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Table of Contents

Weed Management in Enhanced Glyphosate-Resistant Cotton

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ABSTRACT

Field experiments were conducted in 2003 and 2004 to evaluate glyphosate rates and timings on control of Palmer amaranth, devil's-claw, ivyleaf morningglory, and silverleaf nightshade in enhanced glyphosate-resistant cotton. Treatments based on cotton growth stage (CS) were compared to as-needed (ASN) treatments based on weed population and size. Palmer amaranth, devil's-claw, and silverleaf nightshade were controlled (> 90%) with postemergence (POST) treatments based on CS or ASN applications in both years. These weeds were controlled with glyphosate at 0.75 lb ae/A and no benefit was observed with an increased glyphosate rate. Ivyleaf morningglory control, in both years, improved with increased glyphosate rates to 1.5 lb ae/A. When the first application was delayed to 11-leaf cotton, three glyphosate applications at 1.5 lb ae/A were required to achieve control. Ivyleaf morningglory in 2003 was controlled with four glyphosate applications applied ASN beginning at two-leaf cotton and ending with the last treatment applied at 20-leaf cotton. In 2004 with increased rainfall and weed pressure, five applications of glyphosate at 1.5 lb ae/A were required for effective control (>90%).

KEY WORDS: *Amaranthus palmeri* S. Wats., cotton, devil's-claw, glyphosate rates, glyphosate timing, *Gossypium hirsutum* L., *Ipomoea hederacea* (L.) Jacq., ivyleaf morningglory, Palmer amaranth, *Proboscidea louisianica* (Mill.) Thellung, silverleaf nightshade, *Solanum elaeagnifolium* Cav., weed management systems.

Abbreviations: ASN, as-needed; cot, cotyledon; CS, crop stage; EB, early-bloom; fb, followed by; lf, leaf; PPI, preplant incorporated; PDIR, postemergence-directed; POST, postemergence.

INTRODUCTION

Glyphosate resistance in cotton was conferred by the incorporation of a 5-enolpyruvylshikimate-3-phosphate synthase (EC 2.5.1.19) gene cloned from

Agrobacterium sp. strain CP4 (CP4-EPSPS) (Johnson 1996). The expression of the CP4-EPSPS gene produces a glyphosate-resistant EPSPS enzyme which can overcome the inhibition of native EPSP synthase in the presence of glyphosate, allowing sufficient production of aromatic amino acids and secondary metabolites (Nida et al. 1996). This technology allows POST applications of glyphosate from emergence through the four-leaf stage of development and PDIR applications when cotton has five-leaves or more (Jones and Snipes 1999). The maximum glyphosate rate allowed for POST or PDIR applications is 0.75 lb ae/A. The CP4-EPSPS gene is not well expressed in male flower tissues (Chen et al. 2003; Pline et al. 2003), and glyphosate applied after the four-leaf stage can compromise reproductive development (Light et al. 2003). When late over-the-top applications were made, there have been performance and yield loss complaints in glyphosate-resistant cotton due to an increase in lower fruiting branch boll abortions and misshapen bolls (Ferreira et al. 1998; Vargas et al. 1998).

Due to the limitation of the current glyphosate-resistant cotton, an enhanced glyphosate- resistant genotype has been introduced. Roundup Ready® Flex cotton, event MON 88913, was created by transforming Coker 312 plant material using a disarmed *Agrobacterium tumefaciens* method and a CP4-EPSPS gene construct (Burns et al. 2004). The CP4-EPSPS protein as expressed in the Roundup Ready® Flex cotton is the same protein contained in the current glyphosate resistant cotton product (Burns et al. 2004). The CP4-EPSPS protein is expressed in both vegetative and reproductive tissues at levels necessary to provide resistance to glyphosate (Burns et al. 2004). Glyphosate applications at 1.5 and 2.25 lb ae/A at the 3-, 6-, 10-, and 14-lf stages did not affect yield or fiber quality compared to the non-treated control (May et al. 2004). Glyphosate is now registered for use in Roundup Ready® Flex cotton at rates up to 1.12 lb ae/A per application and a total of no more than 4.5 lb ae/A during the growing season (up to 60% open bolls). A total of 6.0 lb ae/A may be applied during the crop year.

Cotton producers throughout the Texas Southern High Plains must control many annual and perennial weeds that reduce crop yields each year. Residual herbicides applied preplant incorporated (PPI) and preemergence (PRE) are successful in managing early-season annual weeds such as Palmer amaranth (Keeling et al. 1997). However, as the residual soil activity declines, late-season control of Palmer amaranth escapes and other annual weeds including devil's-claw and ivyleaf morningglory becomes more difficult (Everitt et al. 2002; Keeling et al. 1997). These weeds compete with cotton, reducing yields, and complicating harvest. With the development of new crop herbicide resistance technologies, producers on the Texas High Plains have an opportunity to implement a variety of weed control strategies for improved annual and perennial weed management.

Glyphosate provides excellent control of Palmer amaranth, devil's-claw, and silverleaf nightshade; however, due to a limited application window and environmental conditions such as wind (causes drift) and rain (prevents equipment entering field), season-long control may be difficult (Everitt et al. 2002; Keeling et al. 1997). Glyphosate is marginally effective on annual morningglory (*Ipomoea* sp.) (Culpepper et al. 2001; Jordan et al. 1997) often requiring higher application rates and timely applications to achieve effective control (Jordan et al. 1997; McCloskey et al. 2004). Current weed management systems in glyphosate-resistant cotton provide producers with tools needed to control early-season weeds; however, late-season control requires the use of specialized sprayer equipment (Burns et al. 2004). With the introduction of Roundup Ready® Flex cotton, there is a need to determine optimum glyphosate rates and timing that will provide the most efficient weed control. Therefore, field experiments were conducted to evaluate different weed control strategies for use in Roundup Ready® Flex cotton systems.

MATERIALS AND METHODS

Field experiments were conducted in 2003 at Lubbock and Hockley County, TX and in 2004 at Lubbock, TX. The soil type at the Lubbock location was an Acuff clay loam (Fine-loamy, mixed, thermic Aridic Paleustolls) with less than 1.0% organic matter and pH 7.4. The soil type at the Hockley County location was an Amarillo fine sandy loam (Fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) with less than 1.0% organic matter and pH 7.5.

Cotton (Paymaster 2326 RR and MON 88913) was planted at a depth of 2 in. on 40-in. rows at a seeding rate of 15 lb/A and treated with aldicarb at 0.37 lb ai/A. In 2003, test was irrigated with 5.2 in. using an overhead using an overhead sprinkler irrigation system. All other tests were furrow-irrigated with 6 in. of supplemental water in 2003 and 2 in. in 2004.

A tractor-mounted compressed air sprayer or CO_2 -pressurized backpack sprayer calibrated to deliver 10 gallons per acre (GPA) was used for postemergence (POST) herbicide applications. The tractor sprayer was operated at 35 PSI with 110015 flat-fan nozzles at 3 MPH. A commercial standard treatment was used and required a hooded sprayer calibrated to deliver 10 GPA at a speed of 5 MPH. Percent weed control was estimated each week throughout the season using a scale of 0 to 100, with 0 equal to no control and 100 equaling complete control (Frans et al. 1986). Ratings were made approximately 3-, 60, and 100 days after planting (DAP), reflecting early-, mid-, and late-season control. Cotton lint was harvested in 2004 from both Roundup Ready® Flex varieties using a sample size of 2 rows (6.6 ft) by 6.6 ft. Samples were weighed and a 22 percent turnout was applied to seed cotton weight.

***Ivyleaf morning glory*.** Studies were established in 2003 and 2004 in Hockley County, TX and Lubbock, TX, respectively. A natural infestation of ivyleaf morningglory was present in both years. Plot size was 4 rows (13 ft.) by 30 ft. in length. Trifluralin was applied at 0.75 lb ai/A and incorporated to a depth of 3 in. with a spring-tooth harrow before planting. Glyphosate was applied POST topical at 0.75 or 1.5 lb ae/A in three weed management systems based on crop growth stage (CS), as-needed (ASN: 0.4 to 0.8 in.), or a combination of CS and ASN (Table 1).

***Palmer amaranth, devil's-claw and silverleaf nightshade*.** Experiments were established near Lubbock, TX in areas naturally infested with Palmer amaranth, devil's-claw and silverleaf nightshade in 2003 and 2004 (Table 2). Plot size was 8 rows (26.2 ft) by 30 ft in length. Trifluralin was applied at 0.75 lb ai/A and incorporated to a depth of 3 in. with a spring-tooth harrow before planting. Glyphosate was applied POST at 0.75 or 1.5 lb ae/A in three weed management systems based on CS, ASN, or a combination of CS and ASN

Table 1. Postemergence-topical glyphosate application dates and crop and weed growth stages for ivyleaf morningglory control in 2003 and 2004[a].

Application	2003 Date	2003 Crop stage	2003 Weed stage	2004 Date	2004 Crop stage	2004 Weed stage
POST I	May 29[b]	cotyledon to 1 leaf	cotyledon	May 24[c]	1 leaf	2 leaf
POST II	N/A	N/A	N/A	Jun 1[b]	3 to 4 leaf	cotyledon to 2 leaf
POST III	Jun 11[b]	3 to 4 leaf	cotyledon to 2 leaf	N/A	N/A	N/A
POST IV	N/A	N/A	N/A	Jun 15[c]	6 to 8 leaf	cotyledon to 2 leaf
POST V	Jun 25[c]	8 leaf	cotyledon to 4 leaf	Jun 23[c]	10 to 12 leaf	cotyledon to 3 leaf
POST VI	Jul 1[c]	10 to 11 leaf	cotyledon to 4 leaf	Jul 1[c]	12 to 14 nodes	cotyledon to 4 leaf
POST VII	Jul 9[c]	11 to 12 leaf	cotyledon to 2 leaf	N/A	N/A	N/A
POST VII	Jul 30[c]	early bloom	cotyledon to 4 leaf	Jul 21[c]	early bloom	cotyledon to 4 leaf
POST IX	Sep 3[c]	peak bloom	cotyledon to 4 leaf	Aug 4[c]	peak bloom	cotyledon to 2 leaf

[a] Abbreviations: N/A, not applicable; POST, postemergence-topical.
[b] Glyphosate applied at 1.5 lb ai/A.
[c] Glyphosate applied at both 0.75 and 1.5 lb ai/A.

Table 2. Postemergence-topical glyphosate rate and timing treatments for Palmer amaranth, devil's-claw, and silverleaf nightshade control[a].

Applications 2003	Date	Crop stage	Palmer amaranth	Devil's-claw	Silverleaf nightshade
				in.	
POST I[b]	Jun 11	cotyledon to 1 leaf	0	0	4
POST II[c]	Jul 1	5 to 6 leaf	0	0 to 4	10
POST III[c]	Jul 11	6 to 8 leaf	0	4	1 to 7
POST IV[c]	Jul 15	10 to 11 leaf	6	4	6
POST V[c]	Jul 21	10 to 12 leaf	4	4	6
POSTVI[c]	Jul 29	early bloom	2	12	5
Applications 2004					
POST I[c]	May 24	2 leaf	0	cotyledon to 3	1 to 4
POST II[b]	Jun 1	3 to 4 leaf	0	3 to 4	1 to 6
POST III[c]	Jun 15	6 to 8 leaf	cotyledon to 1	cotyledon to 1	0.5 to 3
POST IV[c]	Jun 23	10 to 12 leaf	cotyledon to 3	cotyledon to 4	0.5 to 5
POST V[c]	Aug 4	early bloom	cotyledon to 12	cotyledon to 12	0.5 to 8

[a] Abbreviations: POST, postemergence-topical.
[b] Glyphosate applied at 1.5 lb ae/A.
[c] Glyphosate applied at both 0.75 and 1.5 lb ae/A.

All experiments were arranged as a randomized block design with a factorial arrangement with three replications. Data were subjected to an analysis of variance, and means were separated using Fisher's protected LSD test at the 5% probability level. Percent weed control data were arcsine transformed before analysis for stability; however, non-transformed data are presented mean separation based on transformed data.

RESULTS AND DISCUSSION

Ivyleaf Morningglory Control.

A weed management system by rate interaction was not observed for early- or mid-season ivyleaf morningglory control in 2003; therefore, data were averaged over weed management systems within rates and over rates within weed management systems. A weed management system by rate interaction was observed for late-season ivyleaf morningglory control in 2003; therefore, data were not averaged across weed management system or rate. A weed management system by rate interaction was not observed for early-season ivyleaf morningglory control assessments in 2004; therefore, data were averaged over weed management systems within rates and within rates over weed management systems. A weed management system by rate interaction was observed for mid- and late-season ivyleaf morningglory.

Early-season ivyleaf morningglory control was greater following glyphosate at 1.5 lb ae/A (81%) than at 0.75 lb ae/A (72%) rate and control was similar among systems (Table 3). Effective mid-season ivyleaf morningglory control (96 to 98%) was observed in all weed management systems (94 to 99%) following both glyphosate rates. In other research, late-season ivyleaf morningglory control was improved with increased glyphosate rates, regardless of weed management system (Jordan et al. 1997; McCloskey et al. 2004). Glyphosate POST applied in CS/ASN and ASN systems controlled ivyleaf morningglory better than glyphosate POST applied in the CS system at both rates.

Application timing was essential for achieving effective ivyleaf morningglory control. Rainfall from January to March totaled 0.5 in. with an additional 7.4 in. recorded throughout the growing season (Apr to Sep). Due to the dry early-season, ivyleaf morningglory emergence was reduced, which decreased the need for early-season ASN applications. More effective control was achieved with the same amount of glyphosate when applied based upon weed density and size (Table 3).

Similar early-season ivyleaf morningglory control (89 to 91%) was achieved with all weed management systems (Table 4). Glyphosate at 1.5 lb ae/A controlled ivyleaf morningglory 94%, which was greater than the 85% control achieved with glyphosate at 0.75 lb ae/A. Mid-season control was not different between weed management systems at each glyphosate rate. However, glyphosate at 1.5 lb ae/A achieved greater ivyleaf morningglory control than glyphosate at 0.75 lb ae/A in the ASN and CS/ASN weed management systems. Effective late-season control (98%) was achieved with glyphosate at 1.5 lb ae/A applied five times in the CS/ASN and ASN weed management systems (Table 4). Regardless of rate, three glyphosate applications in the CS weed management system failed to provide 75% ivyleaf morningglory control.

Similar to 2003, environmental conditions in 2004 affected ivyleaf morningglory emergence and control. Above average rainfall was recorded with January to March rainfall totaling 5.3 in. and a growing season (Apr to Sep) total of 16.7 in. Due to these conditions, early-season CS applications were more beneficial than in 2003 (Tables 3 to4). However, to achieve season-long control, additional ASN applications were necessary to control ivyleaf morningglory. An increase in glyphosate rate improved ivyleaf morningglory control.

Table 3. Effect of glyphosate rate and weed management system on ivyleaf morningglory control in 2003[a].

Evaluation timing	Weed management system	Rate[b] 0.75		1.5		avg	
		%					
early-season	CS (2 leaf)	70		83		77	A[c]
	CS/ASN (2 leaf)	73		79		76	A
	ASN[d]	N/A		N/A		N/A	
	avg	72	Y[e]	81	X		
mid-season	CS (2 fb 7 fb 11 leaf)	99		99		99	A
	CS/ASN (2 fb 7 leaf)	97		98		98	A
	ASN (11 leaf)	91		97		94	A
	avg	96	X	98	X		
late-season	CS (2 fb 7 fb 11 leaf)	55	b[f]y[g]	65	bx	60	
	CS/ASN (2 fb 7 fb 17 fb 19 leaf)	89	ay	99	ax	94	
	ASN (11 fb 17 fb 19 leaf)	87	ay	97	ax	92	
	avg	77		87			

[a] Abbreviations: ASN, as-needed; avg, average; CS, crop stage; fb, followed by; N/A, not applicable.
[b] Rate = lb ae/A.
[c] Weed management system means followed by the same upper case letter (A, B, C) are not significantly different (P=0.05) using Fisher's Protected LSD.
[d] Ivyleaf morningglory emergence was limited by dry conditions; therefore, no applications were required in the ASN weed management system.
[e] Rate means followed by the same upper case letter (X, Y, Z) are not significantly different (P=0.05) using Fisher's Protected LSD.
[f] Weed management system means within a rate followed by the same lower case letter (a, b, c) are not significantly different (P=0.05) using Fisher's Protected LSD.
[g] Rate means within a weed management system followed by the same lower case letter (x, y, z) are not significantly different (P=0.05) using Fisher's Protected LSD.

Palmer amaranth, devil's-claw, and silverleaf nightshade control.
A weed management system by rate interaction was not observed for early or late-season Palmer amaranth, devil's-claw or silverleaf nightshade control or for Palmer amaranth mid-season. A weed management system by rate interaction was observed in mid-season silverleaf nightshade control; therefore, data were not averaged over weed management system or rate.

Table 4. Effect of glyphosate rate and weed management system on ivyleaf morningglory control in 2004[a].

Evaluation timing	Weed management system	Rate[b] 0.75		1.5		avg	
		——— % ———					
early-season	CS (1 fb 7 leaf)	89		92		91	A[c]
	CS/ASN (1 fb 7 leaf)	85		94		90	A
	ASN (1 fb 7 leaf)	82		96		89	A
	avg	85	Y[d]	94	X		
mid-season	CS (1 fb 7 fb 11 leaf)	89	a[e]x[f]	96	ax	93	
	CS/ASN (1 fb 7 leaf fb 13 node)	85	ay	96	ax	91	
	ASN (1 fb 7 leaf fb 13 node)	79	ay	94	ax	87	
	avg	84		95			
late-season	CS (1 fb 7 fb 11 leaf)	73	bx	79	bx	76	
	CS/ASN (1 fb 7 leaf fb 13 node fb EB fb PB)	86	ay	98	ax	92	
	ASN (1 fb 7 leaf fb 13 node fb EB fb PB)	80	aby	98	ax	89	
	avg	80		92			

[a] Abbreviations: ASN, as-needed; avg, average; CS, crop stage; EB, early bloom; fb, followed by; PB, peak bloom.
[b] Rate = lb ae/A.
[c] Weed management system means followed by the same upper case letter (A, B, C) are not significantly different (P=0.05) using Fisher's Protected LSD.
[d] Rate means followed by the same upper case letter (X, Y, Z) are not significantly different (P=0.05) using Fisher's Protected LSD.
[e] Weed management system means within a rate followed by the same lower case letter (a, b, c) are not significantly different (P=0.05) using Fisher's Protected LSD.
[f] Rate means within a weed management system followed by the same lower case letter (x, y, z) are not significantly different (P=0.05) using Fisher's Protected LSD.

Palmer amaranth was controlled at least 99% throughout the season regardless of application timing or rate (Table 5). All weed management systems effectively controlled devil's-claw at least 99%, with the exception of glyphosate at 0.75 lb ae/A applied mid-season in the ASN weed management system (85%). Glyphosate at 1.5 lb ae/A controlled silverleaf nightshade 81%, which was greater than 74% control following glyphosate at 0.75 lb ae/A. Similar to mid-season devil's-claw control, a difference in silverleaf nightshade control was observed in the ASN weed management system. Regardless of rate, three glyphosate applications controlled at late-season silverleaf nightshade at least 93% (Table 5). These results show that an increase in glyphosate rate did not improve control of these weeds. This data supports Croon et al. (2003) who reported that an increase in glyphosate rate may be less important than timely applications.

All weed management systems controlled Palmer amaranth and devil's-claw 90-100%, regardless of application timing or rate (Table 6). Three glyphosate applications at 0.75 lb ae/A in the CS weed management system provided greater mid-season silverleaf nightshade control (92%) than two applications in the CS/ASN (83%) and ASN (86%) systems. No differences in silverleaf nightshade control were observed across weed management systems with the highest glyphosate rate. All weed management systems and rates effectively controlled silverleaf nightshade at least 93% with three glyphosate applications.

These data show that Palmer amaranth, devil's-claw, and silverleaf nightshade can be controlled season-long when glyphosate is applied at 0.75 lb ae/A based upon either CS or ASN application timings (Table 6). Previous research by Dotray and Keeling (1996) reported that a fall application of glyphosate at 0.75 lb ae/A provided effective long-term control of silverleaf nightshade. Keeling et al. (1999) reported that an additional PDIR glyphosate application improved season-long control of silverleaf nightshade.

Yield data were not collected in 2003 due to USDA regulations requiring the test area to be destroyed due to a breach in the borders surrounding the test area. In 2004, glyphosate rate and weed management system had no effect on cotton lint yield. When averaged across rates within weed management systems, cotton lint yields ranged from 533 to 553 lb/A. When averaged across weed management systems within rates, cotton lint yield was at least 539 lb/A (Table 7). This yield was likely due to effective weed control in all weed management systems.

Table 5. Effect of glyphosate rate and timing on Palmer amaranth, devil's-claw, and silverleaf nightshade control 2003[a].

		Palmer amaranth						Devil's-claw						Silverleaf nightshade					
Evaluation		Rate[b]						Rate						Rate					
timing	Weed management system	0.75		1.5		avg		0.75		1.5		avg		0.75		1.5		avg	
		%																	
early-season	CS (2 leaf)	100		100		100	A[c]	100		100		100	A	73		80		77	A
	CS/ASN (2 leaf)	100		100		100	A	100		100		100	A	76		80		78	A
	ASN (2 leaf)	100		100		100	A	100		100		100	A	73		82		78	A
	avg	100	X[d]	100	X			100	X	100	X			74	Y	81	X		
mid-season	CS (2 fb 7 fb 12 leaf)	100		100		100	A	100	a[e]x[f]	99	ax	99		94	ax	97	ax	96	
	CS/ASN (2 fb 5[g] fb 10 leaf)	100		100		100	A	99	ax	100	ax	99		93	ax	93	ax	93	
	ASN (2 fb 5 leaf)	99		100		99	A	85	by	99	ax	92		85	by	93	ax	89	
	avg	100	X	100	X			95		99				91		94			
late-season	CS (2 fb 7 fb 12 leaf)	100		100		100	A	100		100		100	A	95		98		97	A
	CS/ASN (2 fb 5[g] fb 10 leaf)	99		99		99	A	100		100		100	A	94		92		93	A
	ASN (2 fb 5 fb 14 leaf)	99		99		99	A	100		100		100	A	97		96		97	A
	avg	99	X	99	X			100	X	100	X			95	X	95	X		

[a] Abbreviations: ASN, as-needed; avg, average; CS, crop stage; fb, followed by.
[b] Rate = lb ae/A.
[c] Weed management system means followed by the same upper case letter (A, B, C) are not significantly different (P=0.05) using Fisher's Protected LSD.
[d] Rate means followed by the same upper case letter (X, Y, Z) are not significantly different (P=0.05) using Fisher's Protected LSD.
[e] Weed management system means within a rate followed by the same lower case letter (a, b, c) are not significantly different (P=0.05) using Fisher's Protected LSD.
[f] Rate means within a weed management system followed by the same lower case letter (x, y, z) are not significantly different (P=0.05) using Fisher's Protected LSD.
[g] 5 leaf application at 0.75 lb ae/A only..

Table 6. Effect of glyphosate rate and timing on Palmer amaranth, devil's-claw, and silverleaf nightshade control 2004[a].

Evaluation timing	Weed management system	Palmer amaranth Rate[b] 0.75		1.5		avg		Devil's-claw Rate 0.75		1.5		avg		Silverleaf nightshade Rate 0.75		1.5		avg	
		%																	
early-season	CS (2 leaf)	100		100		100	A[c]	99		98		99	A	72		80		76	A
	CS/ASN (2 leaf)	100		100		100	A	100		100		100	A	70		68		69	A
	ASN (2 leaf)	100		100		100	A	98		100		99	A	73		83		78	A
	avg	100	X[d]	100	X			99	X	99	X			72	X	77	X		
mid-season	CS (2 fb 7 fb 11 leaf)	100		99		99	A	99		98		99	A	92	a[e]y[f]	99	ax	96	
	CS/ASN (2 fb 11 leaf)	100		100		100	A	99		99		99	A	83	by	95	ax	89	
	ASN (2 fb 11 leaf)	100		100		100	A	99		99		99	A	86	by	95	ax	91	
	avg	100	X	100	X			99	X	99	X			87		96			
late-season	CS (2 fb 7 fb 11 leaf)	99		99		99	A	99		99		99	A	97		99		98	A
	CS/ASN (2 fb 11 leaf fb early bloom)	99		99		99	A	100		100		100	A	92		94		93	A
	ASN (2 fb 11 leaf fb early bloom)	99		99		99	A	100		100		100	A	96		96		96	A
	avg	99	X	99	X			99	X	99	X			95	X	96	X		

[a] Abbreviations: ASN, as-needed; avg, average; CS, crop stage; fb, followed by.
[b] Rate = lb ae/A.
[c] Weed management system means followed by the same upper case letter (A, B, C) are not significantly different (P=0.05) using Fisher's Protected LSD.
[d] Rate means followed by the same upper case letter (X, Y, Z) are not significantly different (P=0.05) using Fisher's Protected LSD.
[e] Weed management system means within a rate followed by the same lower case letter (a, b, c) are not significantly different (P=0.05) using Fisher's Protected LSD.
[f] Rate means within a weed management system followed by the same lower case letter (x, y, z) are not significantly different (P=0.05) using Fisher's Protected LSD.

