based upon casual observation (Giles, 1978; Robinson and Bolen, 1984) and upon studies incorporating the edge effect into their design (Hanson and Miller, 1961; Patton, 1975; Galli *et al.* 1976; Gates and Mosher, 1981; Eberhardt, 1990). Edge effect has been defined as the changes in a community due to the creation of abrupt edges in areas of previously undisturbed habitats (Soulé, 1986). Although certain "edge effects" have been documented to increase with increases in the amount of edge such as rates of predation (Wilcove, 1985; Yahner and Scott, 1988), rates of parasitism (Gates and Gysel, 1978, Brittingham and Temple, 1983), and species diversity (Rosenzweig, 1995), such edge effects were not the original intent of Leopold (1933).

The law of dispersion, as originally proposed by Leopold (1933: 132), states that "the potential density of game of low radius requiring two or more types is, within ordinary limits, proportional to the sum of the type of peripheries." Unfortunately, wildlife professionals have derived various interpretations of this statement. Some have stated that as habitat interspersion increases, the density of wildlife species as a unit will increase proportionately (Robinson and Bolen, 1984), while others erroneously expressed that species diversity and abundance will increase proportionately (Yahner, 1988; Barnes *et al.,* 1991). Robbins (1979) stated that the theory only applies to certain edge-obligate species. Guthery and Bingham (1992) argued that the constraints placed on the law by Leopold (1933:132) have been ignored; therefore, past interpretations are erroneous. They offered a revision of the edge principle, but like the original principal, empirical data has been lacking to support their conclusions.

Our objective was to determine if Leopold's law of dispersion is a viable interpretation of a possible relationship between the density of edge-obligate species and edge in a southern Texas shrubland-grassland habitat. Three hypotheses were derived from equations and text in Guthery and Bingham (1992) and were tested separately. Hypothesis one involved the concept that edge-benefitted species will exist in the absence of edge. In other words, density of edge species will be greater than zero in shrubland or grasslands areas that do not contain edge (see Guthery and Bingham, 1992 for the equation and graphical depiction). Hypothesis two stated that each species has an edge saturation value where additional amounts of edge will no longer yield an increase in density (for graphical representation, see Guthery and Bingham, 1992:341). Hypothesis three suggested that the probability of use will remain constant out to a perpendicular distance of r from the edge, to be called the radius of full use, where the probability of use then will decrease monotonically to 0 for distances greater than r from the edge (Fig. 1). Cottontail rabbits were chosen as animal models because they (1) inhabit diverse habitats including open prairies, shrublands, and woodlands (Chapman *et al.,* 1980), (2) are a species of low radius requiring two or more habitat types (Janes, 1959; Robinson and Bolen 1984), (3) have an affinity for high contrast grassland-shrubland edge (Smith 1950), (4) increase in abundance by the creation of edge (Chapman *et al.,* 1980), and (5) have a high relative abundance in southern Texas.

MATERIALS AND METHODS

Definitions

Because of the numerous interpretations of Leopold's (1933:132) concept, it is prudent to define each component to avoid ambiguity. The passage begins ". . . the potential density of . . .", which we interpret to mean the maximum sustained mean density of a species that can indefinitely inhabit an area. Based on Leopold's original description in *Game Management* (1933:132), we interpret ". . . game of low radius requiring two or more types . . ." as any species that can not travel great distances in a short period of time and needs two or more habitat types in close proximity to provide its basic requirements (i.e., food, cover, space, water) for survival. In other words, an edge species spends all or most of its time at or near edges (Johnston, 1947; Forman and Godron, 1986;

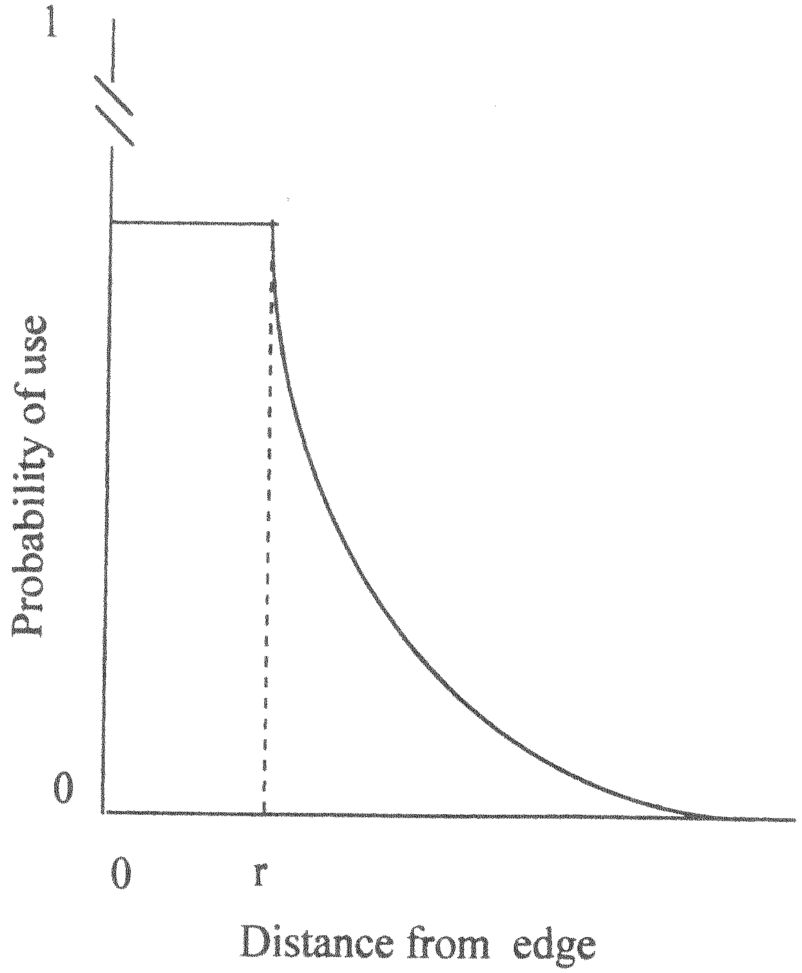

Figure 1. Graphic portrayal of the radius of full use (*r*).

Yahner, 1988). This includes cottontail rabbits, northern bobwhites (*Colinus virginianus*), and white-tailed deer *(Odocoileus virginianus)*. In contrast, game of high radius would include migratory species such as bison *(Bison bison)*. While species of high radius may require more than one habitat type, the types need not be adjacent. Guthery and Bingham (1992:340) suggested that Leopold (1933:132) added the phrase "... within ordinary limits ..." as an apparent qualifier to explain circumstances where the theory did not apply. Finally, we interpret the phrase "... the sum of the type peripheries" to mean the total perimeter of the interspersed habitat types (sensu Patton, 1975; Thomas *et al.*, 1979). However, edge created by adjoining habitat types should be included only once.

Because many different types of edge exist (Giles, 1978; Thomas *et al.*, 1979), it is prudent to explicitly define it. Edge is a transition zone between two habitat types, which in this study, was between shrubland and grassland habitat types. Only high-contrast edge (i.e., ecotones ≤10 yds wide) was used. An area was considered shrubland if it contained >405 woody stems/acre, average woody stem circumference >1.0 inch, average height of woody species >1.5 yds, and canopy cover >50%. An area was considered grassland if it was composed predominantly of grasses (>75%), contained <10 woody stems/acre that were >1.0 inch in circumference, and had brush canopy cover <10%.

Study Area

The three hypotheses were tested on the 2,100 acre DuPont Chemical, Inc. property (Victoria Co.), the 2,000 acre La Copita Research Area (Jim Wells Co.), the 125 acre Marvin and Marie Bomer Wildlife Management Area (WMA) (Duval Co.), the 210,540 acre Santa Gertrudis Division of the King Ranch (Kleberg Co.), and the 200 acre Trant Ranch (Kleberg Co.) in southern Texas. Southern Texas is characterized as mixed grassland-shrubland habitat, where the chief industries include cattle and oil production, and wildlife enterprises. Predominant grasses on the study sites included King Ranch bluestem *(Bothriochloa ischaemum)*, Kleberg bluestem *(Dicanthlum annulatum)*, johsongrass *(Sorghum halepense)*, kleingrass *(Panicum coloradum)*, and windmillgrasses *(Chloris* sp.), while predominant woody species included honey mesquite *(Prosopis glandulosa)*, live oak *(Quercus virginiana)*, and huisache *(Acacia farnesiana)*. The topography is nearly flat to gently sloping and the soils range from clay to sandy loam (Miller, 1982). Mean annual rainfall ranged from 26 to 38 in., increasing from west to east (Miller, 1982). Mean temperature is 72 F with average lows of 43 F in January and average highs of 93 F in July (National Oceanic and Atmospheric Administration, 1994).

Forty acre sites within each study area were selected based on criteria previously outlined for grassland and shrubland habitat. Density of woody stems was determined using belt transect methodology (Burnham *et al.*, 1980). We walked three 325-yd transects within perspective grassland and shrubland habitat types and measured the height and circumference of each woody stem within 10 yds of the transect line. By doing so, approximately 10% of each perspective study site was assessed to verify that specified site parameters were met. Line intercept method was used to estimate percent canopy cover on each transect line (Canfield, 1941). Transect lines within each area were pooled to estimate density of woody stems, average woody stem height and circumference, and percent canopy cover.