Table 7. Effect of glyphosate rate and timing on cotton lint yield in 2004[a].

	Rate[b]		
Weed management system	0.75	1.5	avg
	lb/A		
CS (2 fb 7 fb 11 leaf)	568	538	553 A[c]
CS/ASN (2 fb 11 leaf fb early bloom)	577	516	547 A
ASN (2 fb 11 leaf fb early bloom)	502	562	533 A
avg	549 X[d]	539 X	

[a] Abbreviations: ASN, as-needed; avg, average; CS, crop stage; followed by.
[b] Rate = lb ae/A
[c] Weed management system means followed by the same upper case letter (A, B, C) are not significantly different (P=0.05) using Fisher's Protected LSD.
[d] Rate means followed by the same upper case letter (X, Y, Z) are not significantly different (P=0.05) using Fisher's Protected LSD.

These results indicate that glyphosate rate and timing were essential to effectively control ivyleaf morningglory. Early-season applications made based on CS timings were unnecessary in 2003 due to a lack of early-season rainfall, however in 2004 these timings were beneficial as well as two additional ASN late-season applications. Late-season control also demonstrated the importance of increasing glyphosate rate from 0.75 to 1.5 lb ae/A. Glyphosate applied at 1.5 lb ae/A controlled ivyleaf morningglory at least 97% in 2003 and 98% in 2004 season-long when applications were made based on weed growth stage.

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EFFECTS OF BERMUDAGRASS-CLIPPINGS PELLETS ON GROWTH AND CARCASS CHARACTERISTICS OF LAMB

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ABSTRACT

Sixty Suffolk, Suffolk x Rambouillet, and St. Croix x Dorper (hair sheep) lambs were randomly assigned within breed group to 10 pens to determine if bermudagrass-clippings (*Cynodon dactylon* L.) from lawns could be an alternative forage source in feedlot diets. Each pen, an experimental unit, consisted of Suffolk (n=2), Suffolk x Rambouillet (n=2), and hair crossbred (n=2) lambs. Treatment and control diets were randomly assigned to pens with five replications. Treatment diets contained bermudagrass-clipping pellets with control diets containing alfalfa (*Medicago sativa* L.) pellets, each fed at 10% of the total ration. Lambs were weighed on day 0 and weekly, thereafter, and fed ad libitum to end weights of 54 kg for wethers and 49 kg for ewe lambs at which time they were slaughtered. No differences were observed between treatments for feed efficiency or carcass characteristics, although breed effects existed. While breed did not effect total gain (P > .05), effects were determined (P < .05) for days on feed, average daily gain, consumption, average daily feed intake (ADFI), and feed:gain. No treatment*breed interaction (P > .05) existed for feed efficiency or carcass characteristics. Therefore, bermudagrass-clippings can be an alternative forage source for feedlot lambs when fed at 10% of a finishing diet.

KEY WORDS: Lambs, Bermudagrass, Growth

INTRODUCTION

Bermudagrass is commonly grown in many domestic lawns across the United States. Mowing of these lawns produces millions of tons of lawn wastage annually. The Environmental Protection Agency has stated that grass-clippings and lawn wastage account for approximately 18% of the refuse that has historically been dumped into landfills (EPA, 1998). Other means of disposal of grass-clippings have included mulching and composting but this has made little reduction in the overall wastage.

Alfalfa is a common forage fed to ruminant livestock for production. Alfalfa supplies necessary protein and energy for animals to grow and maintain life.

Bermudagrass is not very similar to alfalfa in general. However, bermudagrass from domestic lawns exhibits many of the same nutritive qualities as alfalfa (Table 1). Therefore, research was conducted to determine if bermudagrass collected from domestic lawns could be used as an alternative forage source in livestock diets. The research had two objectives. The first objective of this study was to determine the affects of feeding bermudagrass-clipping pellets on days on feed, average daily gain, ADFI, feed:gain, hot carcass weight, dressing percent, back fat thickness, leg score, flank streaking, and quality grade of lambs. The second objective was to compare breed types of lambs to determine if feed efficiency or carcass characteristics were affected by feeding bermudagrass-clipping pellets.

Table 1. Chemical Composition of Bermudagrass-Clipping Pellets and Alfalfa Pellets

	Bermudagrass	Alfalfa
DM, %	89.25	92.81
Ash, %[a]	15.35	12.3
CP, % [a]	24.23	18.81
Ca, % [a]	1.12	1.19
P, % [a]	0.3	0.22
NDF, % [a]	58.51	45.52
Nitrates, %[a]	0.18	--

[a]DM Basis

MATERIALS AND METHODS

Animals, Diets, and Management: Sixty medium wool and hair breed lambs (average initial BW=36.73 kg) were used to study the effects of bermudagrass-clipping pellets on growth efficiency and carcass characteristics. On day 0, lambs were weighed and within breed sex combination were randomly allotted to pens within treatment. Each pen consisted of one Suffolk wether, one Suffolk ewe lamb, one Suffolk x Rambouillet wether, one Suffolk x Rambouillet ewe lamb, one hair breed wether, and one hair breed ewe lamb. The experimental unit was considered the pen. All animals had free access to water. Two treatments consisting of either 10% alfalfa pellets or 10% bermudagrass-clipping pellets (Tables 2) were randomly assigned to the 10 research pens. Table 3 lists the chemical compositions of the treatment and control diets.

Alfalfa pellets used in the experiment were analyzed to determine percent DM, ash, CP, Ca, P, and NDF. Bermudagrass-clippings used in the study were collected from a local landscape company immediately after clipping. The lengths of the grass-clippings were approximately 0.635 cm to 1.27 cm in length. After collection, clippings were weighed and dried for 48 h. After drying, grass-clippings were then weighed to determine percent shrink. Clippings were then pelleted through a 0.953 cm dye and bagged.

Table 2. Ingredient Composition of Diets (% of diet, DM basis)

Ingredient	Treatment	Control
Cracked Corn	64.87	63.26
Cottonseed Meal 41% CP	5.75	5.75
Soybean Meal 44% CP	2.05	3.76
Cottonseed Hulls	10.50	10.50
Pelleted Bermudagrass-Clippings	10.00	0.00
Alfalfa Pellets	0.00	10.00
Calcium Carbonate	1.30	1.20
Ammonium Chloride	0.50	0.50
Cane Molasses	5.00	5.00
Premix[a]	0.03	0.03

[a]Premix included Vitamin A, Selenium, and Decox at levels recommended by NRC (1985)

Table 3. Chemical Composition of Treatment and Control Diets

	Treatment Diet	Control Diet
DM, %	86.81	87.26
Ash, %[a]	8.71	7.53
CP, %[a]	13.65	13.82
Ca, %[a]	1.12	1.03
P, %[a]	0.33	0.39

[a] DM Basis

Laboratory analysis was also performed on the bermudagrass clippings to determine percent DM, ash, CP, Ca, P, NDF, and Nitrates.

Feed bunks were visually evaluated between 1600 and 1700 daily for estimation of the daily feed allotment. The quantity of unconsumed feed remaining in each bunk was estimated, and the quantity of feed delivered was adjusted to ensure ad libitum feed intake. Feed samples of each treatment were obtained for DM determination. After completion of the 98-d study, feed samples were sorted by treatment and a composite of each treatment was made. These composites were then analyzed for contents of DM, CP, ash, Ca, and P (AOAC, 1990).

Lambs were weighed every seven days during the trial. At the conclusion of the trial, feed bunks were swept and any remaining feed was removed from the bunk, weighed, and sampled for DM content. The DM content of the feed weigh-back was determined in the same manner as weekly feed samples, and the quantity of dry feed removed from the bunk was subtracted from the total of the dry feed delivered to obtain an accurate measurement of ADFI and consequently feed efficiency.

As lambs reached their target weight, they were removed from the study. Target weight for wethers was set at 54 kg and 49 kg for ewe lambs. Carcass data was collected from the wethers. Ewe lambs were used as replacement ewes for the Texas Tech University sheep flock. When target weights were met, lambs were slaughtered. Animals were slaughtered at four different time periods. Carcass characteristics including hot carcass weight, dressing percent, back fat thickness, leg score, flank streaking, and quality grade were collected. Fat thickness was measured at the 12th rib and flank streakings were scored and used as a measure of quality. The scale from least to most streaking was: devoid, practically devoid, slight, modest, moderate, slightly abundant, and abundant. Leg scores were used to assign a muscle score to a carcass. The scale from least to the most muscling was: devoid, slight, modest, moderate, slightly abundant, and abundant. Yield grade is based on the fat thickness at the 12th rib, and quality grade is based on the leg and flank streaking score.

Statistical Analysis: Initial weight, days on feed, ADG, Total DMI, ADFI, and feed:gain ratio was analyzed as a completely randomized split plot design in the Mixed procedure of SAS (1999). Within breed sex combination, lambs were randomly allotted to pens within treatment. Treatment effect was analyzed in the main plot and breed and treatment*breed interaction was analyzed in the sub-plot. Pen was considered the experimental unit for all feed efficiency data.

Hot carcass weight, dressing percent, back-fat thickness, leg score, conformation, flank streaking, and quality grade were also analyzed as a completely randomized split plot design in the Mixed procedure of SAS (1999). Just as with the feed efficiency data, lambs were randomly allotted to pens within treatment within breed sex combination. Carcass data was only collected on the wethers because ewe lambs were returned to the flock as replacement ewes. Treatment effect was analyzed in the main plot and breed and treatment*breed interaction was analyzed in the sub-plot just as in the feed efficiency data. Animal was considered the experimental unit for all carcass data.

RESULTS AND DISCUSSION

Initial weight, days on feed, average daily gain, ADFI, and feed:gain ratio were not significantly different ($P > .05$) between the treatment group and the control group. However, initial weight was different ($P < .02$) between Suffolk and hair sheep as well as Rambouillet x Suffolk and hair sheep ($P < .05$). Hair sheep were significantly higher ($P < .001$) than Suffolk and Rambouillet x Suffolk for days on feed and total dry matter intake. This however, may be attributed to the difference in initial weight rather than breed type. Average daily gain and ADFI were lower ($P < .01$) for hair sheep than for Suffolk and Rambouillet x Suffolk, and feed:gain ratio was higher ($P < .001$) for hair sheep than for Suffolk and Rambouillet x Suffolk. Feed efficiency data for treatment effects and breed effects are reported in Table 4 and 5.

Table 4. Treatment Effects on Feed Efficiency of Lambs Consuming Either Alfalfa or Bermudagrass at 10% of a Concentrate Diet

	Treatment		
Item	Alfalfa Diet	Grass Diet	SEM
Initial wt., kg	36.19[a]	37.41[a]	1.25
Days on feed	59.39[a]	55.74[a]	4.61
Daily gain, kg/d	0.318[a]	0.310[a]	0.018
Total dry matter intake, kg	85.08[a]	79.88[a]	5.83
Average daily feed intake, kg/d	1.45[a]	1.45[a]	0.015
Feed:Gain	5.02[a]	4.90[a]	0.298

[a,b]Means within the same row with different superscripts differ (P < .05) SEM =Standard Error of the Mean; n=30 for each mean

Table 5. Breed Effects on Feed Efficiency of Lambs Consuming Either Alfalfa or Bermudagrass at 10% of a Concentrate Diet

	Breed			
Item	Suffolk	Hair	Suffolk x Rambouillet	SEM
Initial wt., kg	38.63[a]	34.21[b]	37.55[a]	1.53
Days on feed	45.77[a]	76.26[b]	50.6[a]	2.56
Daily gain, kg/d	0.359[a]	0.245[b]	0.338[a]	0.022
Total dry matter intake, kg	67.56[a]	106.16[b]	73.71[a]	7.14
Average daily feed intake, kg/d	1.47[a]	1.40[b]	1.46[a]	0.018
Feed:Gain	4.23[a]	6.11[b]	4.54[a]	0.365

[a,b]Means within the same row with different superscripts differ (P < .05) SEM =Standard Error of the Mean; n=20 for each mean

Live weight, hot carcass weight, dressing percent, fat thickness, leg score, conformation, flank streaking, and quality grade were not significantly different (P < .05) between the treatment group and the control group. Live weight, hot carcass weight, dressing percent, leg score, and conformation were not different (P < .05) between hair, Suffolk, and Rambouillet x Suffolk lambs. However, Suffolks had less (P < .05) fat thickness than hair or Rambouillet x Suffolk lambs. Hair sheep had more (P < .05) flank streaking than Suffolk lambs and tended to have a higher quality grade (P < .06). Carcass caracteristic data for treatment effects and breed effects are reported in Table 6 and 7.

Table 6. Treatment Effects on Carcass Characteristics of Lambs Consuming Either Alfalfa or Bermudagrass at 10% of a Concentrate Diet

	Treatment		
Item	Alfalfa Diet	Grass Diet	SEM
Live weight at slaughter, kg	54.87[a]	55.28[a]	1.73
Hot carcass weight, kg	29.34[a]	30.00[a]	1.01
Dressing percent	53.53[a]	54.43[a]	1.26
Fat thickness, in.	0.256[a]	0.270[a]	0.025
Leg score	12.6[a]	12.73[a]	0.481
Conformation	12.53[a]	12.60[a]	0.458
Flank streakings	11.20[a]	11.21[a]	0.392
Quality grade	11.73[a]	11.54[a]	0.287

[a,b]Means within the same row with different superscripts differ ($P < .05$) SEM =Standard Error of the Mean; n=20 for each mean

Feeding systems that promote rapid lamb growth, such as concentrates fed in drylot, usually result in greater feed efficiency (McClure et al., 1994). Lambs fed in this trial were fed in a drylot situation to determine feed efficiency differences between concentrate diets containing either alfalfa pellets or bermudagrass-clipping pellets. No treatment differences were seen for any feed efficiency parameters or carcass characteristics. However, breed effects were significant for several factors.

Initial weight was lower ($P < .05$) for hair sheep than for Suffolk and Suffolk x Rambouillet. Because of this, days on feed and ADFI may be invalid when determining differences. Average daily gain was lower for hair sheep than for Suffolk and Suffolk x Rambouillet. This agrees with Wildeus (1997) stating that growth rates of hair sheep are generally lower than those of traditional wool breeds in the United States. Wildeus (1997) further stated that this difference can be partially attributed to the low input management systems and stressful tropical environmental conditions under which these breeds were developed.

ADFI was lower for hair sheep than for Suffolk and Suffolk x Rambouillet. This agrees with findings of Horton and Burgher, 1992 stating that DMI of high energy diets was lower ($P < .05$) in Saint Croix and Blackbelly Barbado lambs than in Dorset and Katahdin. Feed:gain ratio was higher for hair sheep than for Suffolk and Suffolk x Rambouillet. This contradicts the findings of McClure et al. (1991); Horton and Burgher, (1992); and Phillips et al. (1995) who claimed that Saint Croix and Blackbelly Barbado had similar feed:gain ratios to those of wool breeds. However, the ratios of Blackbelly Barbados and Blackbelly Barbado crosses were lower for feed:gain ratio (Shelton, 1983a; Horton and Burgher, 1992).

Live weight, hot carcass weight, dressing percent, leg score, and conformation were not different ($P > .05$) between breed groups. These findings are not unusual but there are not any consistent differences in dressing percent reported between hair and wool breeds (Wildeus, 1997). Fat thickness was less (P < .05) for Suffolk lambs than for hair and Suffolk x Rambouillet lambs. Data on differences in backfat thickness are also not consistent (Wildeus, 1997). Although, McClure et al. (1991) and Solomon et al. (1991) found increased backfat thickness (P < .01) in Targhee compared with Saint Croix, but these lambs had 20 to 30% lower slaughter weights. Flank streaking was higher (P < .05) for hair sheep when compared to Suffolk lambs, but not higher (P > .05) when compared to Suffolk x Rambouillet lambs. Quality grade was higher (P < .05) for hair sheep when compared to Suffolk lambs. Quality grade for hair sheep and Suffolk x Rambouillet lambs were not different (P < .05). Wilderus, 1997 also states that differences in quality grades are also inconsistent between hair and wool type sheep. Ockerman et al. (1982) found that Blackbelly Barbado had lower (P< .05) quality grades than Saint Croix and wool breeds. These lower grades may have been the result of a lower slaughter weight.

CONCLUSION

Bermudagrass clippings, as managed in this experiment, can be used as an alternative forage source in a concentrate diet for lambs. Feed efficiency and carcass characteristics were favorable for all lambs consuming the treatment diet. Breed effects tended to be significantly different (P < .05) for some feed efficiency as well as carcass characteristics. However, this was not due to the bermudagrass clipping or alfalfa pellet diet.

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Long-Term Financial Impacts of Cattle and Wildlife Management Strategies in South Texas

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ABSTRACT

Wildlife management is becoming the principal, as opposed to a supplemental, enterprise in many ranches. Specifically in South Texas, forage and brush control considerations for wildlife habitat have become an integral, if not the predominant, management issue for some ranch operations. In this time of shifting away from range management dominated by livestock needs, this paper illustrates the financial implications of alternative management strategies targeted toward optimizing wildlife habitat and the profitability of ranching/hunting operations.

KEY WORDS: wildlife, ranching, management strategies, financial, profitability

INTRODUCTION

Over the past 25 years, wildlife management involving deer and bird hunting has become a key component of a typical ranch operation. This has largely resulted from the growth in the number of hunting enthusiasts living in major metropolitan areas acquiring ownership or leasing ranches for hunting purposes. Over the past decade, many land owners and cattle producers have reduced or eliminated their cattle herds to concentrate more on deer and bird hunting recreation or lease opportunities.

Completely eliminating the livestock enterprise could be going one step too far. Range management experts, emphasizing that the same tools that destroyed habitat such as the axe, the plow, fire, the cow, and the rifle (Leopold, 1933), can be used to enhance and maintain wildlife populations. There is a need to maintain grazing at adequate livestock stocking rates to help manage proper forage and brush conditions for wildlife. If done properly, livestock grazing can be an income producing habitat management strategy. Mechanical and/or chemical brush control can also be used to manage and enhance native wildlife habitat.

Ranchers in South Texas have three basic livestock enterprise options available, including cow-calf, stockers or a mix of the two. All three options have benefits and consequences which may not fully be recognized in the short term. However, a mix of cow-calf and stockers is not a common practice in the South Texas area. The long-term implications of each option make management analysis and decisions difficult, particularly when cattle prices are expected to cyclically decline over the next few years.

REVIEW OF LITERATURE

Various authors have discussed the need of good management of grazing animals as a tool in enhancing wildlife habitat or keeping grasses from getting too dense or too tall. This in turn improves overall income possibilities from livestock and wildlife enterprises. Fulbright and Ortega (2006) explain that livestock is an integral part of managing the dry-land ranching habitat of Oklahoma, Texas and Northern Mexico. Range and wildlife managers should have a greater appreciation of the synergy between range and wild management, particularly in deer management. Guthery (1986) makes a simple point that quail and cattle can coexist with excellent production from both. Guthery shows that grazing, properly managed, is one of the simplest and most encouraging tools for providing a diversity of cover types for bobwhite quail. Fuhlendorf, et al, (2006) recognize grassland ecosystems are dependent on periodic disturbance, such as grazing by native herbivores, periodic burning, and/or mowing/haying, for habitat maintenance. The authors emphasize that the habitat mosaic is probably best maintained through some type of rotational management system involving herbivores in which grassland areas receive management on a regular schedule.

From an economic perspective, the portfolio effects of enterprise diversification are well known. In the case of wildlife and livestock, the synergistic impacts on habitat can be complemented by the financial risk reducing benefits of diversification. Mishra and El Osta (2002) clearly illustrate the risk management value of enterprise diversification as they study the likelihood of managers to use the technique. The value of hunting and other recreational enterprises are continually growing and becoming an ever more significant factor contributing to the market value of land (Henderson and Moore, 2006). With the increasing demand for leasing hunting rights, it is important for the ranch manager to find an appropriate mix of traditional livestock enterprises with recreational activities without overemphasizing a single enterprise.

MATERIALS AND METHODS

The Financial And Risk Management (FARM) Assistance financial planning model was used to evaluate and illustrate the individual financial impacts of various management strategies on a representative ranch in South Texas. FARM Assistance is a farm-level stochastic simulation model and is the basis of an outreach program by Texas AgriLife Extension. It is a decision support system (DSS) available to any Texas producer which addresses the decision steps of formulating strategic business alternatives and evaluating their likely financial impact. As a DSS, FARM Assistance simplifies the evaluation process, increasing the likelihood that farm managers will more accurately evaluate alternative strategies (Klose and Outlaw, 2005). Kaase, et al (2003) describe the FARM Assistance process as a unique combination of a state-of-the-art decision-support system with an extension risk management specialist working one-on-one with a producer to provide individualized economic and risk assessment evaluations. Klose and Outlaw (2005) describe the technical simulation methodology and the philosophy of providing information to help producers choose among long-term strategic business alternatives. To accomplish that objective, a baseline is created representing the current strategic plan for moving the operation through a ten-year planning horizon. The baseline serves as a benchmark for comparing the long-term financial implications of alternative plans (Kaase, et al, 2007). The FARM Assistance stochastic financial forecast methodology serves as the basis for analyzing the potential impacts a producer might expect from common wildlife habitat management strategies in South Texas.

The FARM Assistance model is used to develop financial projections for a model ranch under four distinct management scenarios. The projected financial position and performance was evaluated across five major categories including profitability, liquidity, repayment capacity, solvency, and financial efficiency. Representative measures were chosen for each of these categories to assess the financial implications of each scenario. The stochastic nature of the model provides information with respect to the projected variability in the ranch=s financial position and performance. When taken as a whole, the analysis provides insight into the risk and return expectations of the ranch throughout the planning horizon under each management strategy.

This case study was based on the expert knowledge and input of area management, range, and livestock specialists. It analyzes four possible scenarios: 1) a 200 head cow-calf operation (1 animal unit to 10 acre stocking rate), 2) a 100 head cow-calf operation (1 animal unit to 20 acre stocking rate), 3) hunting only with no cattle, and 4) hunting with stocker leasing income (250 head stockers grazed March-August).

The ranch is assumed to be 2,000 acres and the basic assumptions and characteristics for each scenario are given in Table 1. Off-farm income is another diversified source of income that contributes to the overall financial picture of the typical landowner/decision-maker in the region. Off-farm operator and spouse income were included in the study as a typical 2,000 acre ranch in South Texas would normally not be a full-time business with the ability to sustain a positive cash flow independently. In all four scenarios, the ranch was assumed fully owned with no royalty income. Across South Texas, royalty income is not common in most ranches. Hunting income was included in the four scenarios as it is a common practice.

Production yields and costs, estimates for overhead charges, and hunting and stocker lease rates were based on representative or typical rates for the region (Table 1). It was assumed that hunting income was based on three-year leases with rate appreciation each renewal. Herbicide costs for weed and brush control varied by management strategy according to typical application rates for South Texas. Stocker grazing and hunting lease rates were held constant for the ten-year planning horizon. The assets, debts, machinery inventory, and scheduled equipment replacements for the projection period were the same in the two cow-calf scenarios. In the hunting only and hunting with stockers scenarios, no cattle or hay trailers were included. Moreover, the hunting with stockers scenario assumed the grass was leased out with no cattle ownership. It is assumed the ranch has only intermediate term debt in all scenarios.

Initially, local cattle prices were obtained from the Live Oak Livestock Commission Company auction report in Three Rivers, Texas, for September 10, 2007. The base year for the ten-year analysis of the representative ranch is 2007 and projections are carried through 2016. Commodity and livestock price trends follow projections provided by the Food and Agricultural Policy Research Institute (FAPRI, University of Missouri), with costs adjusted for inflation over the planning horizon.