Hypothesis 1: Edge-benefitted Species Will Exist in the Absence of Edge

The densities of cottontail rabbits were determined using line transect methodology with a finite boundary (Burnham *et al.*, 1980:17) from June through October 1995. A finite boundary of 16 yds from the transect line was used because that was the maximum distance that a cottontail rabbit could be detected due to vegetation cover. Eight transects were walked within the grassland and shrubland habitat types >220 yds from any edge to determine rabbits use of non-edge habitat. Cottontail movements were verified using radio telemetry (for details see Hypothesis 3: A radius of full use exists). The largest home range of a cottontail rabbit during this study was estimated to be 8.6 acres (averaging size of home range of cottontails during our study was 5.0 ± 0.4 ac; $\overline{X}$ ± SE). This is

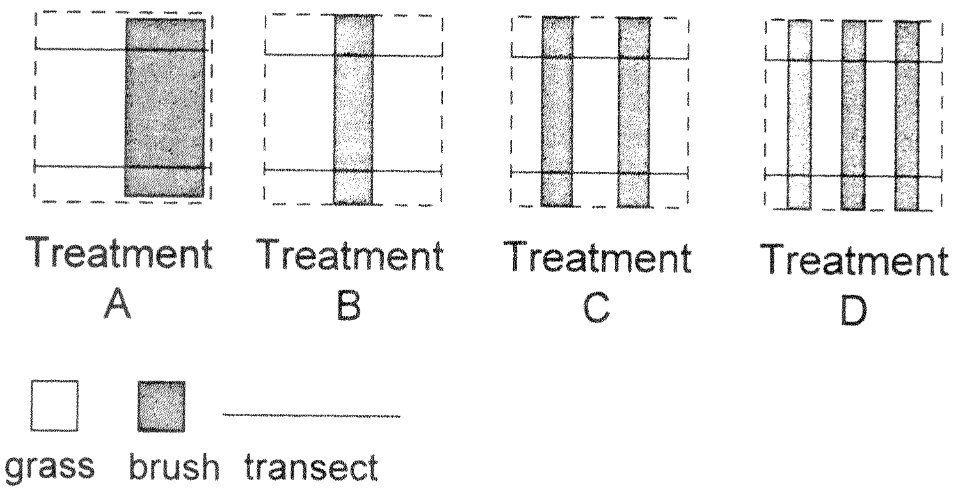

Figure 2. Schematic of 4 different edge lengths in grassland-shrubland ecotones of southern Texas during winter 1995. Each dashed-line square represents a 25-acre area and there were 3 25-acre areas for each edge length class, for a total of 12 25-acre areas. Treatments A, B, C, and D consisted of an average of 345, 688, 1,379, and 2,066 yds of edge length, respectively.

an area equivalent to a square with 204-yd sides. However, cottontail rabbit home ranges typically are elliptical with the long axis of the home range parallel to edge (Althoff, 1983). Therefore it was assumed that cottontails encountered during transects did not have home ranges encompassing edge. Grassland transects were 396, 403, 450, and 533 yds in length and shrubland transects were 261, 321, 495, and 620 yds in length. Each transect was walked ≥5 times during both day and night. Daytime transects were walked during the first and last hour of daylight. Nighttime transects were walked ≥1 hour after sunset and a hand-held 500,000 candle-power spotlight was used to aid detection of animals (Fafarman and Whyte, 1979). The order of the transects was chosen randomly to reduce the bias of reaching the same portion of the transect during the same time interval. Perpendicular distances at which cottontail rabbits were observed from the transect line were determined with a tape measure. Cottontail densities were estimated using the Fourier estimator from program TRANSECT (Burnham *et al.*, 1980). Although >40 objects should be seen on a transect for a precise estimate of density (Burnham *et al.*, 1980:37), our goal was not to provide an estimate but rather to document the presence or absence of animals. The presence or absence of animals was used to determine if animal density was greater than zero in areas with no edge.

Hypothesis 2: Each Species Has an Edge Saturation Value

Twelve 25-acre study areas comprising four edge treatments were chosen (Fig. 2). Treatment A areas had 342, 345, and 347 yds of edge length, treatment B areas had 684, 688, and 692 yds of edge length, treatment C areas had 1,369, 1,377 and 1,390 yds of edge length, and treatment D areas had 2,039, 2,068, and 2,092 yds of edge length. The mean length of edge for each treatment was 345, 688, 1,379, and 2,066 yds, respectively (Fig. 2). Edge length was defined as the cumulative length of edge between shrubland and grassland habitat types contained within a 25-acre area. Edge length in each area was measured using a distance measuring wheel (Rolatape Distance Measuring Wheel, Forestry Suppliers, Inc., Jackson, Miss.).

An index of relative abundance for cottontail rabbits was estimated by scent station methodology from 4 February to 4 March 1996 (Drew *et al.*, 1988). Scent station methodology was selected because it yielded more precise estimates of cottontail relative abundance than nighttime headlight counts (Drew *et al.*, 1988). Each 25-acre area contained two transect lines 110 yds apart, which were approximately perpendicular to the shrubland-grassland edge. The 25-acre areas were >220 yds from each other. Transect lines were used as scent station lines. Each line consisted of 11 scent stations located at 32-yd intervals, which yielded 66 scent stations per treatment. Scent stations were located in grassland and shrubland habitats within each treatment in equal proportion. Each scent station consisted of a 1-yd circular plot of sifted soil that was cleared of debris and vegetation. Scent capsules consisted of perforated, plastic discs (HistoPrep tissue capsules, Fisher Scientific, Pittsburgh, Penn.) that contained cotton saturated with a synthetic lure (W-U lure, Fagre *et al.*, 1983). Scent capsules were placed in the center of each circular plot and were elevated about 2 inches above ground with a 3-inch nail. Scent capsules were placed on the stations in the afternoon and stations were checked the following day. Each station was recorded as either "visited" or "not visited"; species visitation was determined by track identification. An index of relative abundance was calculated for cottontail rabbits by dividing the number of visited stations by the number of operable scent stations per area each night (Linhart and Knowlton, 1975). Scent capsules were removed from the plots after each use to avoid habituation to the lure by cottontail rabbits. Scent station lines were repeated three times; ≥7 days expired between scent station line repetitions.