Table 1: Representative South Texas Ranch Assumptions

	Scenarios			
	1	**2**	**3**	**4**
Selected Parameter	**Hunting & Cow-Calf (200 Cows)[1]**	**Hunting & Cow-Calf (100 Cows)[2]**	**Hunting Only**	**Hunting & Stockers**
Operator Off-Farm IncomeYear	$24,000	$24,000	$24,000	$24,000
Spouse Off-Farm Income/Year	$35,000	$35,000	$35,000	$35,000
Family Living Expense/Year	$30,000	$30,000	$30,000	$30,000
Ownership Tenure	100%	100%	100%	100%
Royalty Income	None	None	None	None
Stocker Leasing Income/Year (March-August)	N/A	N/A	N/A	$8/head/mo. (6 months)
Hunting Income/Acre/Year	$7	$7	$10	$10
Deer Stands, Feeders, Feed	Hunters Provide	Hunters Provide	Hunters Provide	Hunters Provide
Herbicide Costs/Acre	$1.50	$3	$4	$1.50
Herd Size	200 cows, 8 bulls	100 cows, 4 bulls	N/A	250 head
Calf Weaning Rate	85%	85%	N/A	N/A
Cow Herd Replacement	Bred cows	Bred cows	N/A	N/A
Salt/Mineral blocks/Year	$15/cow	$15/cow	N/A	$10.50/head
Hay Fed/Cow/Year	1.5 tons	1.0 tons	N/A	N/A
Protein Cubes Fed/Cow/Year	150 lbs.	100 lbs.	N/A	N/A
Cow Culling Rate/Year	7.50%	7.50%	N/A	N/A
Steer Weaning Weights	525 lbs.	525 lbs.	N/A	N/A
Heifer Weaning Weights	475 lbs.	475 lbs.	N/A	N/A
Steer Prices (2007)	$1.20/lb.	$1.20/lb.	N/A	N/A
Heifer Prices (2007)	$1.10/lb.	$1.10/lb.	N/A	N/A
Cull Cow Prices (2007)	$.50/lb.	$.50/lb.	N/A	N/A
Cull Bull Prices (2007	$.60/lb.	$.60/lb.	N/A	N/A
Bred Cow Prices	$1,100/head	$1,100/head	N/A	N/A
Replacement Bull Prices	$2,000/head	$2,000/head	N/A	N/A
Hay Prices (2007)	$100/ton	$100/ton	N/A	N/A
Range Cube Prices	$.142/lb.	$.142/lb.	N/A	N/A

[1] One animal unit to 10 acres stocking rate.
[2] One animal unit to 20 acres stocking rate.

RESULTS

A comprehensive financial projection, including price and weaning weight risk for the two cow-calf scenarios, is illustrated in Table 2 and Figures 1-3. Table 2 presents the average outcomes for selected financial projections, while the graphical presentations illustrate the range of possibilities for the selected variable. Total cash receipts averaged $113,250 over the ten-year period for scenario 1 (cow-calf, 1-10 stocking rate), which is significantly more than the other three scenarios. Average cash costs were $97,740 for Scenario 1. Variations in cash costs for the four scenarios largely reflect differences in operating costs such as labor, herbicides, feed and cattle purchased, and other production costs.

Profitability measures the extent to which a farm or ranch generates income from the use of its resources. One measure of profitability is net cash farm income (NCFI), which is the total of all operating cash inflows and outflows. NCFI is expected to be the lowest over the ten-year planning horizon in Scenario 3 (hunting only). Net cash farm income is projected to be -$12,470 in 2007, compared to positive NCFI in the two cow-calf scenarios and -$100 in the hunting with stockers scenario (Table 2 and Figures 1-3). For 2007-2016, it is expected to average -$12,850 in Scenario 3, $15,510 for Scenario 1, -$1,580 for Scenario 2 (cow-calf, 1-20 stocking rate), and -$920 for Scenario 4 (hunting with stockers). Over the ten-year period, cash receipts in all four scenarios will generally decline along with projected cattle prices, while operating expenses trend upward with inflation (Figures 1-3). Figure 1 also illustrates the risk in NCFI, with the range indicating profit levels from approximately -$6,000 to $48,000 in Scenario 1 and -$10,000 to $20,000 in Scenario 2 are possible. These ranges suggest that there is significant risk of operating losses over the projected period. The shaded area of the graph suggests that the operation is expected to have a 50% chance of realizing a $1,000 to $34,000 profit level in Scenario 1 and -$6,000 to $12,000 in Scenario 2. Figures 2 & 3 illustrate the NCFI for Scenarios 3 and 4 compared to Scenario 1. Projected hunting income per acre was increased every three years in both scenarios. Stocker lease rates were not changed in the hunting with stocker scenario, reflecting a stable history of lease rates in the area. As a result, expected increases in operating expenses lead to a decline in NCFI over the ten-year period for both scenarios. Figure 2 reflects no risk in projected NCFI due to hunting lease rates contractually increasing every three years. Figure 3 illustrates possible profit levels from -$9,000 to $7,000 in the hunting with stocker scenario, with a 50% chance of realizing a -$4,000 to $2,000 profit level.

Liquidity measures the ability of a farm or ranch to meet its short-term financial obligations without disrupting the normal operations of the business. The liquidity of the operation may be measured by the ending cash balance (Table 2). In all four scenarios, no cash flow problems are expected as cash reserves are projected to grow over the planning horizon. The growth in cash reserves is largely dependent on off-farm income, which is common for a typical ranch. Growth in cash reserves in Scenario 1 is projected to be 36.2% more than Scenario 2, 126% more than Scenario 3 and 46.9% more than Scenario 4.

Table 2: Financial Projections - Selected Indicators

Scenarios	2007	2010	2013	2016	Avg.
Total Cash Receipts ($1,000)					
1-Hunting & Cow-Calf (200 Cows)[1]	121.55	112.75	109.46	110.98	113.25
2-Hunting & Cow-Calf (100 Cows)[2]	68.06	64.18	63.01	64.26	64.50
3-Hunting Only	20.00	21.40	22.80	24.20	21.68
4-Hunting & Stockers	32.00	33.38	34.81	36.22	33.68
Total Cash Costs ($1,000)					
1-Hunting & Cow-Calf (200 Cows)[1]	97.86	97.47	97.50	99.60	97.74
2-Hunting & Cow-Calf (100 Cows)[2]	61.07	62.20	63.45	65.75	62.92
3-Hunting Only	32.47	33.79	35.24	36.80	34.53
4-Hunting & Stockers	32.10	33.63	35.52	37.39	34.60
Net Cash Farm Income ($1,000)					
1-Hunting & Cow-Calf (200 Cows)[1]	23.69	15.28	11.96	11.38	15.51
2-Hunting & Cow-Calf (100 Cows)[2]	6.99	1.97	-0.44	-1.49	-1.58
3-Hunting Only	-12.47	-12.39	-12.44	-12.60	-12.85
4-Hunting & Stockers	-0.10	-0.25	-0.71	-1.17	-0.92
Ending Cash Reserves ($1,000)					
1-Hunting & Cow-Calf (200 Cows)[1]	47.40	147.69	257.40	373.69	
2-Hunting & Cow-Calf (100 Cows)[2]	36.46	105.70	186.35	274.30	
3-Hunting Only	20.58	52.71	103.99	165.37	
4-Hunting & Stockers	31.10	89.47	167.07	254.47	
Probability of Ending Cash Reserves < Zero (%)					
1-Hunting & Cow-Calf (200 Cows)[1]	1	1	1	1	1
2-Hunting & Cow-Calf (100 Cows)[2]	1	1	1	1	1
3-Hunting Only	1	1	1	1	1
4-Hunting & Stockers	1	1	1	1	1
Real Net Worth ($1,000)					
1-Hunting & Cow-Calf (200 Cows)[1]	2,056.76	2,337.48	2,457.12	2,554.94	
2-Hunting & Cow-Calf (100 Cows)[2]	1,967.16	2,223.01	2,332.83	2,416.44	
3-Hunting Only	1,864.11	2,091.42	2,192.81	2,265.22	
4-Hunting & Stockers	1,874.41	2,125.60	2,247.69	2,337.49	
Average Annual Operating Expense/Receipts					
1-Hunting & Cow-Calf (200 Cows)[1]	0.81	0.87	0.90	0.91	0.87
2-Hunting & Cow-Calf (100 Cows)[2]	0.90	0.98	1.01	1.03	0.98
3-Hunting Only	1.58	1.57	1.53	1.52	1.58
4-Hunting & Stockers	1.00	1.02	1.03	1.05	1.04

[1]One animal unit to 10 acres stocking rate.

[2]One animal unit to 20 acres stocking rate.

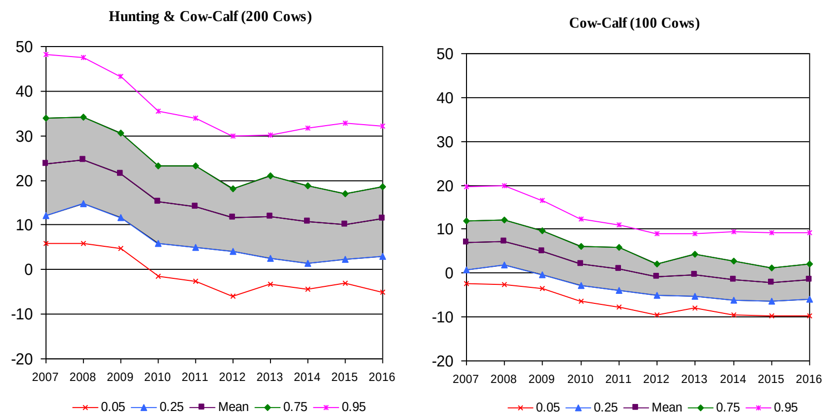

Figure 1. Projected Variability in Net Cash Farm Income for the Hunting & Cow-Calf Scenarios: 200 Cows (1 A.U. to 10 Ac. Stocking Rate) and 100 Cows (1 A. U. to 20 Ac. Stocking Rate).

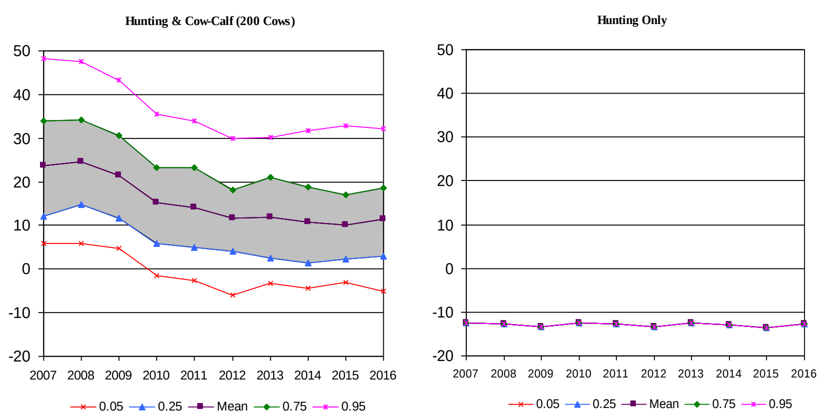

Figure 2. Projected Variability in Net Cash Farm Income for the 200-Cow Hunting & Cow-Calf (1 A.U. to 10 Ac. Stocking Rate) and Hunting Only Scenarios.

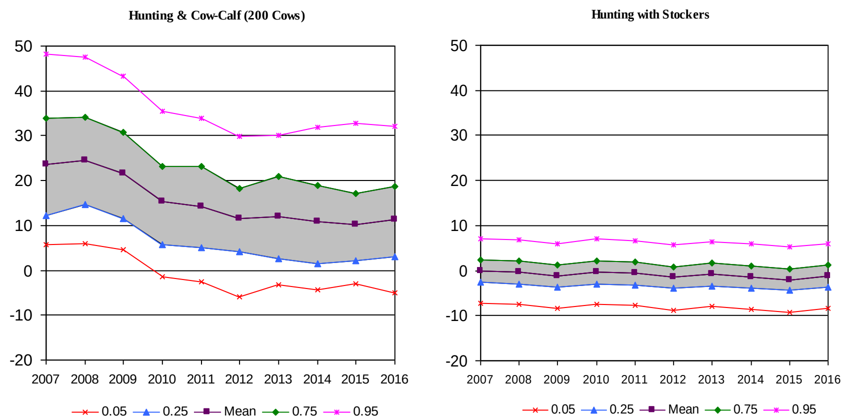

Figure 3. Projected Variability in Net Cash Farm Income for the 200-Cow Hunting & Cow-Calf (1 A.U. to 10 Ac. Stocking Rate) and hunting with Stockers Scenarios.

Repayment capacity measures the ability of a borrower to repay debt. Probability of refinancing measures the likelihood that an individual or business will not be able to meet all financial obligations in a particular year and thus be forced to refinance or roll over operating debt. Table 2 depicts the risk associated with the ending cash balance by showing the probability of refinancing or carryover operating debt. Due to off-farm income, all scenarios have a low probability of cash shortages as cash reserves are expected to grow. The probability of carryover debt is 1% or less over the projection period for all four scenarios.

Solvency is a comparison of the value of owned assets to the amount of debts owed, and real net worth is a measure of the owner's interest or equity adjusted for inflation. Growth in cash reserves and real estate assets translates into a projected increase in real net worth in all scenarios. However, in Scenario 1, real net worth reaches $2,554,940, 5.7% more than Scenario 2, 12.8% more than Scenario 3, and 9.3% more than Scenario 4 (Table 2).

Financial efficiency measures the intensity with which various assets or parts of the business are used to generate revenues. Operating expense-to-receipts ratio indicates what percentage of revenues went for operating expenses (Table 2). Scenario 1 is the most efficient of the four scenarios. The operating expense-to-receipts ratio is projected to average .87 for Scenario 1, .98 for Scenario 2, 1.58 for Scenario 3 and 1.04 for Scenario 4 over the ten-year period.

DISCUSSION

Currently, there is a tendency to charge all ranch expenses to the cattle operation making the wildlife operation look extremely profitable. Whether this tendency is carried out on paper or simply the perception of the rancher, it can lead to ill-informed decisions to shift the hunting/livestock enterprise mix. When expenses are allocated fairly across all enterprises and the ranching operation is analyzed as a whole unit, it is obvious that no one enterprise can stand on its own.

Wildlife management will continue to add to the bottom line of a South Texas ranch and be an integral part of overall operations. Nevertheless, results show that cattle enterprises will likely continue to contribute most significantly to the financial well-being of the typical ranching business. The results of this study also depict that utilizing cattle to manage forage and brush conditions is a preferable alternative for ensuring business profitability and financial condition. The type of cattle operation and stocking rates will be dependent on location, forage, and weather conditions and management preference or business limitations.

Stocker operations may be attractive to some since the cattle are only on the ranch part of the year and can be gone during the hunting season. Ranch managers can still attain the objectives of excess grass removal, stimulation of forbs, and general habitat improvement. Stockers provide flexibility in that the ranch can easily be de-stocked in case of drought or fully stocked in case of excess forage.

Management options have varying opportunities, challenges and benefits ranging from immediate cash flow survival to long-term production and equity retention. While the analysis does not suggest a best management practice in all situations, it provides increased insight into the multi-year impacts of managing cattle and hunting enterprises in concert. More specifically the study illustrates the need for ranch managers to formally analyze their combined financial performance relative to the specific capacities and opportunities associated with the land.

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Spatial Distributions of Adult Male White-Tailed Deer Relative to Supplemental Feed Sites

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ABSTRACT

Nutrient intake of deer in south Texas is lowest in late summer and winter; therefore, supplemental food may be provided during these times by managers. When natural food resources become scarce, white-tailed deer (*Odocoileus virginianus*) may shift home ranges or core areas to incorporate supplemental food sources. Thus, supplemental food sources may influence daily movements and home range characteristics of deer. To examine how deer were distributed relative to supplemental feed sites, 48 adult male white-tailed deer were radio collared and tracked from October 2002 to August 2004. The average density of supplemental feeders within deer home ranges was 47% lower in year 1 and 18% lower in year 2, than the density of feeders in the study area (>0.19 supplemental feeders/mile^2). Home ranges of deer with feed (n = 17, 635.6 ± 64.5 acres) were larger ($t_{25} = 3.44$, $P = 0.002$) than deer home ranges without feed (n = 14, 379.8 ± 37.1 acres). In both years, there was no difference among seasons in the distance between deer locations and supplemental feeders ($P \geq 0.495$). Furthermore, there was no difference ($P \geq 0.667$) between the distances deer were found from supplemental feeders compared to the distance random points were from supplemental feeders during years 1 and 2. These data demonstrated that supplemental feeders had little effect on deer spatial dynamics. Therefore, it appears that other habitat components may have had a stronger influence on deer movements than supplemental protein feeders alone. Our results will help wildlife managers determine how many supplemental feeders to install based on average density and distances deer were located to these resources during times of above average rainfall.

KEY WORDS: Home range, movements, *Odocoileus virginianus*, protein, supplemental feeders, white-tailed deer

INTRODUCTION

Providing pelleted supplemental feed is a common practice during winter to increase survival of cervids (Baker and Hobbs 1985, Carhart 1943, Smith 2001). In northern latitudes, white-tailed deer (*Odocoileus virginianus*) are exposed to harsh winters with reduced food availability, and increased energetic costs (Moen 1976). However, in south Texas, deer may be limited nutritionally during hot, dry summers or need access to feed year-round to supplement low-quality vegetation. For this reason, year-round supplemental feeding (Payne and Bryant 1994) is a common practice in Texas where white-tailed deer are intensively managed (Cooper et al. 2006). An estimated 47% of hunting leases in Texas provide supplemental feed for white-tailed deer (Thigpen et al. 1990). Adult male white-tailed deer on a study area with an intensive supplemental feed program (Webb et al. 2007a) had greater survival compared with other studies of adult males without access to feed (DeYoung 1989, Ditchkoff et al. 2001). However, Webb et al.'s (2007a) study did not show direct evidence that providing supplemental feed was the reason for increased survival.

Animal distributions may be changed when supplemental feed is provided. Altering herbivore distribution has the potential to alter vegetation communities by concentrating animals near feeders, which creates localized areas of high population density (Cooper et al. 2006). If food is readily available, then animals may browse more selectively (Stephen and Krebs 1986) potentially damaging highly palatable plants (Anderson and Katz 1993, Murden and Risenhoover 1993, Augustine and Jordan 1998, Cooper et al. 2006). Cooper et al. (2006) found deer browsing was heavier near feed sites compared to control sites, yet feeder sites appeared to have little effect on home range size of deer.

Little information exists on how year-round supplemental feeding affects deer movements and home range size and shape. Competition at supplemental feed stations may be decreased with increased densities of feed stations (Bartoskewitz et al. 2003). Supplemental feed use by deer during winter in Ontario was lower than expected; possibly due to low densities of feeders (Schmitz 1990). Therefore, it is necessary to determine proper density of supplemental feeders to maximize benefits to deer and avoid wasting resources in establishing excessive numbers of supplemental feeders. Our objectives were to: 1) determine what effect supplemental feeder distribution had on adult male white-tailed deer home ranges, and 2) determine how adult male deer movements were influenced by supplemental feeders.

MATERIALS AND METHODS

Study Area

We conducted our study on a free-ranging population of white-tailed deer on the Callaghan Ranch (27°48'59"N, 99°18'49"W) from October 2002 through August 2004. The Callaghan Ranch is located in Webb County, Texas 26.7 miles northeast of Laredo, TX. The ranch consisted of 85,000 acres of mesquite- (*Prosopis glandulosa*) dominated shrubland (McCoy 2001). The ranch was stocked with domestic cattle at a rate of 1 animal unit/51.9 acres and deer density was estimated to be 1 deer/28.2 acres in 2002 and 1 deer/30.6 acres in 2003 (Callaghan Ranch, unpublished data) based on helicopter surveys not corrected for visibility bias. Free water was distributed across the ranch through earthen stock ponds, concrete troughs, and ephemeral creeks at a density of 0.32

permanent water sources/mile² (Webb et al. 2007b). Supplemental feed sites with pelleted, protein feed were distributed across the study area at an average density of approximately 1 feed site/0.24 mile². Supplemental feeders (1-2/pen) were housed in a circular feed pen (i.e. supplemental feed site) ≥59 feet in diameter and constructed of 2.8 foot tall hog feedlot panels. Supplemental feed sites were constructed to exclude cattle and feral pigs (*Sus scrofa*). Corn was also fed as bait during the hunting season (October through January) along roads and in timer feeders.

Webb County is in the Western Rio Grande Plains of Texas. Cattle ranching and leasing hunting rights for white-tailed deer and other game are primary land-based economic activities. Webb County had an average daily maximum temperature in July of 98.2 F, an average daily minimum in January of 43.3 F, and received a mean annual rainfall of 19.8 inches. Most rainfall (70%) usually fell between April and September (Sanders and Gabriel 1985). Total annual rainfall was 19.2, 25.7 and 27.2 inches in 2002, 2003 and 2004, respectively (Laredo, Texas; National Climatic Data Center 2002, 2003, 2004).

Capture and handling

We captured 19 adult, (estimated ≥4 years-of-age) male white-tailed deer on the Callaghan Ranch during October 2002 using a net-gun fired from a helicopter (Webb et al. 2008). In addition, we recaptured 13 known-age adult males (5.5 years-of-age) originally captured and radio-collared as yearlings in 1998 as part of another study (McCoy et al. 2005). The next year we caught 3 additional adult males (estimated ≥4 years-of-age) in October 2003 and 13 additional adult males (estimated ≥4 years-of-age) in March 2004. To minimize mortalities due to capture myopathy, we did not pursue deer for more than 8 min (DeYoung 1988).

Upon capture, we manually restrained and blindfolded deer then aged them according to tooth replacement and wear (Severinghaus 1949) using site-specific known-age jaws as reference. We placed colored ear-tags and radio-collars equipped with both movement and mortality sensors (Advanced Telemetry Systems, Inc., Isanti, Minnesota) on deer ≥4 years-of-age. We released deer at the site of capture within 20 min to minimize stress. Capture and handling procedures were approved by the Texas A&M University-Kingsville Institutional Animal Care and Use Committee (Permit No. 2003-5-14).

Radio-telemetry

We located deer 1-2 times/week during diurnal, nocturnal, and crepuscular time periods using a Telonics TR-2 radio-receiver with TS-1 scanner (Telonics, Inc., Mesa, Arizona) and a null-peak radio telemetry system consisting of 2 yagi 4-element antennas (Advanced Telemetry Systems, Inc., Isanti, Minnesota). We estimated bearings to the transmitter using the null-peak radio telemetry system and a hand-held compass. We took compass bearings ≥12 m from the truck to reduce interference and corrected for declination (White and Garrott 1990) by adding 6.5º to the final bearing total.

We estimated locations using 2-5 bearings and Location of a Signal software (LOAS; Ecological Software Solutions™, Sacramento, CA). Locations derived from ≥3 bearings were estimated by the Maximum Likelihood Estimator (Lenth 1981) and those derived from 2 bearings were calculated by Best Biangulation Estimator in LOAS. We converted locations to a Geographic Information System (GIS) for use in Arc-View 3.2 software (Environmental Systems Research Institute, Inc., Redlands, CA.). We obtained relocations on deer ≥12 hours apart to reduce autocorrelation. Visual observations were recorded with a differential GPS (DGPS) unit and were used in the final estimation of home range size.

To assess accuracy of the null-peak radio telemetry system, we randomly placed radio transmitters throughout the study area and georeferenced them with a DGPS unit. Mean telemetry error (n = 13) was 89.5 yards ± 12.8 (SE) for locations with ≥3 bearings.

Home range estimation

We used the fixed kernel home range estimator (Worton 1989) to generate 95% home ranges using the Animal Movement Extension (Hooge and Eichenlaub 1997) in ArcView 3.2 software for deer that were tracked 1 full year and that had ≥30 locations. We used the reference bandwidth (h_{ref}) when calculating the 95% probability polygons. We calculated annual home ranges from 15 October 2002 to 14 October 2003 (year 1) and 15 October 2003 to 25 August 2004 (year 2).

Data collection

We mapped all supplemental feeders within the study area using a DGPS and brought the data into ArcGIS 8.2 software. We monitored supplemental feeders to determine number of months per year they contained pelleted feed. Supplemental feeders were never empty more than 3 consecutive weeks and never empty more than 2 months total within a given year. Therefore, supplemental feeders with feed for ≥10 total months/year and not empty >3 consecutive weeks were considered available to deer year-round.

To determine if supplemental feeders had an effect on deer home range placement, we compared supplemental feeder density (supplemental feed sites/mile^2) within annual home ranges of deer to the density of feeders available on the study area. Seaman et al. (1999) recommended that a minimum of 30 locations be obtained for kernel home range estimators. In this analysis, we used only deer that were tracked 1 full year and that had ≥30 locations.

We defined the study area by creating a minimum convex polygon around all deer telemetry locations and buffering out 89.7 yards (the average error of our telemetry system). We excluded areas outside the ranch boundary from the analysis because we did not have access to map feed sites.

To assess seasonal effects of supplemental feeders on deer movements we used telemetry locations within season to determine mean minimum distance to supplemental feeders. We defined seasons by calendar dates (i.e. spring, summer, fall, winter). For each deer within each season we calculated the distance (yards) from each telemetry location to the nearest supplemental feed site using the spatial join function in ArcGIS 8.2 software. Although this analysis did not involve deer home ranges, only telemetry locations within season, we only used deer that were tracked for 1 full year and had ≥30 locations.

To determine if deer were found closer than expected to supplemental feeders within each deer's home range, we generated 1,000 random points using a random point generator in ArcGIS 9.x. Only deer that were tracked 1 full year and that had ≥30 locations were used in the analysis when generating random locations within home ranges. All random locations within a home range were used to determine mean minimum distance to supplemental feed sites. The mean minimum distance of random locations were compared to the mean minimum distance of actual telemetry locations pooled across seasons to determine if actual deer locations were closer than expected to supplemental feeders within the home range.

Statistical analysis

We assessed the influence of supplemental feeders on the location of deer home ranges within the study area using a 1-sample *t*-test by comparing the density of supplemental feed sites within home ranges to the density available on the entire study area. Because the density of supplemental feed sites within the study area changed through the construction of additional supplemental feed sites at the end of year 1, we analyzed the 2 years separately. A 2 sample *t*-test was used to assess home range size differences for deer with feed and without feed in their home ranges. A Satterthwaite approximation was used because of unequal variance.

We used a randomized complete block design (RCBD) analysis of variance (ANOVA) with deer as blocks to test for seasonal (i.e. treatment) differences within year for distance (i.e. response) to nearest supplemental feed site. We used a paired *t*-test to test if actual annual distances from deer locations to supplemental feeders were different from random location distances to supplemental feed sites. Last, we calculated the percent of locations for each deer, regardless of whether they had a supplemental feed site within their home range, to the nearest supplemental feed site within 4 distance categories (0-547, 547-1,094, 1,094-1,640, and 1,640-2,187 yards). We conducted all analyses using SAS (SAS Institute, Inc. 1989). We concluded statistical significance for $P \leq 0.05$. Means are reported ± SE.

RESULTS

During this study, we monitored 48 male deer. Not all deer survived an entire year; therefore, we excluded these deer from annual home range analyses. This left 31 deer (21 deer in year 1 and 10 deer in year 2) in our study. Deer ranged in age from 4.5 to ≥8.5 years-of-age.

Average number of relocations used during years 1 and 2 were 56 ± 1.3 and 40 ± 1.2, respectively. Average 95% fixed kernel home range size was 512.4 ± 50.4 acres and 557.7 ± 74.4 acres for years 1 and 2, respectively (Webb et al. 2007c). Home ranges of deer with feed (n = 17, 635.6 ± 64.5 acres) were larger ($t_{25} = 3.44$, $P = 0.002$) than deer home ranges without feed (n = 14, 379.8 ± 37.1 acres).

Average density of supplemental feed sites in deer home ranges was 47% lower in year 1 (0.1 ± 0.006 feeders/mile^2; $P = 0.006$) than the average density of supplemental feed sites on the study area (0.188 feeders/mile^2). There was no difference in year 2 between feeder density in home ranges (0.235 ± 0.049 feeders/mile^2; $P = 0.333$) and across the study area (0.285 feeders/mile^2). During year 1, 57% (12 of 21) of deer did not have any supplemental feed sites within their home range, whereas 20% (2 of 10) of deer in year 2 did not have any supplemental feed sites within their home range.

More deer were found within 547-1,094 yards of supplemental feed sites during year 1 (Figure 1). During year 2, more deer were found within 547 yards of supplemental feed site (Figure 1). Also during year 2, no deer were found >1,640 yards from supplemental feed sites (Figure 1). When all locations were combined for all seasons and both years; 34.3, 51.3, 14.1, and 0.3% of locations were in distance groups 0-547, 547-1,094, 1,094-1,640, and 1,640-2,187 yards, respectively. Averaged across years, 86% of deer locations were within 1,094 yards of a supplemental feed site, and >99% were within 1,640 yards of a supplemental feed site. The farthest deer were located from supplemental feed site at any time was 1,675 yards, and the closest was 0 yards (deer was in supplemental feeder pen).

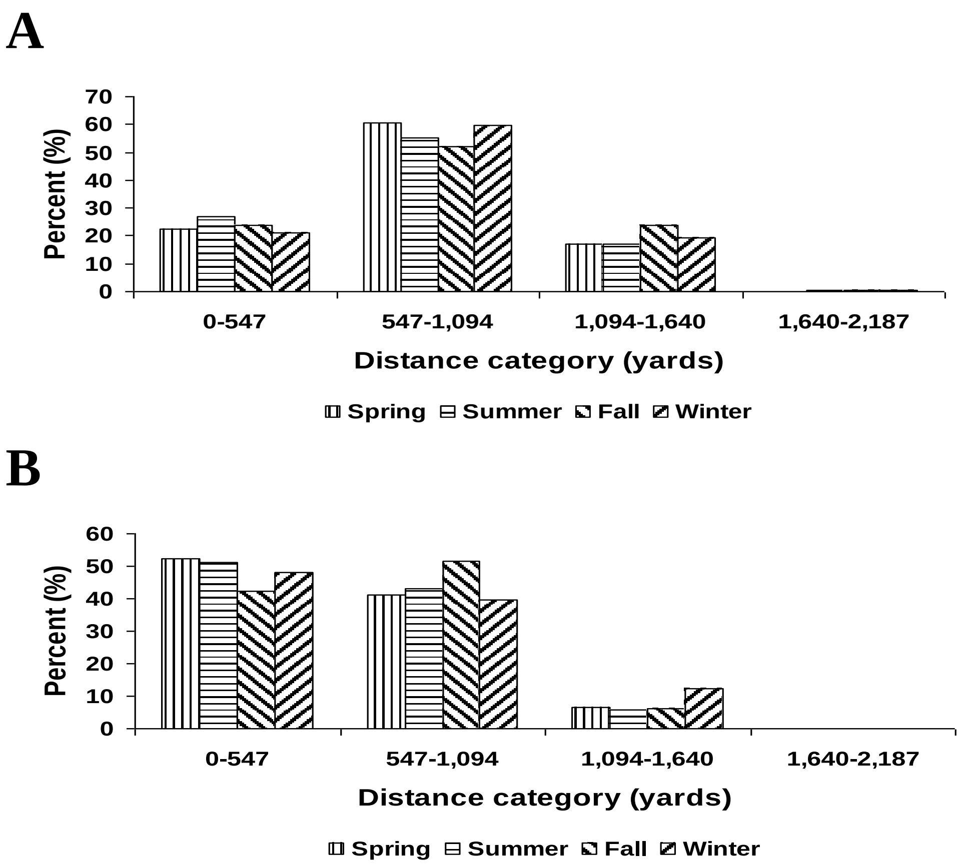

Figure 1. Percent deer locations in categories describing the distance to the nearest supplemental feed site (yards) for spring, summer, fall, and winter during year 1 (A; 15 October 2002 – 14 October 2003) for 21 deer and year 2 (B; 15 October 2003 – 25 August 2004) for 10 deer on the Callaghan Ranch, Webb County, Texas.

In both years, there was no difference among seasons in the distance between deer locations and supplemental feed sites ($P \geq 0.495$; Table 1). There was no difference ($t = -0.44$, df = 20, $P = 0.667$) between the distances deer were found from supplemental feed sites during year 1 (806 ± 56 yards) compared to the distance random points were from supplemental feed sites (810 ± 54 yards). During year 2, distances deer were found from supplemental feed sites (618 ± 83 yards) did not differ ($t = -0.34$, df = 9, $P = 0.74$) from the distance random points were from supplemental feed sites (623 ± 75 yards).

Table 1. Mean minimum distances (yards) to supplemental feed sites for actual telemetry locations within home ranges on the Callaghan Ranch, Webb County, Texas for 2 years. During year 1 deer were tracked from October 15, 2002-October 14, 2003 and during year 2 from October 15, 2003-August 25, 2004.

	Fall	Winter	Spring	Summer	Seasonal[a]	
Year	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	*F*	*P*
1	808 ± 59	821 ± 57	793 ± 57	804 ± 60	$F_{3,20} = 0.42$	0.738
2	647 ± 72	639 ± 93	588 ± 90	600 ± 95	$F_{3,9} = 0.82$	0.495

[a]Results of ANOVA testing the difference in distance among seasons.

DISCUSSION

Our results show that permanent supplemental feed sites had little effect on adult male white-tailed deer movements within home ranges and home range location, but appeared to influence home range size. Cooper et al. (2006) found that supplemental feed, in the form of shelled corn, had little effect on home range size of deer in Texas. However, fawn home ranges in New Hampshire were influenced by feeding sites (Tarr and Perkins 2002). Like supplemental feed, permanent sources of water in south Texas did not affect male deer home range location or movements (Webb et al. 2007b). Even though supplemental feed sites did not appear to affect home range location, it did appear that the shape and size of the home range was affected. If supplemental feed sites were not found within home ranges, then supplemental feed sites were on the periphery of the home range, and it was possible deer used these resources at times other than when we located deer.

Optimal foraging predicts home range size is inversely related to forage abundance (Ford 1983). As a result of increased deer density, forage availability could decrease resulting in increased home range sizes (Harestad and Bunnell 1979, McNab 1963). Despite relatively high deer densities, forage conditions were likely good to excellent during the study as a result of above average rainfall (25.7 and 27.2 inches for years 1 and 2, respectively). Therefore, water (Webb et al. 2007b) and native forage were plentiful so deer movements and home range size were probably minimized as a result. However, home range size of deer with a supplemental feed site in their home range was larger than deer without feed. This may indicate that deer with larger home range sizes had to expand their home range to include a supplemental feed site. Cooper et al. (2006) also found that deer expanded home ranges to include supplemental feed sites during the breeding season.

Supplemental feed is only one habitat component of deer; therefore, other environmental or habitat factors, and their juxtaposition, may have more of an influence on deer home range location and movements. Deer with supplemental feeders in their home ranges could shift core use areas closer to these resources. Previous studies found that feeders tended to be located on the periphery of core areas (Cooper et al. 2006).

Distances deer were located from supplemental feeders generally reflected the distribution of supplemental feeders. Because the density of supplemental feeders on the study area was relatively high (>0.19 supplemental feeders/mile^2) deer were never far from a supplemental protein feeder. The distribution of supplemental feeders on the study area was reflected in the average distance deer were located from them. If deer do travel to feed sites, then this may have a positive effect on deer because they do not have to make long-distance movements to supplemental food sources, which could conserve energy.

These data provide a measurement of adequate supplemental feeder distribution for deer in south Texas during relatively wet years. However, during drier years, deer may require a greater density of supplemental feeders, or need to consume more when at a feeder, to help meet daily and seasonal nutritional requirements. Females and other age classes may have different nutritional needs compared to adult male deer, which may require a different density of supplemental feeders. Therefore, greater densities of supplemental feed sites may be necessary in some instances.

Although some deer did not have supplemental feeders within home ranges, a shift in home range location or size most likely would have included a supplemental feed site. During dry years, deer may expand or shift their home range to include a permanent food source within their home range. We interpret our data to show a density of about 1 supplemental feeders /0.77 mile² is sufficient to minimize movements to supplemental feeders based on home range size and movements of white-tailed deer. Therefore, at the recommended density, deer will never be farther than 1,083 yards from a feeder (Figure 2). Our results will help wildlife managers determine how many supplemental feeders to install based on average density and distances deer were located to these resources during times of above average rainfall. Due to the potential for localized range degradation from long-term supplemental protein feeding in fixed locations (Cooper et al. 2006), supplemental feeders should be moved to new locations every few years.

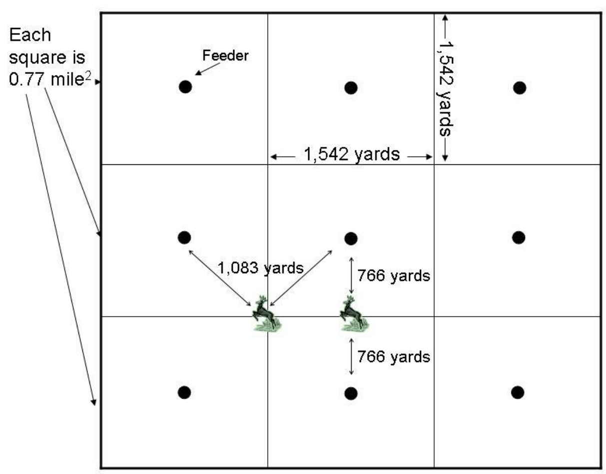

Figure 2. Density of 1 supplemental feed site /0.77 mile² and distances deer were located from them.

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Effects of Military Training Exercises on Texas Horned Lizard, *Phrynosoma Cornutum*, Occurrence on Fort Hood, Texas

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ABSTRACT

Texas horned lizards (*Phrynosoma cornutum*) were once prevalent throughout central Texas but their population has recently declined in abundance and distribution. Fort Hood lies in the historic range of *P. cornutum*. The United States Army was concerned about the status of Texas horned lizards on Fort Hood, abundance of primary prey (i.e., harvester ants [*Pogonomyrmex spp*.]), invasive species (i.e., red imported fire ants [*Solenopsis invicta*]), and any impacts that military maneuvers may have on this state-threatened reptile. Our objectives were to: 1) determine the distribution and abundance of Texas horned lizards, harvester ants and red imported fire ants and 2) assess the impacts of military training exercises on Texas horned lizards. We walked line transects from 14 May to 21 August 2001. We captured and marked 8 Texas horned lizards (5 males, 3 females) on 11 occasions via road cruising. Age ratio of Texas horned lizards was 3 juveniles and 5 adults. We collected all horned lizards within the Live Fire Area (LFA), which is located in the center of Fort Hood. We suspect horned lizards were found in the LFA because of limited vehicular and foot traffic, the area burned frequently due to artillery, and contained their primary prey species, the harvester ant.

KEY WORDS: fire ants, harvester ants, horned lizard, *Phrynosoma cornutum*, *Pogonomyrmex spp*., *Solenopsis invicta*, Texas

INTRODUCTION

Texas horned lizards (*Phrynosoma cornutum*) are not currently listed as federally threatened or endangered under the Endangered Species Act, but are a Texas state-listed threatened species. Historically, Texas horned lizards occurred throughout central Texas, but their distribution and abundance within this region has declined dramatically (Henke 2003). Fort Hood Military Reservation was within the historical range of Texas horned lizards (Horne 2000). Although Texas horned lizards have been noted on Fort Hood (i.e. 6 documented sightings since 1994; Horne 2000), their abundance appears extremely low.

Two species of ants found on Fort Hood Military Reservation include the red imported fire ant (*Solenopsis invicta*) and the native harvester ant (*Pogonomyrmex spp.*). Texas horned lizards are dietary specialitsts (Whitford and Bryant 1979) with 69% of their diet consisting of harvester ants (Pianka and Parker 1975). Fire ants, an invasive species of concern, may negatively affect the diversity and out-compete native species (Horne 2000) such as harvester ants. Fire ants also tend to invade areas where the ground has been disturbed (Horne 2000), so large-scale activities that disturb the topsoil, such as military training exercises (MTE), may alter the distribution of fire ants.

The effects of MTE on Texas horned lizards are not well documented. Therefore, The Nature Conservancy requested preliminary data collection of the Texas horned lizard on Fort Hood. Our objectives were to: 1) determine the distribution and abundance of Texas horned lizards, harvester ants and red imported fire ants and 2) assess the impacts of military training exercises on Texas horned lizards.

MATERIALS AND METHODS

Study Area

Our study was conducted on the 217,181 acre Fort Hood Military Reservation located in central Texas, in Bell and Coryell Counties. A full range of MTE were conducted on Fort Hood including maneuver exercises, firing of live weapons, and aviation training (Horne 2000). The Army also allows grazing, fishing, hunting, off-road vehicle use, and recreational use. Fort Hood was divided into Military Training Areas (MTA's), designated by number, and a central core Live Fire Area (LFA) (Figure 1). Military training areas were grouped into 4 major sections: East Range, West Range, West Fort Hood, and the LFA. The East Range (55,384 acres) was used primarily for wheeled and dismounted exercises and small-scale tracked vehicle training. The West Range (69,419 acres) was primarily used for heavy mechanical, both tracked and wheeled vehicles, and maneuver training. The LFA (30,634 acres) was centrally located and maneuvers and access was restricted due to artillery fire. West Fort Hood (15,550 acres) was used for dismounted and small-scale training and ammunition storage (Greene 2005).

Fort Hood encompassed 2 ecological regions; the Edwards Plateau and Cross Timbers and Southern Tallgrass Prairies (Greene 2005). Climate was characterized by warm summers and mild winters. Annual precipitation averaged 30.7 inches for Killeen, Texas and was concentrated in spring and autumn (Greene 2005). Mean July high temperature was 93.0 F and mean January low temperature was 37.9 F (Greene 2005). For a complete study area description see Greene (2005).

Methods

We used MTA's to systematically search Fort Hood for horned lizards via line transects. We attempted to walk each transect at least once during the morning (0630 to 1200 hr) and late afternoon to evening (1500 to 2030 hr) from 14 May to 21 August 2001. We conducted transects in the LFA as opportunities became available, such as military holidays, and when live-fire operations were cancelled. However, due to restricted access by the military, we did not complete all transects within the LFA. The number of transects and transect lengths were proportional to the size of the MTA's.

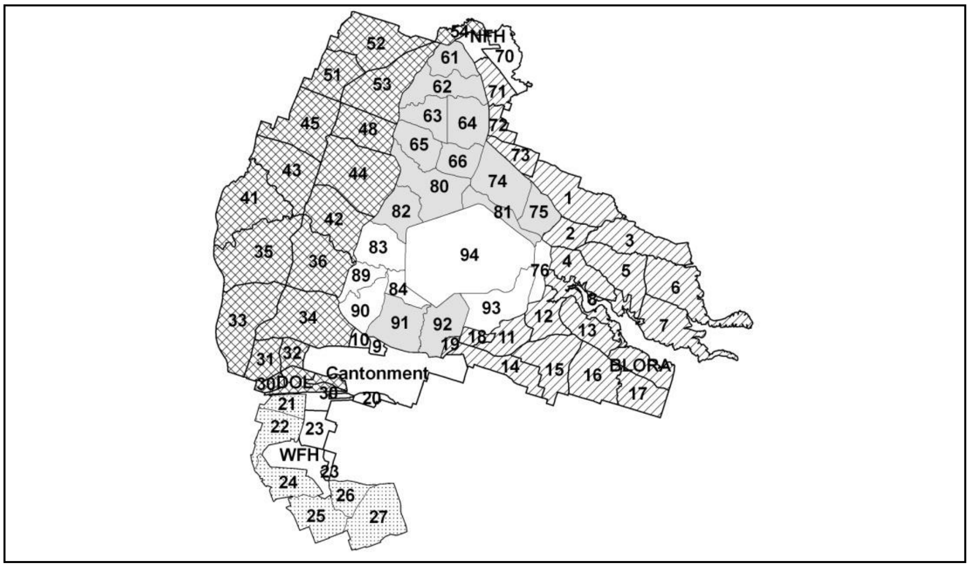

Figure 1**.** Military training areas (MTA's) located on East Range (diagonal), West Ford Hood (dots), West Range (cross-hatch), and Live Fire Area (grey) of Fort Hood, Texas. White MTA's were not searched.

Transects paralleled existing roads, based on previous experience with horned lizards (Fair and Henke 1997a), and consisted of searching for horned lizards and their sign (i.e. scat, tracks).

We recorded date, beginning and ending times, soil compaction, habitat disturbance, habitat type (i.e. % grassland: % woodland), and number of harvester and fire ant mounds per transect. We estimated densities (mounds/acre) of fire ant mounds via the Fourier estimator (Burnham et al. 1980) and densities of harvester ants based on methods by Davis and Winstead (1980) due to low number of mounds encountered.

We took soil compaction readings every 0.2 mile along each transect using a hand-held penetrometer (Land, Inc., Gulf Shores, Alabama, USA). Compaction was recorded from 14-284 PSI; with 14 being the least compact and 284 being the most.

We assigned each area a habitat type (% grassland: % woodland) and relative disturbance rating of 0-6, both by means of an ocular estimate. The following system was used to issue a disturbance rating: 0 = no disturbance, area not used by military; 1 = light disturbance, area used primarily for recreational purposes; 2 = mild disturbance, area used for dismounted foot maneuvers only; 3 = moderate disturbance, area used for dismounted foot maneuvers and non-track vehicles; 4 = heavy disturbance, area used by tracked vehicles or artillery, but $\leq$5 days/month; 5 = extreme disturbance, area used by tracked vehicles or artillery, 6-15 days/month; and 6 = ultimate disturbance, area used by tracked vehicles or artillery, but $\geq$16 days/month.

In addition to line transects, we utilized road cruising, another capture method used for time efficiency (Fair and Henke 1997a), while traveling by vehicle to and from transects. Road cruising consisted of traveling existing roads at <9 mph and searching for horned lizards on or traversing the road.

We sexed, aged, measured (snout-vent length; inches), weighed (ounces), and released Texas horned lizards at the site of capture. We also individually marked horned lizards with passive integrated transponder tags (Avid Company, Norco, California, USA) or by toe clipping. We analyzed ant density, compaction, disturbance, and habitat type based on sections (i.e. East Range, West Range, West Fort Hood, LFA) because use was relatively equal by area within a section. We used chi-square goodness-of-fit tests ($\alpha = 0.05$) to test the hypothesis that the likelihood of Texas horned lizard captures and vegetation composition did not vary by section. We used percent of transects within sections to calculate expected proportions. Thus, we weighted the expected number of captures within section by the percent of transects in the respective section. In addition, we compared densities of ant mounds, disturbance factors, and soil compaction between military sections using a completely randomized 1-way analysis of variance (PROC GLM; SAS Institute Inc. 1989). Distributions were tested for normality by Shapiro-Wilk tests (PROC UNIVARIATE; SAS Institute Inc. 1989). Homogeneity of variances among treatments was evaluated with the Bartlett's Test (Steel and Torrie 1980). Means were compared using Tukey's studentized range (HSD) test when a significant ($P < 0.05$) F-test was noted (Cochran and Cox 1957).

RESULTS

We captured 8 Texas horned lizards (5 males, 3 females) on 11 occasions via road cruising; 6 horned lizards were captured once, 1 horned lizard was captured twice, and another captured on three occasions. Capture rates of horned lizards varied by section ($\chi^2 = 27.6$, df = 3, $P < 0.001$) with all captured horned lizards coming from the LFA (Table 1). We found road cruising yielded higher captures than line transect. Neither horned lizards nor their sign were observed throughout the remainder of Fort Hood. Age class of captured Texas horned lizards was 3 juveniles and 5 adults. Weight and SVL ranged from 0.2-1.3 ounces and 1.6-3.1 inches, respectively.

A total of 113 transects totaling 189.9 miles were walked 3 times in 56 areas (i.e. MTA's and LFA; Table 1). Average transect length walked was 1 mile for every 698.7 acres. Mound densities of harvester ants across all areas of Fort Hood ranged from 0.04 to 2.3 mounds/acre. Mound densities of harvester ants within the LFA section was 0.3 ± 0.1 (SE) mounds/acre (Table 1), and 0.44 mounds/acre in the 1 MTA within the LFA where horned lizards were found. Harvester ant mounds within the LFA coincided with horned lizard occurrence. Mound densities of fire ants ranged from 0.0 to 84.8 mounds/acre across Fort Hood. Mound density of fire ants was greatest in the LFA, followed by West Fort Hood and Eat Range, then by the West Range section (Table 1). Average fire ant mounds within the LFA was 26.3 ± 5.8 (SE) mounds/acre; however, fire ant mounds occurred in sporadic pockets and appeared greater at the periphery of the LFA.

Soil compaction (PSI) for 46 of the 56 training areas tested ranged from 128 ± 8.5 to 247.5 ± 9.9 but, on average, was lowest in the LFA (Table 1). Disturbance for 45 of 56 areas (i.e. MTA's and LFA) ranged from 2-6 and although was highest in the LFA, disturbance factors were not different between the military sections (Table 1). Although disturbance in the LFA was highest, disturbance (e.g., artillery fire) was considered positive for Texas horned lizards. We found that 2.2, 44.4, 26.6, 20.0, and 2.2% of the 45 areas rated had a disturbance rating of 2, 3, 4, 5, and 6, respectively. Percent grassland:woodland was equal between West Fort Hood and in the LFA, but not different between the military sections (Table 1).