The index of abundance for cottontail rabbits was determined for each 25-acre area using pooled (2) transect lines. A completely randomized treatment structure with repeated measures was used to test the effect of edge length and time on the ranks of the indices of abundance for cottontail rabbits (Conover and Iman, 1981). Mean separations for the means of the ranks were made using Tukey's HSD procedure when a significant ($P < 0.05$) F-test was noted. Indices of abundance for cottontails, which were pooled across areas and time, were regressed against the 12 (i.e., three areas within four treatments) edge lengths to develop predictive equations using linear (Cody and Smith, 1991:104) and quadratic equations.

Hypothesis 3: A Radius of Full Use Exists

The radius of full use by cottontails was determined using radio telemetry. A total of 15 cottontails from DuPont Chemical, Inc. property, LaCopita Research Area, and Bomer WMA was captured with 6.6 × 8.5 × 28.3 in. wooden box traps. Each rabbit was fitted with a 150.000 Mh, 2 to 4-in. variable-circumference radio collar (L. L. Electronics, Mahomet, Ill.). Hourly locations of each cottontail rabbit was determined to simulate a 72-hour period. Radio-tracking of cottontails was conducted on La Copita, Dupont Chemicals, Inc. property, and Bomer WMA from 20 June–9 July 1995, 29 July–23 August 1995, and 8 September–2 October 1995, respectively. Each cottontail was tracked for nine 8-hour periods, from 0001 h to 0800 h, 0801 h to 1600 h, and 1601 to 2400 h, which consisted of three repetitions for each 8-hour period. Cottontails were tracked for one 8-hour period each day. Depending on capture success and animal location, multiple cottontails often were tracked concurrently. Radio locations were visually verified and marked with a numbered stake. Perpendicular distance from edge to each radio location was measured using a measuring wheel (Rolatape Distance Measuring Wheel, Forestry Suppliers, Inc., Jackson, Miss.). Distance (yds) and compass direction from a known point to each stake was recorded and plotted on an aerial map. Home range was determined by the 95% minimum convex polygon method (Dixon and Chapman, 1980) using program TELEM88 (Coleman and Jones, 1988).

Frequency distributions of cottontail rabbit hourly locations were plotted against the distance from edge (yds) for grassland and shrubland habitats. A spline model consisting of a horizontal line segment joined to an exponential curve with unknown knot was used to determine the estimated radius of full use (*r*; horizontal coordinate of knot). Because the partial derivative of the model with respect to the parameter used to specify the radius of full use is not continuous, the corresponding asymptotic standard error and confidence interval limits may not be correct. In general, this discontinuity can disturb convergence of the iterative process employed by SAS PROC NLIN (SAS Inst., Inc., 1991), which uses maximum likelihood estimation for nonlinear models, giving different results depending on different specified starting values for the parameters of the model. The model employed was:

$$Y = b_0/(b_1 - 1) \text{ for } 0 \leq X < r \text{ or } b_0/(b_1 - EXP(b_2 \times (X - r))) \text{ for } X \geq r$$

with parameters b_0, b_1, b_2, and r, where r is the radius of full use. For a wide range of reasonable starting values, convergence was obtained to essentially identical parameter estimates, with identical asymptotic standard errors, correlations, and 95% confidence interval limits for the radius of full use.

RESULTS

Hypothesis 1: Edge-benefitted Species Will Exist in the Absence of Edge

Six cottontails were observed on 11.6 miles of transects in shrubland habitat >220 yds from edge. This resulted in a density estimate of 0.13 cottontails/ac in shrubland. However, cottontails were not observed on any grassland transects (44.7 miles) >220 yds from edge. Overall cottontail density in the absence of edge (shrubland and grassland transects pooled) was estimated to be 0.027 cottontails/ac.

Hypothesis 2: Each Species Has an Edge Saturation Value

Ranks of relative abundance indices for cottontail rabbits differed (F = 11.94; 3,8 df; P = 0.0025) between edge lengths (Fig. 3). Mean index of abundance for cottontails was greatest for 345 yds of edge length ($\bar{x}$=0.20), followed by 2,066 ($\bar{x}$=0.17), 1,379 ($\bar{x}$=0.10), and 688 m of edge length ($\bar{x}$=0.03). No time effect (F=1.59; 2, 16 df; P=0.2350) or treatment by time interaction (F=1.69; 6,16 df; P=0.188) were observed.