DISCUSSION

Texas horned lizards occur on Fort Hood, albeit in extremely low numbers. Similar to previous research (Fair and Henke 1997a) we found road cruising yielded higher capture rates of Texas horned lizards. Via road cruising we found an isolated population surviving within the LFA. The LFA is used for light to heavy artillery fire and burns frequently due to artillery fire, which was considered a positive disturbance because fire maintains the area in an early successional stage (i.e. grassland habitat). Previous research found Texas horned lizards preferred open areas that were recently burned (Fair and Henke 1997b). Harvester ant queens also search for open areas to initiate new colonies (DeMers 1993); therefore, the potential for colony initiation may be greater in the LFA due to frequent fires and grassland habitats. Mortality due to vehicles is considered one of the leading causes of death for horned lizards. The Army limits vehicle use in the LFA due to obvious dangers; thus reducing the probability of direct vehicular mortality and decreasing soil compaction. Although the LFA had the highest density of fire ants and lowest density of harvester ants, fire ants were found in sporadic pockets and at the periphery of the LFA, whereas harvester ant mounds were greater where horned lizards occurred compared to the remainder of the LFA.

Impacts caused by MTE often include disturbance of soil and vegetation, but may include incidental killing of wildlife. Soil disturbances include soil displacement, earthmoving or excavation, and soil compaction, which is more pronounced and longer-lasting when vehicles pass over wet soil. Vegetation disturbances can include upheaval, crushing and/or uprooting of vegetation, wildfires, loss of lower vegetation, damage to trees, and alteration of root systems. Soil changes induced by maneuvers may affect burrowing vertebrates associated with the soil surface and subsurface. However, the LFA had the lowest soil compaction ratings, thus soil compaction was probably not a factor for horned lizards in this area. Vegetation changes in areas of horned lizard occurrence were positive due to frequent fires with habitat consisting primarily of bunch grasses. Management options for horned lizards on Fort Hood may include translocation of horned lizards to areas with an abundant prey base (i.e. harvester ants), low red imported fire ant densities, susceptible to cyclic wildfires, and reduced heavy equipment maneuvers. Although Texas horned lizards were not found on other areas of Fort Hood, a number of MTA's appeared promising as a site for potential translocations. These areas contained low densities of fire ant mounds, ample harvester ant mounds, limited vehicular traffic, and an open habitat composed primarily of bunch grasses.

Table 1. Survey effort (number of transects and length), red imported fire ant (*Solenopsis invicta*) and harvester ant (*Pogonomyrmex spp*.) densities (mounds/ha), and habitat characteristics (disturbance, compaction, and vegetation) for East Range (21; number of MTA's searched within section), West Range (17), West Fort Hood (6), and Live Fire Area (12) of Fort Hood, Texas, USA.

	Transects			Ant density[1]		Habitat		
Section	n	Mile	Lizards[2]	Fire	Harvester	Disturbance	Compaction[3]	Vegetation[4]
East Range	39	61.7	0 A[5,6]	12.6 ± 2.2 B[7]	0.4 ± 0.1 A[8]	3.3 ± 0.2 A[9]	207.7 ± 2.8 A[10]	48:52 A[11]
West Range	35	67.4	0 A	4.1 ± 1.1 A	0.5 ± 0.2 A	4.3 ± 0.2 A	231.8 ± 4.3 A	62:38 A
West Fort Hood	10	17.8	0 A	13.7 ± 2.3 BC	0.4 ± 0.2 A	2.8 ± 0.2 A	226.2 ± 1.4 A	73:27 A
Live Fire Area	29	43.0	8 A	26.3 ± 5.8 C	0.3 ± 0.1 A	4.7 ± 0.3 A	157.9 ± 5.7 B	73:27 A

[1]Mounds/acre; [2]All lizards were captured via road cruising; [3]PSI; [4]Percent (%) grassland:woodland; [5]Means with the same capital letter within a column are not different ($P > 0.05$); [6]$\chi^2 = 27.6$, df = 3, $P < 0.001$; [7]$F_{3,44} = 8.75$, $P < 0.001$; [8]$F_{3,44} = 0.25$, $P = 0.86$; [9]$F_{3,44} = 1.46$, $P = 0.27$; [10]$F_{3,44} = 7.97$, $P < 0.001$; [11]$\chi^2 = 7.0$, df = 3, $P < 0.08$

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The Effects of Feeding Ractopamine Hydrochloride To Show-type Gilts On Growth Characteristics and Reproductive Performance

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ABSTRACT

Often, the swine industry in Texas is re-populated each year with replacement gilts which were fed and shown for county livestock shows. During this time of feeding, many of these gilts have been fed additives to enhance muscle development for a market look in the show ring. However, there is limited data regarding the subsequent reproductive performance of these gilts. A study was conducted to evaluate subsequent reproductive performance in 40 show-type gilts fed Paylean during their finishing stage. Gilts were assigned to either control or treatment groups (18 g/ton; n=20 per treatment). Age at first estrus (n=34) was not affected by Paylean treatment. Services per conception (n=24) were 1.41 and 1.17 for control and Paylean treatments, respectively, and were not affected by treatment. Number of piglets born alive (10.5 and 7.3 for control and Paylean, respectively; n=21) and number of piglets weaned (9.5 and 6.8 for control and Paylean, respectively; n=21) were significantly greater for control than Paylean treatment (P<0.05). Number of piglets born dead, average birth-weight, and twenty-one day piglet weight were not affected by treatment. These data are based on a small number of experimental units and further data is needed to verify the results.

KEY WORDS: Gilt, Ractopamine Hydrochloride (Paylean), Reproductive Performance, Piglet

INTRODUCTION

Consumer demand for pork has never been higher and is continuing to rise. American producers have continued to incorporate high-quality management practices in order to maximize production. In Texas, some of these pigs being raised are sold for the show ring, not commercial production. Show pigs are raised to compete in local, county, and state-wide stock shows. These swine are fed to market weight, exhibited and then harvested similar to commercial swine. Certain venues allow gilts to be exhibited and subsequently kept for breeding and reproductive purposes. These gilts are then used to produce barrows and gilts for shows in upcoming years. Thus, exhibitors and breeders strive to use above-average management practices and up-to-date technology to produce the winning show pig. The diet fed to finishing swine is a very important consideration to produce high quality lean pork. Studies continually test new feed additives, such as Paylean®, to promote leanness in swine. It is unknown whether this increased leanness will affect gilts that are kept to produce future show pigs.

Ractopamine Hydrochloride (Paylean®) is a ß-adrenergic agonist that is marketed under the trade name of Paylean® (Elanco Animal Health, Indianapolis, IN) Paylean® has been shown to decrease fat deposition and increases lean muscle formation in swine (Watkins et al., 1990; Schinckel et al., 2002a; Mills et al., 2003). This repartitioning agent was first registered for commercial use as a feed additive for finishing swine only, by the United States Food & Drug Administration (FDA) in December 1999 (Sillence, 2003). Paylean® is chemically classified with compounds known as phenethanolamines (Watkins et al., 1990). Paylean® acts on target tissues with ß-receptors to replicate the functions of naturally occurring catecholamine in the body of swine (He et al., 1992). This exogenous substance alters the manner in which nutrients are directed toward muscle enlargement and fat deposits (Watkins et al., 1990). Feeding Paylean® quickly results in increased retention of nitrogen, improved growth performance, increased feed efficiency, and increased lean carcass content (Crome et al., 1996, Stoller et al., 2003, Williams et al., 1994). Paylean® is commonly fed to finishing swine in confinement operations and to various types of show pigs, but is not approved for breeding animals. The feeding of Paylean® in Texas has become very prevalent in show-type hogs and especially show-type gilts that are exhibited in numerous local and county market swine shows. Many recent studies have proven that Paylean®, when fed at 10 to 20 ppm (9 to 18 grams/ton, respectively), has improved average daily gain (ADG), feed conversion efficiency, carcass leanness, and dressing percentage (Marchant-Forde et al., 2003; Watkins et al., 1990). The objective of this study is to compare the effects of Paylean® on growth characteristics and reproductive performance in show-type swine. Comparisons will be observed for weight gain, back fat, age at first estrus, conception rate, litter size, birth weights, litter size weaned, 21-day litter weights, and return to estrus after first weaning.

MATERIALS AND METHODS

Study Design

The study was conducted at the Tarleton State University Swine Center, Stephenville, Texas. Forty show-type, pre-pubertal cross-bred gilts (of Duroc, Yorkshire and Hampshire breeding) were selected for this experiment at random.

Gilt Selection

Selection of gilts was made based on structural soundness at 90 kg. Gilt soundness was visually scored on a scale of 1 to 5 with 5 being completely sound on their feet and legs, and 1 being lame. Soundness scores were established by a committee of three experts. These individuals evaluated all gilts throughout the study and an average score from the committee was recorded. No gilts selected were lame or had a soundness score below 3.0. Gilts were randomly selected from the entire population of gilts of the proper size, age, and soundness and randomly assigned to either the treatment or control group.

Study Replications

Two replications of this study were conducted at different time periods. Thus, a 4 $\times$ 2 factorial design was utilized; comprising two pens of five gilts for each treatment group during each replication. The two trials spanned two 20-week periods. This time span incorporated the treatment period, breeding and farrowing of the gilts; and ended when the piglets were weaned and the sow was observed for estrus. In each replicate, females (n=20) were selected and assigned randomly to one of four fully slatted 10 ft × 30 ft pens. There were two pens of gilts assigned to each treatment group.

Feeding and Weight Gain

All gilts were fed a complete mixed diet (Table 1).

Table 1. Nutrient analysis of the complete feed ration (Dry matter basis)

Crude Protein, %	16.20
Calcium, %	1.10
Phosphorus, %	0.65
Fat, %	3.00
Lysine, %	0.96
Lysine g/day	12.00
Lys/ME ratio, g/Mcal	2.97

Beginning weights, lameness scores, and ultrasound backfat measurements were recorded when gilts averaged 200 lbs. The manufacturer recommends feeding Paylean® for 21 to 30 days prior to slaughter. In this study the gilts were representing show-type animals. The manufacturers recommended feeding levels of Paylean® is to substitute one-half pound of supplement that contains 18 grams/ton of Paylean® for one pound of feed. Control pens received 5 lbs. of feed per head per day for 21 days. Treatment pens received 4 lbs. with topdressing of 20 ppm (18 grams per ton) per day of Paylean®, as directed by labeling instructions, for 21 days. Pigs were fed in group pens to reflect commercial conditions. Treatment amount agreed with studies conducted by Watkins et al., (1990), Stites et al., (1991), Schinckel et al., (2003). The treatment groups received 4 lbs due to labeling recommendations, as well. Gilts were fed with ad libitum access to water. Weights, lameness, and backfat were again recorded at the end of the 21 day feeding period.

Reproduction

Estrus behavior was visually recorded twice daily after 21 days of treatment until breeding and subsequent pregnancy determinations were made. A mature boar was used to stimulate estrus behavior and detect standing heat. Gilts attain puberty at about 6 to 7 months of age (Tummaruk et al., 2000). Age at first estrus was recorded.

After sexual maturity was reached or approximately two heat cycles (Eliasson, 1991), gilts were artificially inseminated by an experienced technician during a selected two-week period that coincided with Tarleton's typical breeding schedule. Gilts were intended to be bred to farrow at one year of age. No gilts were bred on first estrous. All were inseminated on their second or third estrus cycle. No artificial hormones were used to induce estrus. Gilts were artificially inseminated using semen from boars at random. High quality boar semen was purchased from the same boar stud farm. Estrous behavior continued to be monitored. Remaining gilts were bred during the next breeding schedule, approximately one month later. Gilts were culled if they did not conceive after the second attempt to breed, or did not show any estrus.

Data Analysis

Pre-Farrowing

Gilts were weighed before and after the 21 day treatment period and data were collected for weight gain or loss. Treatment and control gilts were again visually scored for soundness to determine if any serious lameness had occurred from feeding Paylean®. Age at first estrus (as detected by the teaser boar), services per conception, correlation of backfat to the onset of estrus and conception rates were recorded. Ultrasound backfat data was collected to determine a correlation between fat deposition and estrous patterns in pre-pubertal swine. The CORR procedure of SAS (SAS Inst. Inc., Cary, NC) was used to calculate all correlations.

Post-Farrowing

Farrowing data consisted of litter size (number of piglets born alive and dead), average piglet birth weights, average 21-day piglet weights, and number of piglets weaned. Data will indicate whether or not feeding Paylean® had any effect on litter size and weights. After weaning, the sow's return to estrus was recorded and analyzed.

Effects of Paylean® supplementation on services per conception, age at first estrus, piglet birth data, piglet weights, and number of piglets weaned were analyzed using the MIXED procedure of SAS. The model contained the effects of treatment, group, and the treatment × group interaction.

RESULTS AND DISCUSSION

Growth Data

Average Daily Gain

As suspected from previous research, ADG at the end of the 21-day treatment period showed to be greater for treatment groups (Table 2). Feeding Paylean® to gilts (200 lbs.) at 20ppm (18 g/ton per day), and containing at least 16% crude protein improved ADG. These findings are in agreement with (Gu et al., 1991) that the ADG of Paylean® fed hogs increased gradually as body weight (BW) increased in the weight ranges of 59 to 100-kg and 73 to 114-kg. BW was found to decline when Paylean® was fed from 86 to 127-kg (Gu et al., 1991), not necessarily the optimal weight range to feed Paylean®. In this study, the average daily gain of the gilts was 1.98 lbs. for treatment and 1.70 lbs. for control groups (Table 2). Total weight gained during the 21 day treatment period was greater (P<0.05) for Paylean® fed gilts (41.78 lbs.) than for control (35.32 lbs.). Consequently, the ending weights were higher for the treatment group (Table 2).

Table 2. Weight gain of gilts*

	Dietary Treatment	
Treatment	Paylean®	Control
Beginning Weight, lb	199.8	197.6
Average Daily Gain	1.98	1.70
Weight Gain, lb	41.8	35.3 **
Ending Weight,lb	241.6	233.3

*n=40 ** P<0.05

This indicates that Paylean® caused gilts to gain more weight than control gilts. These results agreed with (Crome et al., 1996; He et al., 1992; Herr et al., 2000; Schinckel et al., 2002a; Schinckel et al., 2002b; Stoller et al., 2003; Gu et al., 1991; Watkins et al., 1990; and Weber et al., 2002). No studies comparing the effects of Paylean® on weight gain found opposing conclusions. This repetitive data proved that Paylean® reacts in show-type gilts similarly to lean type commercial hogs.

According to Watkins et al., (1990), weight gain responses from feeding Paylean® may vary depending on genetics or the degree of leanness. Research from Bark et al., (1992) agreed that Paylean® increased (*P*<0.01) weight gain in genetically high and low lean tissue genotypes over control groups. However, the degree of improvement was greater in pigs that are genetically leaner (Bark et al., 1992). Our study did not compare specific genotypes, yet coincidently gilts selected for show usually have high lean tissue potential (Sterle, 2005).

Soundness

Gilt soundness scores were recorded following the treatment period. Forty gilts were observed for soundness before and after treatment comparisons. Soundness scores prior to Paylean® treatment and after treatment were both non-significant when comparing treatment and control gilts (*P*>0.05) for the first replication (Table 3).

Table 3. Average soundness scores of gilts*

First replication	Paylean®	Control
Beginning score	3.20	3.40
Ending score	3.10	3.30
Gain/Loss	-0.10	-0.10
Second replication		
Beginning score	3.90	3.60
Ending score	3.20	0.55
Gain/Loss	-0.70	-0.05 **

*n=40, ***P*<0.05

Gilts in treatment and control groups showed some decrease in their soundness after treatment (Table 3). There was a significant decrease (*P*<0.05) of soundness for Paylean® gilts in the second replication.

Leanness

Ultrasound backfat scores reflected how Paylean® increased leanness of the gilts (Table 4). Backfat was compared at the end of the treatment period, prior to breeding. The study showed that feeding Paylean® decreased backfat in show-type gilts (Table 4).

Table 4. Ultrasound backfat scores of gilts*

Second replication	Paylean®	Control
Pre-treatment, in	0.29	0.32
Post-treatment, in	0.26	0.34
Gain/Loss, in	-0.03	0.02
Prior to breeding		
1st replicate, in	0.42	0.40
2nd replicate, in	0.36	0.41
Backfat averaged, in	0.39	0.405

*n=40 ** *P*<0.05

Table 5. Number of gilts* contained in the study.

	Dietary Treatment	
Treatment	Paylean®	Control
No Estrus	3	3
No Conception	5	5
Sickness	1	0
Total Culled	9	8
Total Bred	11	12

*n=33 ** *P*<0.05

In the second replication only (Table 4), gilts were scanned after treatment, resulting in a decrease of 0.03 inches for Paylean® gilts and an increase of 0.02 inches for control gilts (Table 4). After the first replication was completed, the researchers decided to add another dimension and observe ultrasound backfat data. Therefore, in the second replication, an ultrasound backfat measurement was observed before and after feeding Paylean® as well as prior to breeding.

Reproductive Data
Onset of Puberty

The onset of puberty is defined as the time of first oestrus and ovulation with a continuation of regular oestrus cycles (Eliasson, 1991). The average age for the onset of puberty in gilts is 182 to 222 days (Tummaruk et al., 2000). The initial hypothesis was that Paylean® would not have any effect on the age at first heat in the gilts. Estrus was not observed for six out of the 40 gilts; three from control and three from Paylean® (Table 5).These gilts were culled from the study. There are no previous studies found to support reasons why some gilts did not show estrus or conceive after breeding. One gilt was culled during the breeding period due to sickness (Table 5). Ultimately, 11 gilts from Paylean® and 12 gilts from control were successfully bred (Table 5).

The onset of puberty was compared between treatment and control groups. The ages of the gilts at first estrus were 220.3 and 225.7 days for control and treatment groups (n=17 per group), respectively (Table 5). Therefore, Paylean® did not significantly (P>0.05) affect the age at which the gilts (n=34) first showed signs of estrus (Table 5). Paylean® did not have a subsequent effect on reproductive patterns of estrous behavior.

Also, the onset of puberty was correlated with backfat measurements to determine if there were any effects on estrus, number of cycles prior to breeding, and number of services per conception (Table 6). The evaluation of treatment groups separately indicated no significant (*P*>0.05) correlation between backfat and age at first estrus (Table 6). A follow-up study is suggested to observe greater sample size for backfat and the onset of puberty and conception rate.

Services per conception

Services per conception was 1.41 for control and 1.17 for treatment groups (n=23) (Table 6). The differences for these means were found to be non-significant (P>0.05).

Furthermore, there was no significant (*P*>0.05) correlation between backfat and number of services per conception, age at first estrus, or number of cycles per conception. (Table 6).

Farrowing Data

According to Table 7, Paylean® did not affect (*P*>0.05) the number of piglets born dead, average piglet birth weights, and 21-day piglet weights, but the number of piglets born alive and weaned was significantly greater (*P*< 0.05) for control than Paylean®. The number of piglets born alive was 7.3 for Paylean® and 10.5 for control. There were no differences for the number of piglets born dead.

Table 6. Correlation of backfat measurements, prior to breeding, of gilts* with various reproductive traits.

Backfat	Age at first estrus	No. of cycles	Services/conception
Paylean®	-0.41	-0.01	0.40
Control	-0.22	0.28	-0.10
Total	-0.30	0.15	0.14

*n=33 ** *P*<0.05

The average piglet birth weights were 3.35 lbs. and 3.37 lbs. for piglets in control and Paylean® groups, respectively (Table 7). Obviously, with the piglet weights being so close there were no significant difference due to treatment. Therefore, Paylean® did not affect the size of the piglets when they were born. Knowing this makes it less likely for Paylean® to affect piglet weight any more after birth. The 21-day weight or standard weaning weight was also not significant (*P*>0.05). Average piglet 21-day weights were 12.10 lbs. for control and 12.83 lbs. for Paylean® (Table 7). Though there were fewer piglets born in a litter for the Paylean® group the piglet 21-day weights were not affected significantly.

Table 7. Farrowing data for gilts*.

	Dietary Treatment	
Treatment	Paylean®	Control
Piglets Born Alive	7.30	10.47 **
Piglets Born Dead	0.70	0.97
Piglet Birth Weight (Ave.), lbs.	3.37	3.35
Piglet 21-Day Weight, lbs.	12.83	12.10
No. of Piglets Weaned	6.80	9.52 **

*n=33 ** P<0.05

CONCLUSIONS

According to this research, feeding Paylean® to show-type gilts effects litter size, yet does not have adverse effects for other reproductive traits. Data from this study will allow show-type swine producers to make decisions regarding the feeding of Paylean® to gilts and subsequently select replacement gilts to enter the sow herd.

Results on growth data will allow commercial pig producers to continue to feed Paylean® to finishing swine to enhance leanness and growth efficiency. According to Houseknecht et al., (1998), animal performance and health will be enhanced by understanding the basic mechanisms that regulate adiposity, feed intake, and energy metabolism. The results of weight gain and leanness on gilts fed Paylean® only strengthens this knowledge. Paylean® gilts showed to gain more weight than control gilts. Also, soundness was not a concern between treatment and control groups in the first replication, but was a concern for the Paylean® gilts in the second replication.

This study provides evidence about and will help answer questions regarding the feeding of Paylean® and its effects on inhibiting gilts from showing estrus. Data did not show that Paylean® affected gilts' ability to conceive. Answers to these questions could benefit show-pig producers who are interested in saving gilts fed Paylean® for replacements. According to this research, there were no significant correlations between backfat and age at first estrus, number of cycles, and services per conception. Producers should not have any problems with retaining the qualities of market swine, except for litter size, while also having the ability to breed any gilt selected from show gilts that have been exhibited for replacements. Gilts can be primed to compete in market shows and still be capable of conceiving and farrowing. Yet, Paylean is not approved and is not recommended by the manufacturer for replacement gilts.

Subsequent reproductive effects of Paylean® may consist of decreased litter sizes and therefore decreased numbers at weaning. Data showed the number of piglets born alive and the number of piglets weaned to be greater for control groups. Yet, Paylean® did not affect the number of piglets born dead per litter. The piglets' growth abilities were not hindered due to Paylean® treatment. Paylean® did not affect average piglet birth and 21-day weights. Further research with larger group numbers is needed to validate these findings.

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Grazing Alternatives in the Face of Declining Groundwater: A Case from the Southern High Plains of Texas

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ABSTRACT

In the Southern High Plains of Texas, current agricultural production primarily consists of cotton and grain production. However, with the depletion of the Ogallala aquifer and rising energy costs, other production systems are being considered. This study analyzed grazing scenarios with stocker steers grazing WW-B. Dahl bluestem pastures. The economic analysis included net returns from gain of grazing steers as a function of irrigation and fertilizer. The highest returns were obtained when nitrogen fertilizer was applied on dryland WW-B. Dahl pasture.

KEY WORDS: irrigation, grazing steers, WW-B. Dahl bluestem

INTRODUCTION

Agriculture is the predominant industry in the Southern High Plains of Texas (SHPT). The total annual business effect of crop and cattle production in the region is $3.44 billion and $6.27 billion, respectively (HPUWCD1, 2004) , with beef cattle and cotton being the leading agricultural enterprises. Despite limited rainfall in the SHPT, cotton production boomed with the introduction of irrigation technology in the 1940's. In 2004, the region produced 3.4 million bales of cotton representing 15% of United States production (USDA-NASS, 2005a, 2005b). While only 37% of the region's cropland is irrigated, 75% of the value of major crop production came from irrigated land.

Agriculture production in the SHPT is largely supported by irrigation from the Ogallala Aquifer, with 95% of water pumped from the aquifer being used for irrigation. The average decrease in saturated thickness as a measure of depletion of the Ogallala Aquifer from 1996 to 2006 was 0.25 meters per year (HPUWCD1, 2006). Research has been conducted to develop more efficient irrigation methods; however, these improvements in efficiency may not lead to improved conservation. The best opportunities for water conservation lie in the use of improved irrigation systems in tandem with other conservation practices.

Managing cropping systems and water use to extend the life of the aquifer has become the goal of multiple water users and agricultural producers. Integrating cattle management systems into land management programs may provide an opportunity for farmers to improve water conservation and maintain profitability (Allen, et al., 2005; Krall and Schuman, 1996). Incorporating a stocker steer system into a cropping system would decrease water and chemical use while also decreasing variable costs. Many grass cultivars require fewer inputs than crops, such as water, fertilizer, and pesticides, to generate sustainable production. Sustainability in this case is defined as generating profitability without depleting resources. Also, stocker steer management systems do not require the extensive investment in equipment and maintenance associated with large-scale crop production. The SHPT was originally grassland and is well suited to stocker steer grazing. With better adapted cultivars of bluestem grasses in a stocker steer operation, producers could achieve higher yields than with native grass cultivars.

With the need to conserve water and maintain profitability, farmers in the SHPT are considering alternative management systems. One possible alternative is to graze stocker steers on improved grass cultivars. WW-B. Dahl (formally WW-857 and, scientifically, *Bothrichloa bladhii (RETZ.), S.T. BLAKE*) is a potential cultivar well adapted to the SHPT; however, information on the profitability of stocker steers grazing WW-B. Dahl bluestem is scarce. The purpose of this study was to determine the economic response of stocker steers grazing WW-B. Dahl bluestem using various levels of irrigation and nitrogen fertilization.

Specific objectives were to:

1. Develop an economic analysis of total stocker steer gains per hectare in response to grazing WW-B. Dahl bluestem.
2. Develop an economic analysis of total stocker steer gains per hectare in response to nitrogen fertilization and applied irrigation on WW-B. Dahl bluestem.
3. Develop an economic analysis of total stocker steer gains per hectare in response to starting weight when grazing WW-B. Dahl bluestem.

Old World Bluestem Varieties

Old World bluestems were first introduced to the United States because of their ability to produce a greater quantity of forage than native varieties. They have proven to be responsive to fertilization, tolerant of drought and cold, able to withstand close grazing, and palatable to cattle (Redfearn, 2004). WW-B. Dahl was native to India and Pakistan and selected for palatability, production, and later maturation by the Southern Plains Range Research Station in Woodward, Oklahoma, as a superior Old World bluestem strain worthy of release in central and southern Texas. Its lower winter hardiness makes it more suitable for the warmer climate of those regions (Bell and Caudle, 1994; U.S. Department of Agriculture-Agriculture Research Service, 1994). WW-B. Dahl is a warm-season, perennial bunchgrass of dark green foliage with basal and broader cauline leaves than other Old World bluestem strains. At maturity the cauline leaves measure 5-10 mm wide and 25-50 cm long with an average foliage height of 0.70-0.90 m. WW-B. Dahl reproduces asexually (apomictic reproduction), preventing mixing with other strains.

Selected Research of Management of Old World Bluestem

Old World bluestems have shown production ranges from 1,350-11,000 kg of forage per hectare (ha) per year depending on the management techniques used and the surrounding environment. In previous studies, forage production has been known to drastically drop if needed nutrients are not available. Old World bluestems may require nitrogen fertilization to reach optimal forage quality and yield. Some studies show that applying nitrogen increased yields by 20-50 kg of forage per kg of nitrogen fertilizer applied. With 65-90 kg of nitrogen per ha, it is reasonable to expect 4,500-6,700 kg of forage per ha on fertile soils. In addition, nitrogen has been shown to improve crude protein content by 2-5%. Phosphorus fertilization on low phosphorus soils has resulted in a 10-70% increase in forage production (Berg, Dewald, and Sims, 1996; Bell and Caudle, 1994; Redfearn, 2004; Roberts, 2004).

Forage quality is important for daily gains in cattle. All released Old World bluestem varieties are similar in forage quality; however, the digestibility percentage ranges from 50-60% and crude protein from 4-13%. Forage quality is highest from May through June when the plant is growing. From May to July, Old World bluestems meet or exceed cattle nutrient requirements for animal growth. From July to August, they offer higher quality forage than many other grasses. However, native range has been preferred for wintering cattle (Bell and Caudle, 1994; Redfearn, 2004; Roberts, 2004).

By using proper establishment and management practices, summer and winter cattle grazing is usually acceptable. The recommended stocking rate for year-round grazing is 0.7-1.2 ha per yearling steer with gains ranging from 0.1-0.2 kg per day from December-March and 0.5-1.0 kg per day from April-September. However, studies have shown cattle gains can be significantly increased by increasing forage quality and yields. Increased forage quality is obtained with the proper amounts of water, fertilizer, temperature, and soil nutrients (Berg, Dewald, and Sims, 1996; Bell and Caudle, 1994; Redfearn, 2004, Roberts, 2004).

Research on weight gain response of cattle within a WW-B. Dahl grazing system includes irrigation and grazing systems effects, whole cottonseed and corn supplementation effects, biuret and urea protein supplementation effects, and irrigation level effects (Villalobos, et al., 2000; Bezanilla and Villalobos, 2000; Villalobos, et al., 2002; Ortega-Ochoa and Villalobos, 2003). A study by Benzanilla (2002) derived a production function for stocker steer gains at various levels of nitrogen and irrigation application. The results indicated that WW-B. Dahl was productive with or without irrigation and that irrigation increased average daily gain.

METHODS

Data

Two panel data sets for WW-B. Dahl bluestem forage production and quality were obtained from previous work at the Texas Tech University research farm in Lubbock County, Texas (33º.45'N, 101º.47'W), from 2001 to 2003 on Pullman soil (0-1% slope). The first data set was from a study which captured the effect of irrigation and nitrogen on the WW-B. Dahl bluestem forage and quality (Philipp, 2004). In Philipp's study, clippings were taken in July and October and analyzed for accumulated forage mass and quality. Various irrigation amounts were used (0%, 33%, 66%, and 100% of potential evapotranspiration (PET)) within each year while various nitrogen levels were used from 2001 to 2003. The second data set was similar to the first and was collected from 2001 to 2003 by Duch (2005) to study the effect of multiple cuttings on WW-B. Dahl for forage production and quality. Seventy-two kg of nitrogen were applied in August each year of the study. A different plot was cut each month from May to September with second cuttings in October for all plots. The Philipp and Duch panel data sets were combined to provide 103 observations for forage quantity and 81 observations for forage quality. Philipp's data included 73 observations for quantity and 64 for quality. Duch's data provided 31 quantity and 17 quality observations.

Profit Maximization with Two Variable Inputs

Equation (1) specifies profit from stocker steer production subject to the production function, $Y=f(X_1, X_2)$,

(1) $\pi = P_Y Y - C = P_Y Y - R_1 X_1 - R_2 X_2 - b$,

where π represents profit and is equal to unit selling price (P_Y) multiplied by the amount of output minus the total cost (C). Furthermore, C is equal to the input price per unit for each input

1 and 2 (R_1 and R_2) multiplied by the number of units of inputs used (X_1 and X_2) plus total fixed costs (b). This leads to the final profit equation in which the production function (constraint) is substituted for Y. In this study, the two variables are irrigation and nitrogen fertilizer. In the case of two different production functions that are one-product-two-factor production functions, one function can be created if the final product, (Y_2), is a function of the first product (Y_1). In this study, forage production is represented by Y_1 and beef production is represented by Y_2. These relationships are exhibited in the equations below.

(2) $Y_1 = f(X_1, X_2)$,

(3) $Y_2 = f(Y_1)$,

(4) therefore, $Y_2 = f[Y_1\, f\, (X_1, X_2)] = f(X_1, X_2)$.

The profit equation would be expressed as equation 1. To obtain profit maximizing factor levels, equations 1 and 4 must be simultaneously solved for X_1 and X_2 as functions of prices. The first order condition is

(5) $(\partial\pi / \partial X_1) = P_Y\, (\partial Y / \partial X_1) - R_{X1} = 0$, and

(6) $(\partial\pi / \partial X_2) = P_Y\, (\partial Y / \partial X_2) - R_{X2} = 0$.

Therefore,

(7) $P_Y = R_{X1} / (\partial Y / \partial X_1) = R_{X2} / (\partial Y / \partial X_2)$.

Then the rate of technical substitution (RTS) can be set equal to the ratio of marginal factor costs of X_1 and X_2 ($MFC_{x1,\, x2}$)

(8) $(\partial Y / \partial X_1) / (\partial Y / \partial X_2) = R_{X1} / R_{X2}$.

At the point where RTS equals MFC, profit maximization occurs because the difference between total revenue and total cost is greatest. If the RTS is greater than the inverse MFC ratio, then more inputs could be used to increase total revenue at a faster rate than the increase in total cost. After this point, the RTS is less than the inverse MFC ratio, meaning that the marginal cost is more than the marginal profit.

Sensitivity analysis can show the response of returns above variable costs to selling price, yields, variable input use, and costs. The gross margin sensitivity equation is

(9) $GM = (\overline{P}_G * SSG) - (N * \overline{C}_N) - (I * \overline{C}_I) - VC$

where GM represents gross margin (returns above variable costs), SSG represents total stocker steer gains in kg (the production function), $\overline{P}_G$ represents the price of gain in dollars per kg, N represents the amount of nitrogen applied in kg, $\overline{C}_N$ represents the price of nitrogen per kg, I represents the amount of irrigation applied in mm, $\overline{C}_I$ represents the cost of irrigation per mm, and VC represents other variable costs.

Table 1. Returns Above Variable Costs (Best Case Scenario).

Fixed Variables		
$/kg gain	0.79	$/kg
Cattle Weight	181	kg
Nitrogen Amount		kg
Nitrogen Cost	0.44	$/kg
Irrigation Amount		mm ha
Irrigation Cost	0.51	$/mm ha
Other Costs	9.32	$/ha

	Nitrogen (kg)							
IRR (mm)	0	20	40	60	80	100	120	140
0	148	172.3	196.7	221	245.4	269.7	294.1	318.4
20	128	154.5	180.9	207.4	233.9	260.4	286.9	313.3
40	108	136.6	165.2	193.8	222.4	251	279.7	308.3
60	88	118.7	149.5	180.2	211	241.7	272.5	303.2
80	68	100.9	133.7	166.6	199.5	232.4	265.3	298.1
100	48	83	118	153	188	223	258.1	293.1
120	28	65.1	102.3	139.4	176.6	213.7	250.8	288
140	8	47.3	86.5	125.8	165.1	204.4	243.6	282.9
160	-12	29.4	70.8	112.2	153.6	195	236.4	277.9
180	-32	11.5	55.1	98.6	142.2	185.7	229.2	272.8
200	-52	-6.4	39.3	85	130.7	176.4	222	267.7

RESULTS

The production functions for stocker steer gain from May to July for three stocker steer starting weights, 181 kg, 227 kg, and 272 kg, are estimated to be

(10) $\text{Total Steer Gain}_{181\ kg} = 199.1229+(0.02524{*}I)+(2.097876{*}N)+(0.00675{*}IN)$
(56.86) (0.85) (50.11) (19.08)

(11) $\text{Total Steer Gain}_{227\ kg} = 169.3788+(0.075906{*}I)+(2.035336{*}N)+(0.00556{*}IN)$
(42.08) (2.23) (42.30) (13.67)

(12) $\text{Total Steer Gain}_{272\ kg} = 145.2936+(0.120988{*}I)+(1.996929{*}N)+(0.004724{*}IN)$
(33.52) (3.30) (38.54) (10.79)

For a pasture lease, the price per kilogram of stocker steer gain ranges from $0.44 to 0.79 per kg of gain (Johnson, 2005). The cost of nitrogen ranges from $0.44 to 0.88 per kg (Bronson, Boman, and Segarra, 2005). Irrigation repair and maintenance variable costs are estimated at $0.08 per mm ha (Smith and Yates, 2005). Energy cost for irrigation is $0.51 per mm ha using electricity and $0.97 per mm ha using natural gas. This energy cost is based on a 90-meter lift and a system pressure of 2.1 kg/cm (HPUWCD1, 2005). The other variable costs held constant through the analysis include phosphorus fertilizer at $6.03 per ha with an application cost of $3.29 per ha. For a profit sensitivity analysis, annual fixed costs are fencing at $2.47 per ha, land at $98.84 per ha, and irrigation system at $74.13 per ha (Schuster, et al, 2001; Segarra, 2004; Smith and Yates, 2005).

In Table 1, with other variable costs fixed, returns above variable costs for nitrogen fertilization and applied irrigation are maximized. In this best case scenario, the price per kg of gain is $0.79 and initial stocker steer weight is 181 kg, giving the highest revenue possible. Nitrogen and irrigation costs of $0.44 and $0.51, respectively, are reduced to the lowest levels. In cases where irrigation is heavily applied with a low nitrogen application, the costs of production are higher than the revenue. For instance, when applying 200 mm of water and 0 kg of nitrogen, the producer has a return above variable costs of -$52.03 per ha. With other variable costs fixed, the producer's returns above variable cost were maximized at $318.41 per ha with 0 mm of applied irrigation and 140 kg of nitrogen fertilization. In this study, average rainfall of 246.7 mm over the growing season is assumed.

Table 2 illustrates the returns above variable costs in a worst case scenario with the lowest $/kg gain, high levels of nitrogen fertilization and low levels of applied irrigation are preferred. The table indicates that even with nitrogen fertilization prices at $0.88 per kg, the returns from increased gains per ha due to the nitrogen fertilization outweighed the cost.

Table 3 is a sensitivity analysis illustrating the marginal change in returns above variable costs due to an increase in price per kg of stocker steer gain and cost of nitrogen fertilization. As shown in Table 3 with a steer weight of 181 kg, a $0.05 increase in price per kg of gain causes an increase of $24.64 per ha in returns above variable costs. A $0.09 increase in nitrogen fertilizer cost decreases returns above variable costs by $12.32 per ha.

Table 2. Returns Above Variable Costs (Worst Case Scenario).

Fixed Variables		
$/kg gain	0.44	$/kg
Cattle Weight	181	kg
Nitrogen Amount		kg
Nitrogen Cost	0.88	$/kg
Irrigation Amount		mm ha
Irrigation Cost	0.97	$/mm ha
Other Costs	9.32	$/ha

	Nitrogen (kg)							
IRR (mm)	0	20	40	60	80	100	120	140
0	78.3	79.2	80.0	80.9	81.7	82.6	83.5	84.3
20	39.7	41.8	43.8	45.9	47.9	50.0	52.0	54.1
40	1.1	4.4	7.6	10.8	14.1	17.3	20.6	23.8
60	-37.4	-33.0	-28.6	-24.2	-19.7	-15.3	-10.9	-6.5
80	-76.0	-70.4	-64.8	-59.2	-53.6	-48.0	-42.3	-36.7
100	-114.6	-107.8	-101.0	-94.2	-87.1	-80.6	-73.8	-67.0
120	-153.2	-145.2	-137.2	-129.2	-121.2	-113.2	-105.2	-97.3
140	-191.8	-182.6	-173.4	-164.2	-155.1	-145.9	-136.7	-127.5
160	-230.3	-220.0	-209.6	-199.2	-188.9	-178.5	-168.1	-157.8
180	-268.9	-257.4	-245.8	-234.3	-222.7	-211.1	-199.6	-188.0
200	-307.5	-294.8	-282.0	-269.3	-256.5	-243.8	-231.0	-218.3

Table 4 shows the effects of marginal changes in returns above variable costs due to an increase in the price per kg gain and cost of applied irrigation. The marginal change in returns above variable costs from a $0.05 change in price per kg gain is $28.52 per ha while the marginal change in returns above variable cost for a $0.09 change in the cost of applied irrigation is $14.72 per ha. Again, the price per kg gain has a larger effect on profitability than do input prices. However, input usage is within the producer’s control while input and output prices are generally not.

Table 5 displays the marginal change in returns above variable costs as nitrogen fertilization and applied irrigation costs increase. For input levels of 181 kg steers, 140 kg per ha of nitrogen, and 80 mm per ha of irrigation, the marginal response for a $0.13 increase in nitrogen fertilizer price is a decrease of $17.64 per ha return above variable costs and for a $0.09 increase in applied irrigation cost, a decrease of $14.72 per ha return above variable costs.

Table 6 shows the impact of initial steer weight on returns. From 181 to 227 kg initial steer weight, the increase of 46 kg will decrease returns above variable costs by $16.94 per ha with cost of gain at $0.44 per kg, and by $30.42 per ha with a cost of gain at $0.79 per kg. From 227 and 272 kg initial steer weight, returns will decrease by $12.96 per ha at $0.44 per kg gain and $23.27 per ha at $0.79 per kg gain. The effect of the price of gain becomes more significant as stocker steer weight increases.

Table 3. Returns Above Variable Costs Comparing Gain ($/kg) and Nitrogen ($/kg).

Fixed Variables		
$/kg Gain		$/kg
Cattle Weight	181	kg
Nitrogen Amount	140	kg
Nitrogen Cost		$/kg
Irrigation Amount	0.00	mm ha
Irrigation Cost	0.51	$/mm ha
Other Costs	9.32	$/ha

	Gain ($/kg)							
N ($/kg)	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.79
0.44	145.9	170.6	195.2	219.8	244.5	269.1	293.8	318.4
0.48	139.8	164.4	189.0	213.7	238.3	263.0	287.6	312.3
0.53	133.6	158.2	182.9	207.5	232.2	256.8	281.5	306.1
0.57	127.4	152.1	176.7	201.4	226.0	250.7	275.3	299.9
0.62	121.3	145.9	170.6	195.2	219.8	244.5	269.1	293.8
0.66	115.1	139.8	164.4	189.0	213.7	238.3	263.0	287.6
0.70	109.0	133.6	158.2	182.9	207.5	232.2	256.8	281.5
0.75	102.8	127.4	152.1	176.7	201.4	226.0	250.7	275.3
0.79	96.6	121.3	145.9	170.6	195.2	219.9	244.5	269.1
0.84	90.5	115.1	139.8	164.4	189.0	213.7	238.3	263.0
0.88	84.3	109.0	133.6	158.2	182.9	207.5	232.2	256.8

Table 4. Returns Above Variable Costs Comparing Gain ($/kg) and Irrigation ($/mm ha).

Fixed Variables		
$/kg Gain		$/kg
Cattle Weight	181	kg
Nitrogen Amount	140	kg
Nitrogen Cost	0.66	$/kg
Irrigation Amount	80.00	mm ha
Irrigation Cost		$/mm ha
Other Costs	9.32	$/ha

	Gain ($/kg)							
IRR $/mm ha	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.79
0.51	67.7	96.2	124.7	153.2	181.8	210.3	238.8	267.3
0.56	60.3	88.8	117.4	145.9	174.4	202.9	231.4	260.0
0.60	53.0	81.5	110.0	138.5	167.0	195.6	224.1	252.6
0.65	45.6	74.1	102.6	131.2	159.7	188.2	216.7	245.3
0.69	38.2	66.8	95.3	123.8	152.3	180.8	209.4	237.9
0.74	30.9	59.4	87.9	116.4	145.0	173.5	202.0	230.5
0.79	23.5	52.0	80.6	109.1	137.6	166.1	194.6	223.2
0.83	16.2	44.7	73.2	101.7	130.2	158.8	187.3	215.8
0.88	8.8	37.3	65.8	94.4	122.9	151.4	179.9	208.5
0.92	1.4	30.0	58.5	87.0	115.5	144.0	172.6	201.1
0.97	-5.9	22.6	51.1	79.6	108.2	136.7	165.2	193.7

Table 5. Returns Above Variable Costs Comparing Nitrogen ($/kg) and Irrigation ($/mm ha).

Fixed Variables		
$/kg Gain	0.44	$/kg
Cattle Weight	181	kg
Nitrogen Amount	140	kg
Nitrogen Cost		$/kg
Irrigation Amount	80.00	mm ha
Irrigation Cost		$/mm ha
Other Costs	9.32	$/ha

	Nitrogen ($/kg)							
IRR $/mm ha	0.44	0.50	0.57	0.63	0.69	0.76	0.82	0.88
0.51	98.5	89.7	80.8	72.0	63.2	54.4	45.6	36.7
0.56	91.1	82.3	73.5	64.7	55.8	47.0	38.2	29.8
0.60	83.8	74.9	66.1	57.3	48.5	39.7	30.8	22.0
0.65	76.4	67.6	58.8	49.9	41.1	32.3	23.5	14.7
0.69	69.0	60.2	51.4	42.6	33.8	24.9	16.1	7.3
0.74	61.7	52.9	44.0	35.2	26.4	17.6	8.8	-0.1
0.79	54.3	45.5	36.7	27.9	19.0	10.2	1.4	-7.4
0.83	47.0	38.1	29.3	20.5	11.7	2.9	-6.0	-14.7
0.88	39.6	30.8	22.0	13.1	4.3	-4.5	-13.3	-22.2
0.92	32.2	23.4	14.6	5.8	-3.1	-11.9	-20.7	-29.5
0.97	24.9	16.1	7.2	-1.6	-10.4	-19.2	-28.1	-36.9

Table 6. Returns Above Variable Costs Comparing Gain ($/kg) and Initial Steer Weight (kg).

Fixed Variables		
$/kg Gain		$/kg
Cattle Weight		kg
Nitrogen Amount	140	kg
Nitrogen Cost	0.66	$/kg
Irrigation Amount	0.00	mm ha
Irrigation Cost	0.51	$/mm ha
Other Costs	9.32	$/ha

	Gain ($/kg)							
Steer Weight (kg)	0.44	0.49	0.54	0.59	0.64	0.69	0.74	0.79
181	115.1	139.8	164.4	189.0	213.7	238.3	263.0	287.6
227	98.2	120.9	143.6	166.3	189.0	211.8	234.5	257.2
272	85.2	106.5	127.7	149.0	170.2	191.4	212.7	233.9

CONCLUSION

Changes in forage mass production and quality resulting from irrigation and nitrogen management have significant implications for stocker steer gains. The amounts and combinations of irrigation water and nitrogen result in different costs which have large effects on stocker profitability. Analysis of input combinations at the different input prices and stocker steer prices provides insight into appropriate management systems for stocker steers grazing WW-B. Dahl grass.

Total stocker steer gains increase with increasing nitrogen and irrigation use. However, the increased gains achieved by high input use often do not outweigh the cost. Nitrogen has a greater impact than irrigation in terms of economic returns from steer gains. This study showed that, with average rainfall during the growing season, grazing WW-B. Dahl pasture under dryland conditions could produce the highest returns over variable costs, especially if used with high levels of nitrogen. The SHPT currently faces increasing pumping lifts and increasing energy costs, making irrigated crop production an expensive and often unprofitable alternative, thus having a dryland pasture and grazing cattle system alternative increases in importance. With irrigation in both May and June, the cost of irrigation outweighs the value of increased steer gains. Conversely, in the sensitivity analysis, nitrogen use had a greater positive effect than irrigation in all scenarios, even when nitrogen prices were high.

Another finding was the importance of selecting cattle at lower starting weights to maximize stocking rates and total gains. Since these lighter cattle have a lower individual dry matter intake, they can be stocked at higher rates on the early high quality grass.

While this study found dryland pasture to be the most profitable with average rainfall during the growing season, irrigation may be necessary in a dry year to maintain an adequate level of plant-available water. Management can be used for nitrogen and irrigation. Small amounts of irrigation at crucial times during the growing season may result in higher returns over variable costs than would dryland production, especially if used with high levels of nitrogen. By applying irrigation only at selected times in the growing season, costs could be reduced so that stocker steer gains could be achieved more economically. Such an analysis was beyond the scope of this study and would provide an avenue for future research.

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Nutritive Evaluation of Two Legumes (*Strophostyles*) Supplemented to Goats Fed a High Quality Coastal Bermudagrass (*Cynodon dactylon*) Hay Diet

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ABSTRACT

The objective of this study was to compare effects of supplementing coastal bermudagrass (*Cynodon dactylon*; CBG) hay with *Strophostyles helvula* (98 g crude protein (CP)/kg dry matter (DM), 476 g neutral detergent fiber organic matter basis (NDFOM)/kg DM, *S. leiosperma* (117 g CP/kg DM, 497 g NDFOM /kg DM), or cottonseed meal (506 g CP/kg DM, 352 g NDFOM /kg DM; CSM) on intake of CBG hay (127 g CP /kg DM, 691 g NDFOM /kg DM) and apparent digestibility of dietary DM, organic matter (OM), NDFOM, and CP by goats. Six Boer × Spanish cross wethers (46.22 ± 3.99 kg) were fed CBG plus *S. helvula*, *S. leiosperma*, or CSM at 122 or 216 g/kg DM intake in a 6 × 6 Latin square with 3 × 2 factorial arrangement of treatments. There were no (*P* = 0.53) supplement type × amount interactions. Intake of DM, OM, and NDFOM of CBG was unaffected (*P* = 0.33) by supplementation with CSM, *S. helvula*, and *S. leiosperma.* Although intake of CBG was not affected, total diet NDFOM intake was 10.5% less (*P* = 0.01) when CSM and *S. helvula* were supplemented than when *S. leiosperma* was used. Supplement type did not affect (*P* = 0.21) OM digestibility, but OM digestibility increased (*P* = 0.05) 6.4% at the 216 versus 122 g/kg DM level of supplementation with the legumes or CSM. Supplementation with CSM and *S. leiosperma* improved (*P* = 0.02) NDFOM digestibility 7% versus supplementation with *S. helvula*. As supplement amount increased NDFOM digestibility increased (*P* = 0.02) by 5.5%. The diet supplemented with CSM had the greatest CP digestibility, and *S. helvula* CP was 6% less digestible (*P* = 0.02) than *S. leiosperma*. As supplement amount increased, CP digestibility increased (*P* = 0.01) 7%. Considering digestibility and intake, CSM and *S. leiosperma* were the best supplements fed in this experiment. *Strophostyles leiosperma* is recommended as a forage supplementation for goats when CBG hay basal diet is fed.