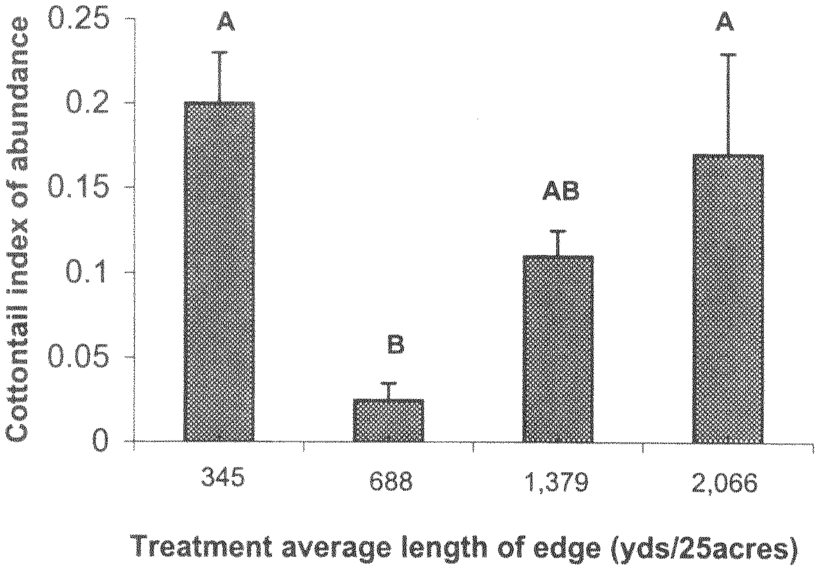

Figure 3. Cottontail rabbit mean index of abundance (proportion of scent stations visited by rabbits, $n = 66$) in relation to edge lengths in southern Texas grassland-shrubland ecotones during winter 1995–1996. Bar heights are actual mean index values and the terminal horizontal bars represent standard errors for cottontail index of abundance. Statistical analysis was conducted on ranked means of abundance. Rank means with the same letter did not differ ($P>0.05$) by Tukey's HSD test.

Linear models, as suggested by Leopold (1933), using the indices of abundance and arcsine transformation of indices of abundance for cottontails for each of the 12 different edge lengths, were not significant [($F=3.28$; 1,34 df; $P=0.08$; $R^2=0.09$) and ($F=1.55$; 1,34 df; $P=0.22$; $R^2=0.04$)], respectively. A predictive equation using untransformed indices of abundance for cottontails yielded the linear model: cottontail index of abundance = 0.00004(edge length/area) + 0.06.

A posteriori quadratic model using the indices of abundance for cottontail rabbits was significant ($F=9.79$; 2,33 df; $P=0.0005$; $R^2=0.37$). A predictive quadratic equation for cottontail index of abundance is 0.00000018 (edge length/area)^2 − 0.00037 (edge length/area) + 0.22.

Hypothesis 3: A Radius of Full Use Exists

Cottontail rabbits averaged over all 3 areas were found to travel a mean distance of 27.5 ± 30.1 yds ($\bar{x} \pm$ SE; $n = 15$) into shrubland and 36.8 ± 27.5 yds into grassland from edge. The greatest distances traveled into shrubland and grassland by cottontails were 155 yds and 143 yds, respectively. The estimated radius of full use for grasslands was 3.1 yds with asymptotic 95% confidence interval limits of 2.8 yds and 3.5 yds ($R^2=0.956$). Radius of full use by cottontails in shrubland was undefined by the spline model and therefore was graphically estimated as 0 yds. However, 60%, 77%, and 85%