KEY WORDS: Boer × Spanish cross goats; Forage legumes; Trailing wild bean; Smooth-seeded wild bean; *Strophostyles*

INTRODUCTION

Goat producers in the USA are unable to meet consumer demand, which is expected to rise as population increases. In the USA, most pastures are grass based, and in the south central region the primary cultivated grass utilized is coastal bermudagrass (*Cynodon dactylon*) (Redmon, 2002). Even with quality coastal bermudagrass fed at maximum intake, goat requirement for protein may not be met without supplementation (NRC, 1981; Packard et al., 2007). Previous experiments fed goats coastal bermudagrass hay at various maturities with up to 149 g crude protein (CP)/kg dry matter (DM) and 760 g neutral detergent fiber (NDF)/kg DM and the nutritional requirement of the goats were not met (Luginbuhl, 1984).

Warm-season grasses, such as coastal bermudagrass, contain greater concentrations of neutral detergent fiber organic matter basis (NDFOM), acid detergent fiber organic matter basis (ADFOM), and lignin which limit forage intake by the ruminant animal because of decreased forage quality (Johnson et al., 2001). Legumes may have greater intake rates than grasses due to less rumination time and quicker rate of passage because legumes tend to break into smaller particle size in the rumen versus warm-season grasses (VanSoest, 1994; Wilson, 1994). For the warm-season, there is currently no widely adapted legume species capable of competing with coastal bermudagrass in mixed swards in the southern USA (Muir et al., 2005b).

Native warm-season legumes are adapted to local climate and soil, and retain greater quality even under stress conditions such as drought (Muir et al., 2005a; Muir et al., 2005b). However, they are currently not widely seeded in improved pasture or native grassland production systems (Call, 1985). If warm-season perennial grasses, including bermudagrass, are inter-seeded with a warm-season legume, nutritional limitations can be mitigated and agronomic benefits can improve warm-season grass pasture systems.

Smooth-seeded wild bean (*Strophostyles leiosperma*; LEIO) and its close relative, trailing wild bean (*S. helvula*; HELV), are native North American annual, warm-season legumes that often colonize open, disturbed areas (Diggs et al., 1999; Muir et al., 2005a). Both are persistent and productive even when sod grasses are dominant (Gee et al., 1994; Muir et al., 2005a). Trailing wild bean has been documented as an important range plant throughout the United States and Canada while smooth-seeded wild bean, perhaps because it produces less herbage, has been researched less despite reports of its existence as far north as Illinois (Diggs et al., 1999). In previous experiments HELV produced 372 g ADFOM/kg DM, 80.6 g lignin/kg DM, and 101 g CP/kg DM and less for plants defoliated to 10-cm stubble height (Muir et al., 2005a). In the same experiment LEIO produced 314 g ADFOM/kg DM, 67.5 g lignin/kg DM, and 145 g CP/kg DM and was not affected by defoliation (Muir et al., 2005a). While agronomic data was available for these two legume species, no animal response trials had been completed.

The objective of this study was to determine effects of two levels of HELV, LEIO, or cottonseed meal (CSM) supplementation upon intake of coastal bermudagrass hay (CBG) and apparent digestibility of dietary DM, organic matter (OM), NDFOM, and CP.

MATERIALS AND METHODS

Animals and Diets

Seed of HELV and LEIO were collected from the Cross Timbers region of Texas and from research plots at the Texas AgriLife Research Station (TARS) in Stephenville, Texas, and were used to establish pastures of these annual legumes in Windthorst fine sandy loam soil. Plants were harvested at early reproductive stages 5 cm from the ground, and dried in a forced air oven at 55°C for 72 h. Coastal bermudagrass hay was harvested June 2003 from fields at TARS in Stephenville, and stored in a fully enclosed barn. Solvent-extracted CSM was purchased at a local feed store. Boer × Spanish cross wether goats (46.22 ± 3.99 kg; 18 months old) were each assigned to a 7-d adaptation phase followed by a 7-d data collection phase in metabolism crates for each diet. Water and purchased mineral blocks containing 0.35% Zn, 0.2% Fe, 0.2% Mn, 0.03% Cu, 0.005% Co, and 0.007% I were available to the goats at all times. After drying, HELV and

LEIO hay was chopped with a mechanical mulcher (at least 2.5 cm particle size) to reduce refusal rates by the wethers.

Intake and Digestibility Measurements

Six diets consisting of 0.34 or 0.68% of goat body weight (BW) of HELV, LEIO, or CSM as supplement to a basal diet of CBG *ad libitum* were fed in a 6 × 6 Latin square design to each of six goats with a 3 × 2 factorial arrangement consisting of three types of supplement fed at two amounts. The CBG plus CSM diet was utilized as a non-leguminous control to determine effects of legume supplemented versus non-legume supplemented diet.

Total dietary intake was estimated as 225 g DM/kg of BW (Van Soest, 1994) and the amount of supplement (150 or 300 g/kg DM of intake) was calculated for each feeding period based on the weight taken the first day of the adjustment period, resulting in supplementation rates of 34 or 68 g DM/kg of BW. Legume and CSM supplements were fed in two equal feedings twice daily at 0800 h and 1700 h. Coastal bermudagrass hay was fed *ad libitum* and orts were collected daily to determine total intake. Because supplement and basal diet were fed separately, intake of each dietary component was used to calculate total diet nutritive value. Random forage samples were collected from each of CBG, CSM, HELV, and LEIO, and all forage samples dried at 55°C in a forced-air oven. Feces were collected every 24 h and the total excretion of feces weighed, a 10% aliquot taken, and frozen until dried at 55°C.

Laboratory Analyses

Forage, ort, and fecal samples were ground to pass a 1 mm screen of a sheer mill (Wiley, Arthur H. Thomas Co., Philadelphia, PA). Samples were placed in a forced air oven at 100°C in a crucible for 4 h to determine DM (AOAC, 1990). The OM concentration was determined by incineration in a muffle furnace at 540°C for 4 h (AOAC, 1990). Nitrogen (N) concentrations were determined using a modified aluminum block digestion (Gallaher et al., 1975) and analyzed by semi-automated colorimetry (Hambleton, 1977) using a Technicon Autoanalyzer II (Technicon Industrial Systems, Tarryton, NY). Procedures of Van Soest and Robertson (1980) were utilized to determine NDFOM, ADFOM, and lignin of forage and fecal samples. Digestibility of DM, OM, NDFOM, and CP were calculated based on forage, ort, and fecal sample analyses.

Statistical Analyses

The general linear model procedure of SAS based on the 6 × 6 Latin square (6 goats and 6 dietary treatments) with 3 × 2 (supplement type by supplement amount) factorial arrangement of treatments was utilized for statistical analysis (SAS, 1991). When the restriction level and treatments are equal, such as number of animals and dietary treatments in this experiment, treatments may be arranged factorially in a Latin square designed experiment (Montgomery, 2004). The model included period, animal, supplement type, supplementation level, and the supplement type × level interaction. Dependent variables measured were apparent digestibility of dietary DM, OM, NDFOM, and CP, and DM, OM, NDFOM, ADFOM, lignin, and CP intakes of CBG and total diet. Studentized differences among least-squares means (LSM) were utilized for mean separation (SAS, 1991). Significance was declared at $P \leq 0.05$ and tendencies at $P \geq 0.05$ and ≤ 0.10.

RESULTS

There were no interactions between supplement type and supplement amount for any of the response variables. Because actual total intake differed from the estimated 225 g DM/kg of BW, the actual amount supplemented differed from the original target 150 or 300 g/kg DM intake and averaged 122 and 216 g/kg DM intake supplement in the total diet. There were no supplement refusals during this experiment.

Table 1. Chemical composition (g/kg DM) of coastal bermudagrass hay (CBG), Strophostyles helvula (HELV), S. leiosperma (LEIO), and cottonseed meal (CSM).

	DM	OM	NDFOM	ADFOM	Lignin	CP
Feedstuff			g/kg DM			
CBG	953	883	691	335	40	127
HELV	953	894	476	279	47	98
LEIO	952	892	497	324	60	117
CSM	948	879	352	171	64	506

Forage Laboratory Analyses

Neutral detergent fiber concentration of CBG was at least 39% greater and ADFOM concentration at least 3% greater than any of the supplements fed in this experiment (Table 1). Diets containing LEIO had 32% less CP and HELV diets 47% less CP than CSM containing diets (Table 2). When supplemented at the 122 g/kg DM intake level, total diet NDFOM was 3.4% and ADFOM was 2.2% greater than the 216 g/kg DM intake supplementation (Table 2). At the lower level of supplementation lignin and CP concentrations were 3.8 and 7.5% less, respectively, than at the 216 g/kg DM intake supplementation level.

Table 2. Mean chemical composition of coastal bermudagrass diets supplemented with *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cottonseed meal (CSM) at two levels of supplementation.

	OM	NDFOM	ADFOM	Lignin	CP
			g/kg DM		
Supplement type					
HELV	885.1	648.5	326.1	41.1	122.4
LEIO	884.8	652.9	333.3	43.1	125.5
CSM	882.8	631.0	309.9	43.7	185.0
Supplement amount					
122 g/kg DM of intake	883.9	655.5	326.8	41.8	139.2
216 g/kg DM of intake	884.4	633.5	319.7	43.4	149.6

Intake

Coastal bermudagrass DM, OM, NDFOM, ADFOM, lignin, and CP intakes were not affected by supplement types or amounts (Table 3). The total diet intakes of DM, OM, and CP were not different among the supplement types. Goats fed LEIO had greater intakes of NDFOM and ADFOM than CSM or HELV diets, whereas goats fed LEIO and CSM supplements had a tendency for greater (*P* = 0.1) lignin intake than goats supplemented with HELV. Goats supplemented at the 122 g/kg DM intake level had less DM, OM, NDFOM, and ADFOM intakes than goats fed the 216 g/kg DM intake supplementation level. However, intakes of lignin and CP were not different (*P* = 0.12) between supplementation levels.

Apparent Digestibility

There was a tendency for differences (*P* = 0.07) in the digestibility of DM among diets containing the three supplement types (Table 4). Dry matter digestibility of diets supplemented with CSM and LEIO were greater than the DM digestibility of HELV containing diets. There were no differences in OM digestibility among diets containing either the legumes or CSM supplements. Diets with CSM and LEIO supported greater digestibility than diets with HELV. Digestibility of CP differed for all three supplement types. The diet supplemented with CSM had the greatest CP digestibility, and HELV tended to be 6% less digestible (*P* = 0.1) than LEIO.

At the higher supplementation level, DM digestibility tended to be 5.3% greater (*P* = 0.08) than DM digestibility of the low supplementation level (Table 4). As supplementation level increased, OM digestibility increased by 6.4% regardless of whether leguminous or non-leguminous supplement was fed. Diet NDFOM digestibility at the 216 g/kg DM intake supplementation level was 5.5% greater than at the 122 g/kg DM intake supplementation level. When goats were fed the higher supplementation level, CP digestibility was 7% greater than the 122 g/kg DM intake supplementation amount.

Table 3. Intake of coastal bermudagrass hay (CBG) and of CBG supplemented with *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cottonseed meal (CSM) at two levels of supplementation.

	Supplement type				Supplement amount (g/kg DM intake)		
Item	HELV	LEIO	CSM	SEM	122	216	SEM
CBG intake g/kg DM/kg BW							
DM	25.7	26.8	26.8	0.8	30.3	32.3	0.7
OM	22.7	23.7	23.7	0.7	27.0	25.9	0.6
NDFOM	12.2	12.8	12.7	0.4	23.9	22.9	0.3
ADFOM	8.6	9	8.9	0.2	9.2	8.6	0.1
Lignin	1	1.1	1.1	0.03	1.1	1	0.02
CP	3.3	3.3	3.3	0.1	3.4	3.2	0.1
Total diet intake g/kg DM/kg BW							
DM	30.6	31.7	31.6	0.8	30.3[b]	32.3[a]	0.7
OM	27.1	28.1	27.9	0.7	26.8[b]	28.6[a]	0.6
NDFOM	14.6[b*]	16.1[a]	14.4[b]	0.4	14.5[b]	15.6[a]	0.3
ADFOM	10.0[b]	10.6[a]	9.8[b]	0.2	10.0[b]	10.3[a]	0.1
Lignin	1.3[b]	1.4[a]	1.4[a]	0.03	1.3	1.4	0.02
CP	3.8	3.9	3.7	0.1	3.2	3.7	0.1

[*] Values in the same row followed by different superscript letters differ ($P \leq 0.05$) according to least-squares means (LSM) multiple range test.

DISCUSSION

The greater NDFOM concentration in the CBG hay vis-á-vis both legumes is consistent with previous research that indicates grasses generally contain greater concentrations of NDFOM than legumes (Johnson et al., 2001). The greater amount of lignin in the legumes versus the CBG hay is likewise consistent with previous research that indicates that legumes often contain greater lignin concentrations because of differences in plant structure of legumes, namely more developed stem tissue than grasses (Collins and Fritz, 1995). The greater CP concentration in the CBG hay versus the legumes is consistent with high N fertilization rates (Johnson et al., 2001). The two legume hays were harvested in mid-reproductive stages and would likely have had greater nutritive value had they been cut earlier, but values here are consistent with previous trials utilizing plants not defoliated until final harvest (Muir et al., 2004). Wild bean forage concentration varies from 80 g CP/kg DM in mature plant material to 220 g CP/kg DM in re-growth following defoliation (Muir et al., 2005a).

The DM intake of CBG hay did not increase with increased supplementation amount and/or type, but as supplement level increased total diet intake increased. This is consistent with a study comparing *Chloris gayana* (61.9 g CP/kg DM; 829 g NDFOM /kg DM) hay diet supplemented with maize or one of three legumes; goats on the control diet consumed more hay than those supplemented with legumes (Mupangwa et al., 2000). In that study, diets supplemented with legumes did not differ in hay intake but total diet intake did increase (Mupangwa et al., 2000). The legume and CSM supplements were additive to the CBG hay basal diet, indicating that they are all high quality supplements when supplemented to a basal bermudagrass hay diet. Neutral detergent fiber organic matter basis and ADFOM intakes of LEIO were greater than that of the other supplement types because of a greater concentration of NDFOM and ADFOM.

As the amount of supplement increased, digestibility increased, regardless of supplementation type. Although the legumes used as supplement in this experiment contained greater amounts of ADFOM and less CP than CSM; as the amount of supplement increased, total dietary CP increased. Because of the greater ADFOM and lignin concentrations of LEIO, the 5% greater CP digestibility of LEIO versus HELV is unusual. The increase in CP digestibility at increasing supplementation rates was unusual because the CP concentration of the CBG exceeded the amount in the legumes, and supplementing with legumes did not increase CP concentration of the diet. However, the amount of digestible CP did increase indicating that legume CP was more digestible than the grass CP (Wilson, 1994). In a pasture situation, goats would likely select a greater proportion of legumes than grasses than was fed in this experiment, especially as grass matures (Singh and Shankar, 2000; Muir, 2002; Pande et al., 2002; Goodwin et al., 2004). Greater selection of the leaves of young legumes should increase digestible CP concentration of the diet (Ahmed and Nour, 1997; Singh and Shankar, 2000).

The digestibility of DM, OM, NDFOM, and CP when LEIO was supplemented was greater than that of HELV despite the greater ADFOM and lignin concentration of LEIO, likely because LEIO has smaller stems than that of HELV. This morphological characteristic of LEIO may have promoted more particle size reduction in the rumen through microbial degradation and mastication than when HELV was supplemented. The increased intake and digestibility of LEIO indicates that it would support improved animal performance when supplemented to CBG hay.

Table 4. Apparent digestibility (g/kg DM intake) of coastal bermudagrass hay diets supplemented with either *Strophostyles helvula* (HELV), *S. leiosperma* (LEIO), or cotton seed meal (CSM) at two levels of supplementation.

	Supplement type				Supplement amount (g/kg DM intake)		
Nutrient	HELV	LEIO	CSM	SEM	122	216	SEM
DM	595.1[*b]	639.0[a]	646.5[a]	16.3	610.1[b]	644.2[a]	13.3
OM	598.2[b]	632.5[a]	638.8[a]	16.8	602.6[b]	643.8[a]	13.7
NDFOM	601.7[b]	646.0[a]	647.9[a]	12.4	614.0[b]	649.7[a]	10.1
CP	658.0[c]	692.2[b]	718.0[a]	14.4	673.5[b]	705.3[a]	11.8

[*] Values in the same row followed by different superscript letters differ ($P \leq 0.05$) according to least-squares means (LSM) multiple range test.

CONCLUSIONS

Although CBG hay intake was not affected by supplementation, digestibility increased indicating that CSM and *S. leiosperma* allowed the same dietary intake to be utilized more efficiently than *S. helvula*. Considering digestibility of CP and NDFOM, the best supplements fed in this experiment were CSM and *S. leiosperma*, with *S. leiosperma* being as digestible as the CSM supplement. The 216 g/kg DM intake supplementation level tended to improve digestibility of all factors considered, and was found to be the better level of supplementation of the two in this experiment. Because the *S. leiosperma* hay used in this trial had comparable NDFOM and CP digestibility (but not concentration) to CSM, this native legume could be a resource to improve the poor quality of pasture grasses in mid-summer. Pasture studies are recommended for follow up as they may produce different results from those of this study, primarily because protein concentrations of legume hays in this study were likely low relative to live plants as a result of leaf shattering and late harvest of mature plants.

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Compost Type Affects Bermudagrass (*Cynodon dactylon* (L.) Pers.) Invasion

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ABSTRACT

A study was conducted on the Texas A&M-Commerce campus in Commerce, TX to evaluate the rate of bermudagrass reestablishment following incorporation of 4 different compost blends. Five beds were created by mechanically removing bermudagrass from an area approximately 60 cm (24") wide and 300 cm (120") long. All beds were tilled to a depth of 15 cm (6"). Compost was added at the following rates: 1) poultry litter compost (PLC) @ 10 tons / ac, 2) yard waste compost (YWC) @ 20 tons / ac, 3) dairy compost (DC) @ 10 tons / ac, or 4) a mix of dairy and poultry litter compost @ 10 tons / ac. The remaining bed had no compost added and was used as a control. EC and pH did not differ between compost types, but N was slightly higher in PLC. Compost type had a strong effect on bermudagrass invasion. By day 30, PLC and YWC had significantly more coverage than other treatments. The PLC plots covered significantly faster, achieving 100% coverage by day 60. All compost plots reached at least 90% coverage by day 90. Coverage was significantly slower in the control plot, with full coverage not achieved until day 120.

KEY WORDS: Poultry litter, Dairy compost, Yard waste compost

INTRODUCTION

Bermudagrass (*Cynodon dactylon* (L.) Pers.) is an important, but invasive, grassy weed throughout the southern U.S. Its aggressive, stoloniferous and rhizomatous nature allows it to rapidly invade, especially in areas with adequate moisture (Knoop, 1986). It was likely introduced in 1751 from Africa (Cudney et al., 2007), and by 1807 was listed as one of the principle grasses in the southern states (Duble, 2006). Because bermudagrass is one of the most common lawn grasses in the southern U.S., its control and elimination from landscape beds is a major concern for many gardeners (Chalmers et al., 2006; Cudney et al., 2005).

Hybrid bermudagrass responds readily to increasing rates of N regardless of inorganic or organic N source (Evers, 1998; Osborne et al., 1999). This yield response to N is generally linear up to about 560 kg N/ha and then becomes quadratic (Robinson, 1996). Due to the genetic diversity, common bermudagrass forage yield and growth may or may not be similar to hybrid bermudagrass (Alabama Cooperative Extension Service, 1996). In years of average precipitation, N and P uptake from organic wastes has been shown to be similar across bermudagrass types

(Brink et al., 2003) but not in dry years (Brink et al., 2004). The effects of poultry litter are generally greater than other organic fertilizers, as over 50% of the N is found as ammonia based uric acid (Guerra-Rodriguez et al., 2001; Mitchell and Donald, 1995).

Numerous studies have demonstrated the benefits of compost as an organic fertilizer and bed amendment, beginning with Sir Albert Howard's *The Soil and Health: A Study of Organic Agriculture* in 1945 (Beck, 1997). The addition of composts generally results in many improvements to the soil including, but not limited to: 1) increased macro and micronutrient availability, 2) increased water retention and porosity, and 3) improved soil structure (Fitzpatrick et al., 2005; Beck, 1997). Studies on turfgrasses, including bermudagrass, St. Augustine grass, Kentucky bluegrass, and tall fescue, have all found composts to be an effective alternative to inorganic fertilizer sources (Wright et al., 2007; Sloan et al., 2006; Linde and Hepner, 2005). Dairy manure compost, in particular, proved to be very effective at providing sufficient fertility to landscape beds and bermudagrass turf plots (Sloan et al., 2006).

Because the addition of compost to landscape beds and gardens can make these areas more prone to bermudagrass invasion, this study was conducted to evaluate what might be observed in a new or updated home landscape. The purpose of this study was to ascertain the potential invasiveness of bermudagrass in newly amended compost beds using various compost sources: poultry litter, yard waste, and dairy composts.

MATERIALS AND METHODS

At the onset of the study, five beds, in each of 3 blocks, were created by mechanically removing all vegetation from an area 1.2 m (4') x 6.1 m (20'). Beds were tilled to a depth of 15 cm (6"), and any vegetative remains were removed and discarded. Compost was randomly added from one of four blends: 1) poultry litter compost (PLC), 2) yard waste compost (YWC), 3) dairy compost (DC), and 4) a 1:1 mixture of PLC and DC. PLC, DC, and MC received application rates of 1.78 kg / m^2 (10 tons / acre). YWC was known to have lower nitrogen levels (Table 1) and was applied at 3.56 kg / m^2 (20 tons / acre). Composts were applied at average moisture content between 25 and 30%. The fifth bed was not amended with compost and used as a control. All composts were analyzed for NO_3^- levels prior to incorporation, using the cadmium reduction method (Table 1). In terms of actual N applied, PLC was the highest at 0.052 kg N / m^2 (4.72 lbs. N / 1,000 ft^2) and DC was the lowest at 0.036 kg N / m^2 (3.25 lbs N / 1,000 ft^2). YWC and MC were applied at a rate of 0.039 kg N / m^2 (3.58 lbs N / 1,000 ft^2). No mulch was applied to the planting area. Plots were analyzed prior to initiation of the study for electrical conductivity (EC) and pH (Table 1).

Four, one-meter long transects were taken within each plot every thirty days. Ten points (10 cm apart) were used to score for hits. Presence of a bermudagrass plant was considered a hit. Zero (0) hits per transect indicated no bermudagrass coverage. Ten (10) hits indicated one hundred percent coverage. Data collection continued until all beds reached 100% coverage.

Experimental design was a randomized complete block design, with each transect an experimental unit and four transects per treatment. Square root arc-sin transformations were made prior to statistical analysis. Statistical analysis was conducted using Proc ANOVA of SAS (Statistical Analysis Software, Cary, NC). Means were separated using Duncan's Multiple Range test. Data were back-transformed for presentation purposes.

RESULTS AND DISCUSSION

Chemical analyses of plots and composts showed only minor variation among the treated beds. Nitrogen levels were slightly higher in PLC at 2.9% and lowest in the YWC at 1.1% (Table 1). EC again was slightly higher in the PLC, consistent with salt and fertility levels found in other studies.

Table 1. Initial chemical analysis of landscape soils amended with various compost materials in treatment plots.

Compost Blend	Compost %N	Soil pH	Soil EC (ųS/cm)
Control (None)	N/A	7.12	152
Yard Waste Compost (YWC)	1.1	7.15	141
Poultry Litter Compost (PLC)	2.9	7.05	164
Dairy Compost (DC)	2.0	7.12	136
Mixed Compost (MC)	2.2	7.02	134

At day 30, PLC and YWC had significantly higher bermudagrass invasion than other treatments with roughly 70% coverage in all treatment plots (Table 2). Dairy compost had greater bermudagrass invasion than the control with approximately 40% coverage. Bermudagrass invasion in MC was not significantly greater than the control by day 30. It is interesting to note that bermudagrass invasion in YWC was significantly higher than MC at day 30; given that N application rates were identical, suggesting differences in N availability between the composts.

Table 2. Bermudagrass invasion scores in landscape beds amended with various compost types. Each point represents 10% coverage.