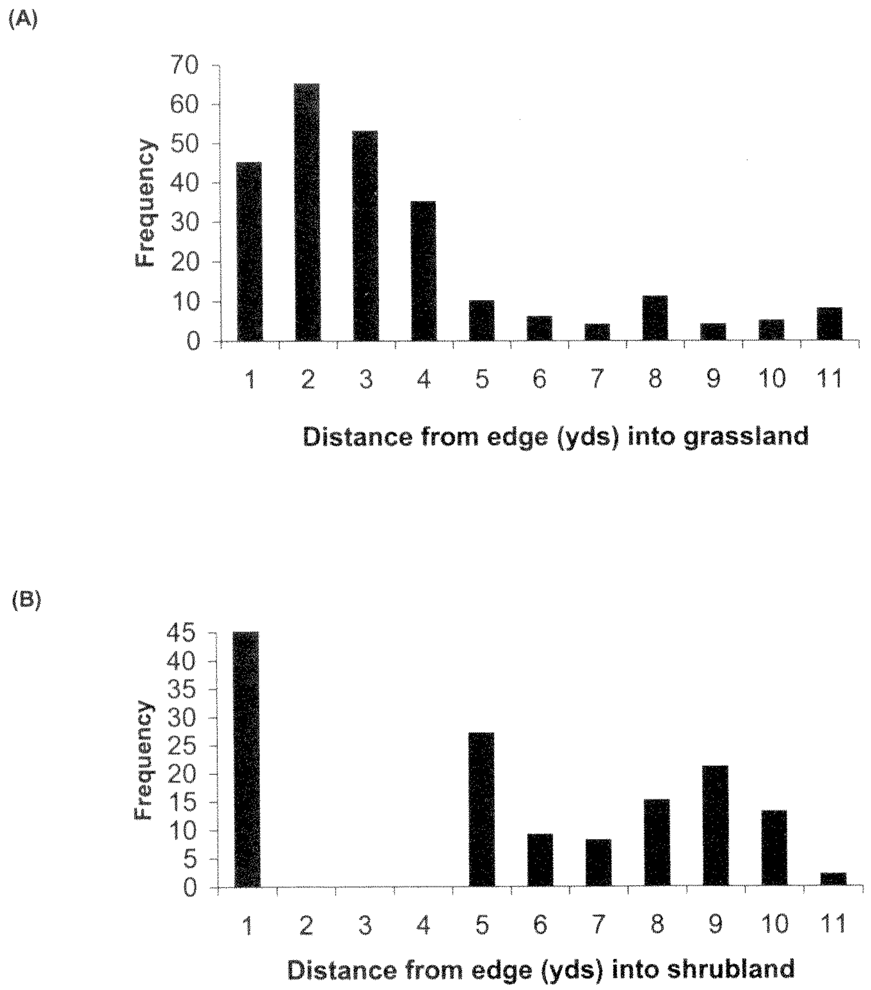

Figure 4. Frequencies of cottontail rabbit locations in (A) grassland and (B) shrubland habitat of southern Texas during summer 1995, with respect to distance (yds) from edge.

of cottontail activity was concentrated within 16, 32, and 49 yds of edge, respectively (Fig. 4). The greatest home range of a cottontail rabbit was 8.6 ac.

DISCUSSION

Empirical data were collected to examine the law of dispersion as originally outlined by Leopold (1933:132) and modified by Guthery and Bingham (1992). Our data did not fully support either theoretical model. Leopold (1933:132) suggested that edge-related species would not exist in the absence of edge, whereas Guthery and Bingham (1992) argued that edge-related species could exist in areas without edge. However, our data were ambivalent concerning this point. Cottontail rabbits were not observed in grasslands away from edge, which supports Leopold's (1933:132) theory; however, they were observed in shrublands, albeit few individuals, which favors the idea of a positive intercept as proposed by Guthery and Bingham (1992). Although our definition of shrubland included a canopy cover >50%, which constituted extremely dense brush, patches of open areas within the shrubland did exist. Such open areas intermixed within dense vegetation effectively could have been perceived by cottontails as edge. Fagan *et al.* (1999) realized that other species may visually perceive edges differently than humans. Morrison *et al.* (1992:32) recognized that humans only can hypothesize how animals perceive their environment and deemed this concept niche gestalt. Therefore, it only may be possible to determine if cottontail rabbits exist in the absence of edge within a shrubland if the shrubland has 100% canopy cover. Unfortunately, large tracts of land with 100% canopy cover are extremely rare because of current land-use practices, so such an hypothesis may not be testable using this habitat type.

Neither Leopold's (1933:132) nor Guthery and Bingham's (1992) model provided an adequate interpretation of cottontail rabbit data concerning hypothesis two. Leopold (1933:132) suggested a direct relationship between the densities of edge-related species and quantity of edge, whereas Guthery and Bingham (1992) argued that the Leopold model would hold true up to an edge saturation value where the potential density of a species would not be greater for additional edge, but beyond which, an inverse relationship would exist between densities of edge and edge-related species. However, abundance of cottontail rabbits exhibited a positive quadratic function with regards to increasing lengths of edge, which may have resulted from predator avoidance. Chapman and Tretheway (1972) noted that cottontail predation risk was directly related to distance traveled away from edge.

Redundant edge, as defined by Guthery and Bingham (1992), did not occur for cottontail rabbits on our study areas. Optimum edge density for cottontail rabbits was 1,462 yds/acre, according to the equation outlined by Guthery and Bingham (1992:343). Therefore, habitat that contains optimum edge density for cottontails would be quite patchy, such as a shrubland intermixed with open areas that do not exceed 6.2 yds from refuge cover (i.e., $2r$, where r = radius of full use). Cottontail rabbits may prefer patchy habitat as a means to avoid predators and temperature extremes. Cottontails are known to use brushpiles, hedgerows, and dense brush for escape (Chapman *et al.*, In Pennsylvania, cottontail rabbits select resting and bedding sites to avoid cold temperatures (<32 F; Althoff *et al.*, 1997); however, cottontails in southern Texas used resting sites <0.5 yd from shrub stems probably to escape hot (>95 F) rather than cold temperatures. Similar behavior of heat avoidance has been noted in other species in southern Texas (Kopp *et al.*, 1998).

We recognize that our interpretations of our results are dependent on our definitions of habitat parameters. For example, different results might have been obtained in our study had shrubland, grassland, and ecotone been defined differently. Yahner (1988) also recognized this problem and suggested that a standardized protocol for measuring and comparing edge effects in different landscapes be developed. Definitions of edge species, edge dimensions, edge age and structure, plant community types, and methods of quantifying edge effects need to be considered *a priori* (Yahner, 1988). Yahner (1988) also believed that additional studies of edge effect are needed because greater quantities of edge will be created in future landscapes due to current land-use practices.

Creation of edge was emphasized to past wildlife professionals as being beneficial to wildlife because it was widely believed that wildlife was a product of habitat interspersion

(Yoakum and Dasmann, 1971; Harris, 1988). However, recent research suggests that creation of additional edge does not always positively affect wildlife (Harris, 1988). Edges can modify distribution and dispersal of wildlife species and attract nest parasites and predators (Harris, 1988; Temple and Cary, 1988), reduce the size of large tracts of habitat necessary to interior species and cause isolation of patches and corridors (Yahner, 1988), and cause deleterious effects of herbivores on sensitive plant species (Alverson *et al.*, 1988).

Although the original premise by Leopold (1933:132) does not appear to hold true for all edge-related species and not all species are benefitted by the creation of edge, the relationship between ecotones and wildlife is intriguing and worthy of investigation. According to the definition of a scientific law (Bronowski, 1973:240), Leopold's (1933:132) law of dispersion should not be considered 'a law' because the principle does not occur with unvarying uniformity. However, it does provide a framework of ecological theory from which the more complex interactions of community ecology can be addressed.

REFERENCES

Alverson, W. S., D. M. Waller, and S. L. Solheim. 1988. Forests too deer: edge effects in northern Wisconsin. Conserv. Biol. 2:348–358.

Althoff, D. P. 1983. Daytime home range, habitat selection and microenvironments used by cottontail rabbits in central Pennsylvania. Unpubl. Ph.D. Diss., Penn. State Univ., State College, Penn. 167pp.

Althoff, D. P., G. L. Storm, and D. R. Dewalle. 1997. Daytime habitat selection by cottontails in central Pennsylvania. J. Wildl. Manage. 61:450–459.

Barnes, T. G., R. K. Hietschmidt, and L. W. Varner. 1991. Wildlife. P. 179–189 *In:* R. K. Heitschmidt and J. W. Stuth (eds.) Grazing management: an ecological perspective. Timber Press, Portland, Oreg.

Brittingham, M. C., and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? BioScience 33:31–35.

Bronowski, J. 1973. The ascent of man. Little, Brown, and Co., Boston, Mass. 448pp.

Burnham, K. P., D. R. Anderson, and J. L. Laake. 1980. Estimation of density from line transect sampling of biological populations. Wildl. Monogr. 72:1–202.

Canfield, R. H. 1941. Application of line intercept method in sampling range vegetation. J. For. 39:388–394.

Chapman, J. A., and D. E. Tretheway. 1972. Movements within a population of introduced eastern cottontail rabbits. J. Wildl. Manage. 36:155–158.

Chapman, J. A., J. G. Hockman, and M. M. Ojeda. 1980. *Sylvilagus floridanus.* Mammal. Species 136:1–8.

Cody, R. P., and J. K. Smith. 1991. Applied statistics and the SAS programming language, Third edition. Prentice Hall, Englewood Cliffs, N.J. 403pp.

Coleman, J. S., and Jones, A. B., III. 1988. User's guide to TELEM88: Computer analysis system for radio-telemetry data. Dept. Fish. And Wildl., Virginia Poly. Inst. State Univer., Blacksburg. Research Series No. 1. 49pp.

Conover, W. J., and R. L. Iman. 1981. Rank transformations as a bridge between parameteric and nonparametric statistics. Amer. Statist. 35:124–125.

Dixon, K. R., and J. A. Chapman. 1980. Harmonic mean measure of animal activity areas. Ecology 61:1040–1044.

Drew, G. S., D. B. Fagre, and D. J. Martin. 1988. Scent station surveys for cottontail rabbit populations. Wildl. Soc. Bull. 16:396–398.

Eberhardt, L. L. 1990. Using radio-telemetry for mark-recapture studies with edge effects. J. Appl. Ecol. 27:259–271.

Fafarman, K. R., and R. J. Whyte. 1979. Factors influencing nighttime roadside counts of cottontail rabbits. J. Wildl. Manage. 43:765–767.

Fagan, W. F., R. S. Cantrell, and C. Cosner. 1999. How habitat edges change species interactions. Amer. Nat. 153:165–182.

Fagre, D. B., W. E. Barnum, R. Teranishi, T. H. Schultz, and D. J. Stern. 1983. Criteria for the development of coyote lures. Vert. Pest Control Manage. Material. 4:265–277.

Forman, R. T. T., and M. Godron. 1986. Landscape ecology. John Wiley and Sons, New York, N.Y. 233pp.

Galli, A. E., C. F. Leck, and R. T. T. Forman. 1976. Avian distribution patterns in forest islands of different sizes in central New Jersey. Auk 93:355–364.

Gates, J. E., and L. W. Gysel. 1978. Avian nest dispersion and fledgling success in field-forest ecotones. Ecology 59:871–883.

Gates, J. E., and J. A. Mosher. 1981. A functional approach to estimating habitat edge width for birds. Amer. Midl. Nat. 105:189–192.

Giles, R. H. 1978. Wildlife management. W. H. Freeman and Co., San Francisco, Calif. 416pp.

Guthery, F. S., and R. L. Bingham. 1992. On Leopold's principle of edge. Wildl. Soc. Bull. 20:340–344.

Hanson, W. R., and R. J. Miller. 1961. Edge types and abundance of bobwhites in southern Illinois. J. Wildl. Manage. 25:71–76.

Harris, L. D. 1988. Edge effects and conservation of biotic diversity. Conserv. Biol. 4:330–332.

Hunter, M. L. 1990. Wildlife, forests and forestry: principles of managing forests for biological diversity. Prentice-Hall, Englewood Cliffs, N.J. 370pp.

Janes, D. W. 1959. Home range and movements of the eastern cottontail in Kansas. Univ. Kansas, Museum Nat. Hist. 10:553–572.

Johnston, V. R. 1947. Breeding birds of the forest edge in Illinois. Condor 2:45–53.

Kopp, S. D., F. S. Guthery, N. D. Forrester, and W. E. Cohen. 1998. Habitat selection modeling for northern bobwhites on subtropical rangeland. J. Wildl. Manage. 62:884–895.

Laudenslayer, W. F. 1984. Predicting effects of habitat patchiness and fragmentation-the managers viewpoint. P. 332–334 *In:* J. Verner, M. L. Morrison and C. J. Ralph (eds.) Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madkson, Wisc.

Leopold, A. 1933. Game management. Charles Scribner's Sons, New York, N.Y. 481pp.

Linhart, S. B., and F. F. Knowlton. 1975. Determining the relative abundance of coyotes by scent station lines. Wildl. Soc. Bull. 3:119–124.

Miller, W. L. 1982. Soil Survey of Victoria County, Texas. USDA, Soil Conservation Service, Texas Agricultural Experiment Station, Austin, Tex. 148pp.

Morrison, M. L., B. G. Marcot, and R. W. Mannan. 1992. Wildlife-habitat relationships: concepts and applications. University of Wisconsin Press, Madison, Wisc. 343pp.

National Oceanic and Atmospheric Administration. 1994. Climatological data annual summary; Texas 1994. National Climatic Data Center, Asheville, N.C. 76pp.

Patton, D. R. 1975. A diversity index for quantifying habitat "edge." Wildl. Soc. Bull. 3:171–173.

Reese, K. P., and J. T. Ratti. 1988. Edge effect: a concept under scrutiny. Trans. N. Amer. Wildl. Nat. Resour. Conf. 53:127–136.

Robbins, C. S. 1979. Effects of forest fragmentation on bird populations. p. 198–212 *In:* C. S. Robbins (ed.) Management of northcentral and northeastern forests for nongame birds. Northcentral Forest Experiment Station, St. Paul, Minn.

Robinson, W. L., and E. G. Bolen. 1984. Wildlife ecology and management. Macmillan Publishing Co., New York, N.Y. 478pp.

Rosenzweig, M. L. 1995. Species diversity in space and time. Cambridge Univ. Press, New York, N.Y. 436pp.

SAS Institute, Inc. 1991. SAS system for regression, Second ed. SAS Institute, Inc., Cary, N.C. 210pp.

Smith, R. H. 1950. Cottontail rabbit investigations, final report. Pittmann-Robertson Proj. 1-R. New York, N.Y. 84pp.

Soulé, M. E. 1986. The effects of fragmentation. p. 233–236 *In:* M. E. Soulé (ed.) Conservation biology: the science of scarcity and diversity. Sinauer Assoc., Inc., Sunderland, Mass.

Temple, S. A., and J. R. Cary. 1988. Modeling dynamics of habitat-interior bird populations in fragmented landscapes. Conserv. Biol. 4:340–347.

Thomas, J. W., C. Maser, and J. E. Rodiek. 1979. Edges. p. 48–59 *In:* J. W. Thomas (ed.) Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA Forest Service, Washington, D.C.

Wilcove, D. S. 1985. Nest predation in forest tracts and the decline of migratory songbirds. Ecology 66:1,211-1–214.

Yahner, R. H. 1988. Changes in wildlife communities near edges. Conserv. Biol. 4:333–339.

Yahner, R. H., and D. P. Scott. 1988. Effects of forest fragmentation on depredation of artificial avian nests. J. Wildl. Manage. 52:158–161.

Yoakum, J., and W. Dasmann. 1971. Habitat manipulation practices. p. 173–231. *In:* R. Giles (ed.) Wildlife management techniques, Third edition. The Wildlife Society, Washington, D.C.

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