Compost Blend	Day 30	Day 60	Day 90	Day 120
Control (C)	3.3a	6.7a	8.3a	10.0a
Dairy Compost (DC)	4.7b	8.0b	9.0b	10.0a
Mixed Compost (MC)	4.3ab	7.7b	9.3b	10.0a
Poultry Litter Compost (PLC)	7.7c	10.0c	10.0c	10.0a
Yard Waste Compost (YWC)	6.7c	8.3b	10.0c	10.0a

By day 60, the PLC plots were 100% covered, significantly faster than any other treatment (Table 2). This can be explained by the slightly higher N concentration in the compost. Coverage in the control group was significantly lower than other treatments with approximately 67% coverage. DC, MC, and YWC treatments had approximately 80% coverage.

By day 90, all treatments had reached at least 83% coverage (Table 2). The control treatment remained significantly lower than other treatments. YWC matched PLC at 100%

coverage. Bermudagrass in MC and DC treatments exceeded 90% coverage. Full coverage in all treatments was reached at day 120 of the study.

CONCLUSIONS

The type of compost can affect the invasion of bermudagrass, as the choice of compost can affect the amount and availability of soil N. In this study, the compost selection significantly affected the rate at which bermudagrass invaded, with poultry litter, a compost known for N supplied by uric acid (Guerra-Rodriquez et al., 2001) providing an immediate response, while dairy composts, that are subject to potentially high levels of N mineralization (Shi et al., 2004), were invaded slowly. Because bermudagrass responds quickly to nitrogen increases, it is likely to invade adjacent gardens as incorporated composts increase soil fertility. This further emphasizes the need for weed control measures in newly amended soils.

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Water Conservation Policy Evaluation: The Case of the Southern Ogallala Aquifer

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ABSTRACT

The Great Plains region of the United States is characterized by a significant dependence on agriculture;specifically irrigated agriculture. The regional economic dependence on irrigated agriculture and the decline of the Ogallala Aquifer due to agricultural pumping have been much of the basis for the relatively recent governmental interest in developing policy alternatives for conserving water in the aquifer. The objectives of this study were to analyze and evaluate the outcomes of specified water conservation policy alternatives on the Ogallala Aquifer underlying the Southern High Plains of Texas and Eastern New Mexico using non-linear optimization models. Results indicate that due to varying land use and hydrologic conditions in the Ogallala Aquifer, blanket water conservation policies will likely be inefficient.

KEY WORDS: Ogallala Aquifer, Dynamic Optimization, Natural Resource Management

INTRODUCTION

Irrigated agriculture has played a vital role in the development and growth of the Great Plains Region of the United States. The primary source of water for irrigation in this region is the Ogallala Aquifer, which encompasses 174,000 square miles and underlies parts of eight states: Texas, New Mexico, Oklahoma, Colorado, Kansas, Nebraska, South Dakota, and Wyoming (Alley et al. 1999). According to the High Plains Water District, in the Great Plains Region, the water pumped from the Ogallala Aquifer accounts for approximately 65% of the total water used for irrigation in the U.S. annually.

The Great Plains region produces approximately 45% of the national production of wheat, 25% of the national production of corn, over 88% of the national production of grain sorghum, and 32% of the national production of cotton according to the National Agricultural

Statistics Service (NASS) data for 1999. Another important agricultural activity in the Great Plains is the cattle feeding industry, composed of feedlots and beef packing plants, where over 15 million head of cattle, or 18% of the national production, are produced annually (Dennehy et al. 2002).

Ninety percent of the recharge in the aquifer is percolated through the soil through small playa lakes that dot the landscape from Texas to Nebraska (Alley et al. 1999). In the early 1950's, approximately 480 million cubic feet of groundwater per day was used for irrigation from the Ogallala Aquifer. By 1980, that amount had increased to 2,150 million cubic feet per day (Alley et al. 1999). Water table levels in the Ogallala currently decline in a range from approximately half a foot to several feet annually. The effect of recharge when compared to the rate of depletion is insignificant (Birkenfeld 2003). Many believe that a decline in the aquifer toward economic depletion will likely have a detrimental impact on the irrigated agriculture dependent regional economy of the Great Plains.

Study Area

As the decline of the aquifer becomes a timely topic in state legislatures across the Great Plains, researchers have found it necessary to sub-divide the aquifer into regions where more specialized and accurate information can be analyzed. The Southern portion of the Ogallala Aquifer is often divided into three sub regions: the Northern region which includes Kansas and Eastern Colorado, the Central region which includes the Texas Panhandle and Western Oklahoma, and the Southern region which includes the Southern High Plains of Texas and South-eastern New Mexico (see Figure 1). This study focuses primarily on the Southern sub-region of the Ogallala Aquifer which lies on the 100th meridian and is the second largest water use area, behind Nebraska, accounting for approximately 12% of annual extraction (National Research Council 1996).

The Southern portion of the Ogallala Aquifer is considered exhaustible due to the relatively low rate of recharge when compared to the quantities of water pumped annually for agricultural production of cotton, corn, grain sorghum, wheat, and peanuts.

Sources vary on the exact amount of recharge in the Southern portion of the Ogallala Aquifer, but many agree on a range from half an inch to several inches per year per surface acre (High Plains Water District #1). Additionally, the most recent water use projection made by the Amosson Group for the Texas Water Development Board Groundwater Availability Model estimated water used for irrigation in the Southern Ogallala Aquifer to be approximately 3,800,000 acre feet annually which are used to irrigate 3,500,000 acres (Amosson et. al. 2003).

Figure 1. Map of the Ogallala Aquifer
Source: High Plains Underground Water Conservation District # 1, Lubbock, Texas.

The 3,500,000 irrigated acres overlying the Southern Ogallala Aquifer in Texas account for a significant proportion of the state's agricultural crop production including 59% cotton, 10% corn, 26% grain sorghum, and 40% peanut, and 46% wheat of the state's total production according to 2006 NASS data. Within the vast area including forty-six counties that overlie the Southern Ogallala Aquifer, some areas are more heavily irrigated than other areas. These areas generally have higher levels of saturated thickness, but much more rapid rates of depletion. Other areas have small amounts of irrigation and actually show an increase in saturated thickness occurring through time.

The specific counties included in this study were: Andrews, Bailey, Borden, Cochran, Crosby, Dawson, Dickens, Floyd, Gaines, Garza, Glasscock, Hale, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Midland, Motley, Terry, and Yoakum in Texas, and Lea and Roosevelt Counties in New Mexico.

Water conservation policies may effectively extend the economic life of the Ogallala Aquifer in the Southern High Plains of Texas and Eastern New Mexico and maintain the viability of a regional economy dependent on agriculture. This study evaluates water conservation policies which limit drawdown of the aquifer over a sixty year planning horizon. Because the majority of the study area is in Texas, the addressed water conservation policy alternatives find their basis and are most applicable to the Texas counties of the study area. The goal of the policy alternative is to allow agricultural irrigation and water for other uses to be available further into the future than would result under current water extraction practices.

The policy alternatives considered and compared in this study include: 1) compensating producers for decreasing water usage to 0% drawdown relative to the amount that would have otherwise been used over sixty years through a water conservation reserve program, 2) reduce water usage to limit drawdown to 50% of the water that would have been used in the absence of a policy over sixty years, 3) reduce water usage to limit drawdown to 75% of the remaining saturated thickness over sixty years, and 4) limiting water usage to an annual extraction quota to achieve 50% drawdown relative to the amount of water that would have been used over the sixty year planning horizon. The first alternative considered is similar to the Federal Conservation Reserve Program (CRP) enacted for soil conservation, but with a goal of water conservation. The second, third, and fourth alternatives are directly linked to Senate Bills 1 and 2 passed by the Texas Legislature in 1997 and 2001, respectively giving Underground Water Conservation Districts (UWCDs) the right to regulate water usage.

A baseline scenario was estimated to establish future economic and hydrologic characteristics given current water extraction rates. The baseline was compared to the 0% drawdown (CRP) alternative as well as the 50% and 75% total drawdown policies. Additionally, the 50% total alternative was compared to the 50% annual quota restriction alternative in order to provide insight to policy makers to help decide whether the short term annual 50% restriction or the 50% total drawdown restriction would lead to the most efficient outcome. Comparisons were conducted between the policy alternatives to weigh the costs and benefits to producers and society under the contrasting alternatives. These comparisons illustrate the marginal effects of water usage under the different alternatives.

The primary objective of this study was to analyze and evaluate the impacts of selected water conservation policy alternatives on the Ogallala Aquifer underlying the Southern High Plains of Texas and Eastern New Mexico for the purpose of identifying which alternative or alternatives most effectively achieve conservation of the aquifer and keep the heavily agriculturally dependent economy viable. The specific objectives were to:

1. Determine the characteristics of water conservation policy alternatives which could extend the economic life of the aquifer, and
2. Evaluate the economic life of the aquifer across the region under different water conservation alternatives for a sixty year planning horizon.

MATERIALS AND METHODS

General Algebraic Modeling System (GAMS), a computer software optimization program, was used in the study to solve the optimization models formulated and to evaluate the water rights buyout policies (Brooke, 1998). The framework of the county level optimization models used in this study was originally developed by Feng and Segarra (1992) and has been expanded and modified by Terrell, Johnson, and Segarra (2001), Johnson (2003), and Das and Willis (2006). The objective of this study's county level optimization models is to maximize net present value of net returns to land, management, groundwater, and irrigation systems over a sixty year planning horizon for a given county as a whole.

The objective function is defined as:

(1) $$\text{Max NPV} = \sum_{t=1}^{60} NR_t (1 + r)^{-t},$$

where NPV is the net present value of net returns, r is the discount rate, and NR_t is net revenue at time t. NR_t is defined as:

(2) $$NR_t = \sum_i \sum_k \Theta_{ikt} \{ P_i Y_{ikt} [WA_{ikt}, WP_{ikt}] - C_{ik} (WP_{ikt}, X_t, ST_t)\}.$$

where i represents the crops grown, k represents the irrigation technologies used, Θ_{ikt} represents the percentage of crop i produced using irrigation technology k in time t, P_i represents the output price of crop i, WA_{ikt} and WP_{ikt} represent per acre irrigation water applied and water pumped per acre respectively, $Y_{ikt}[\cdot]$ represents the per acre yield production function, C_{ikt} represents the costs per acre, X_t represents pump lift at time t, ST_t represents the saturated thickness of the aquifer at time t.

The constraints of the model are:

(3) $ST_{t+1} = ST_t - [(\sum_i \sum_k \Theta_{ikt} * WP_{ikt}) - R]A/s,$

(4) $X_{t+1} = X_t + [(\sum_i \sum_k \Theta_{ikt} * WP_{ikt}) - R] A/s,$

(5) $GPC_t = (ST_t/IST)^2 * (4.42*WY/AW),$

(6) $WT_t = \sum_i \sum_k \Theta_{ikt} * WP_{ikt},$

(7) $WT_t \leq GPC_t$

(8) $PC_{ikt} = \{[EF(X_t + 2.31*PSI)EP]/EFF\}*WP_{ikt},$

(9) $C_{ikt} = VC_{ik} + PC_{ikt} + HC_{ikt} + MC_k + DP_k + LC_k$

(10) $\sum_i \sum_k \Theta_{ikt} \leq 1$ for all t,

(11) $\Theta_{ikt} \geq (2/3)\, \Theta_{ikt-1},$

(12) $\Theta_{ikt} \geq 0.$

Equations (3) and (4) represent the two equations of motion included in the model which update the two state variables, saturated thickness and pumping lift, ST_t and X_t respectively, where R is the annual recharge rate in feet, A is the percentage of irrigated acres expressed as the initial number of irrigated acres in the county divided by the area of the county overlying the aquifer, and s is the specific yield of the aquifer.

Constraints (5), (6) and (7) are the water application and water pumping capacity constraints, respectively. In equation (5), GPC represents gross pumping capacity, IST represents the initial saturated thickness of the aquifer and WY represents the average initial well yield for the county. Equation (6) represents the total amount of water pumped per acre, WT_t, as the sum of water pumped on each crop. Constraint (7) requires WT_t to be less than or equal to GPC.

Equations (8) and (9) represent the cost functions in the model. In Equation (8), PC_{cit} represents the cost of pumping, EF represents the energy use factor for electricity, EP is the price of energy, EFF represents pump efficiency, and 2.31 feet is the height of a column of water that will exert a pressure of 1 pound per square inch. Equation (9) expresses the cost of production, C_{ikt}, in terms of VC_{ik}, the variable cost of production per acre; HC_{ikt}, the harvest cost per acre; MC_k, the irrigation system maintenance cost per acre; DP_k, the per acre depreciation of the irrigation system per year; and LC_k, the cost of labor per acre for the irrigation system.

Equation (10) limits the sum of all acres of crops i produced by irrigation systems k for time period t to be less than or equal to 100%. Equation (11) is a constraint placed in the model to limit the annual shift to a 33% change from the previous year's acreage. Equation (12) is a non-negativity constraint to assure all decision variables in the model take on positive values.

Specific data was compiled for each county within the study region for both Texas and New Mexico. The county specific data included a five year average of planted acreage of cotton, corn, grain sorghum, wheat and peanuts; total acreage under conventional furrow, low energy precision application (LEPA) and dryland. Operating costs associated with the most commonly used crop production practices were also collected for specific crops, including fertilizer, herbicide, seed, insecticide, fuel, irrigation technology maintenance, irrigation, labor, and harvesting costs. Finally, hydrologic data was collected, including the area of each county overlying the aquifer, average recharge, total crop acres per irrigation well, average saturated thickness of the aquifer, initial well yield, and average pump lift.

Hydrologic Data: The amount of annual recharge in the Southern Ogallala is not known, and most estimates are considered controversial at best. For the purposes of this study, a recharge estimate by Stovall (2001) using Texas Water Development Board data was used. Stovall separated county acre-inch recharge into two categories, primary and secondary. Primary recharge values were available for each square mile in the study area. However, there were fewer values for secondary recharge. Therefore, the recharge value used was average primary recharge by county plus a weighted secondary county recharge value to account for the differences in data availability between the two recharge estimates. There were no values of secondary recharge for Andrews, Midland, and Glasscock Counties. Therefore, Martin County secondary values were used for Midland and Andrews Counties and Howard County values for Glasscock County. Additionally, recharge values were unavailable for Lea and Roosevelt Counties in NM. For this reason the bordering counties in Texas recharge values were used. Specifically Gaines County, TX values were used for Lea County, NM and Bailey County, TX values were used for Roosevelt County, NM.

Saturated thickness and pump lift by county were calculated from the TWDB groundwater database reports for the most recent year's data. Saturated thickness was calculated by subtracting the depth to water from the depth of the well. Pump lift was calculated as the depth from the surface to the water level. An estimated specific yield of 0.15 was used for the entire study area and the initial well yield by county was estimated using the Analytical Study of the Ogallala Aquifer in various counties (Texas Water Development Board, 1976). Initial acres served per well was calculated from the TWDB Survey of Irrigation from 2000 as the number of acres irrigated with groundwater divided by the number of wells in the county.

Acreages: General county acreages including area of the county were obtained from the 2000 U.S. Census. Estimating county acreages by crop was a two-step process: 1) dryland and irrigated county planted acres by crop were obtained from the Farm Service Agency (FSA) for 1999-2003, 2) FSA planted acres were converted to harvested acres using the ratio of planted to harvested acres for the same crops and systems for 1999-2003 from NASS.

In order to allocate irrigated acres between furrow and LEPA, the TWDB Survey of Irrigation (2000) was used to obtain the total acres irrigated by furrow and by LEPA for each county in the study region. Assuming only two systems, furrow and LEPA, allowing the subtraction of acres irrigated with sprinkler (LEPA) from total groundwater irrigated acres to obtain the percent of acres under furrow and LEPA for each county. Finally, the percent irrigated by each system was multiplied by the number of irrigated acres of each crop in a county to estimate county acreages by crop and system with the exception of peanuts and corn due to the fact that no dryland corn and only LEPA peanuts are grown.

Production Functions: The crop simulation software CropMan Version 3.2 developed at the Blackland Research Center in Temple, TX was used to estimate county production function parameters by crop and system (Gerik and Harman). The most prevalent soil types along with the weather data from the closest weather stations were used for each county. CropMan data files for

New Mexico counties were unavailable; therefore Gaines County and Bailey County productions functions were used for Lea and Roosevelt Counties, respectively. Yields were obtained from CropMan for LEPA (95% efficiency) and furrow (60% efficiency) for varying water application rates. Regressions for each crop and system were then estimated where Y was calculated as the CropMan yield minus the actual NASS 1999-2003 average dryland yield, X was water application rate, and X^2 was water application rate squared. The regression was estimated setting the intercept to zero, then adding back the dryland intercept.

Commodity Prices: Prices for wheat, corn, and sorghum were collected from the Agricultural Marketing Service. The prices were 1999-2003 AMS quotes for South of Line from Plainview to Muleshoe. Due to the fact that the price of cotton for the same five year period was below the marketing loan price, a price equal to the loan price plus coupled government payments ($0.57) was used in place of the AMS price. Additionally, AMS does not include peanut prices and therefore the 1999-2003 NASS peanut price was used.

Costs of Production: 2005 Texas Crop and Livestock Budgets produced by the Texas Agricultural Extension Service for Districts 1&2 were the primary sources for costs of production. Costs are both crop and irrigation system specific. Electricity is the primary power source for this study area; therefore budgets were converted from natural gas to electricity when needed. The electricity price used was the South Plains Electric Coop 1998-2002 average price of .06442 $/kwh. Additionally, several sprinkler budgets were converted to furrow budgets when needed.

RESULTS

Optimal levels of saturated thickness, annual net revenue per acre, pump lift, water applied per cropland acre, cost of pumping, and net present value of net returns per acre (NPV) by county were derived in GAMS using the non-linear dynamic optimization model for the baseline scenario and the three water conservation policy alternatives for nineteen of the twenty-four counties in the study area. Five counties in the study area, Borden, Dickens, Howard, Martin, and Motley show increases in saturated thickness over the sixty year planning horizon likely due to minimal irrigation in these counties. For this reason, policy results reported for these counties are the baseline scenario, and the 0% drawdown policy; however, the remaining policy alternatives' results for these counties are not reported because the policy restrictions were non-binding and showed no deviation from the baseline.

Comparison of Policy Alternatives for Gaines County, TX

In this section, comparisons pertaining to specific policy alternative results are compared to the baseline solution. Figures 2-3 show the nominal net revenue per acre and saturated thickness respectively over the sixty year planning horizon corresponding to the baseline scenario. The 0% Drawdown Policy resulted in the constraint forcing all irrigated acres into dryland acres causing significant differences in saturated thickness in year sixty compared to the baseline. Saturated thickness in the 0% case is 77 feet above the baseline level. The model also showed major differences in the net revenue per acre. In the 0% scenario, nominal net revenue per acre was $96.00 less than the baseline in year two. The gap between nominal net revenue per acre did narrow slightly between the two scenarios in later time periods, but yearly baseline net revenue remained well above the 0% policy net revenue over the entire planning horizon. In the 0% drawdown scenario, NPV per acre was $2,278.81, or 81% lower than the baseline. Therefore, $2,278.81 would be the approximate per acre compensation that would have to be provided to Gaines County producers in year one for them to be no worse off by discontinuing water usage for sixty years.

The 50% Total Drawdown Policy resulted in the saturated thickness being 25.5 feet above the baseline saturated thickness at the end of the planning horizon. Nominal net revenue per acre was not significantly affected by the 50% restriction, remaining about $3.00 per acre below the baseline through year sixty. NPV per acre for the 50% policy was $531.34, or 19% below the baseline level.

The 75% Drawdown Policy resulted in saturated thickness being 13 feet above the baseline level whereas net revenue per acre remained similar to the baseline until year thirty-three. After year thirty-three, nominal net revenue per acre remained approximately $4.00 below the baseline level through year sixty. NPV per acre was determined to be only $222.08, or 8% below the baseline NPV.

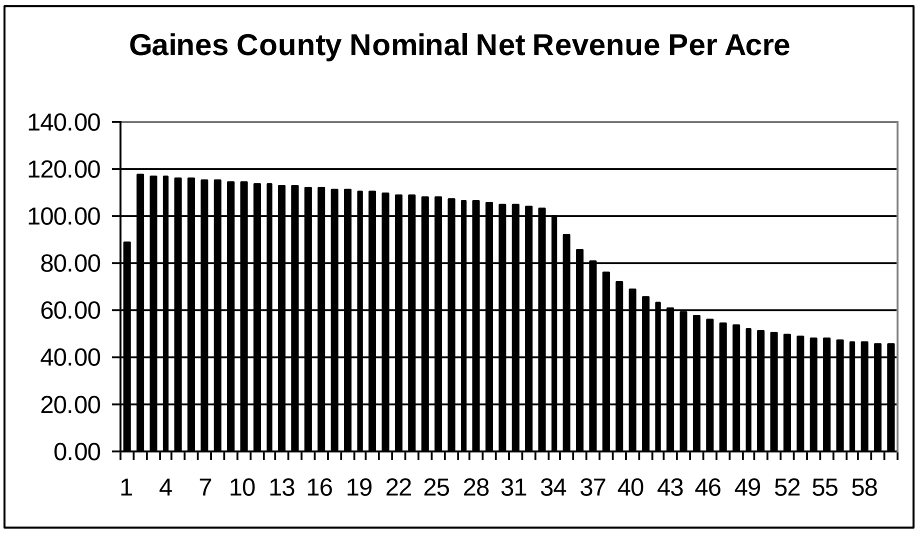

Figure 2 Gaines County Baseline Scenario Per Acre Net Revenue

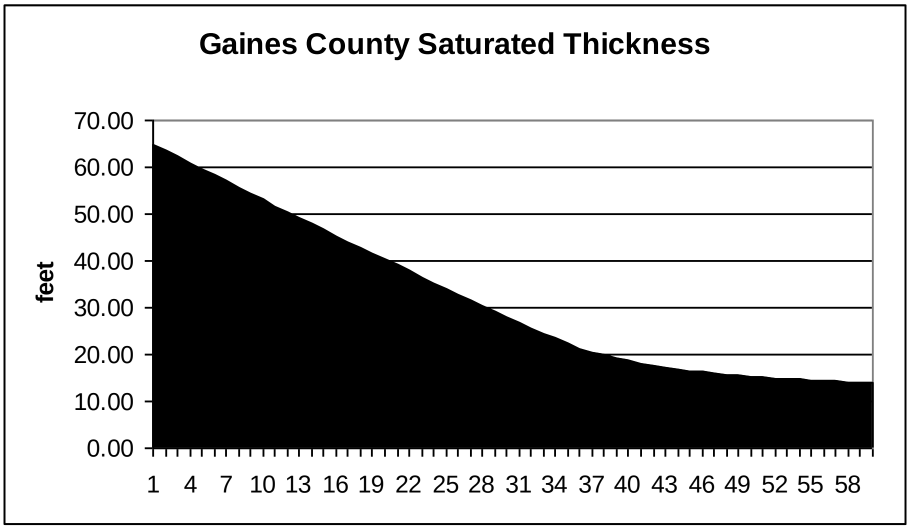

Figure 3 Gaines County Baseline Scenario Saturated Thickness

The 50% Total Drawdown Policy compared to 50% Annual Drawdown Policy resulted in saturated thickness in these two scenarios being quite similar with the saturated thickness in the 50% annual policy being 1.5 feet higher than the 50% total policy in year sixty. In year two, the 50% total policy net revenue per acre was $48.00 higher than the 50% annual net revenue, however; by year twenty-three the 50% annual restriction had a higher net revenue per acre. At the end of the planning horizon, the 50% annual policy nominal net revenue per acre was $21.00 higher than the 50% total drawdown net revenue per acre. NPV per acre differs however, in that NPV for the 50% total drawdown policy is $388.95, or 20% higher than the 50% annual restriction implying that for about the same amount of water conservation, an annual water use restriction causes producers to be worse off than a sixty year planning horizon water use restriction.

As discussed previously, in the baseline scenarios five counties in the region (Borden, Dickens, Howard, Martin, and Motley) showed an increase in the saturated thickness over the planning horizon in addition to comparatively low net revenue per acre and water applied per cropland acre (see Table 1). These counties lie relatively close to the eastern edge of the Ogallala Aquifer and currently have low saturated thickness levels and insignificant amounts of irrigation compared to other counties in the study area. Apart from the five low saturated thickness counties mentioned above, results of the baseline scenarios and policy alternatives showed generally consistent trends across the region in irrigation practices and cropping patterns.

Though the overall regional trends are similar in irrigation practices and cropping patterns, the results show that the impacts of the policies differ greatly across the region. One major factor examined demonstrates major differences across the region is the cost of each policy. Table 2 depicts the implicit cost of water conservation per acre foot of saturated thickness on a cropland acre basis for the 0% drawdown Policy, the 50% total drawdown policy, and the 75% drawdown policy.

The cost of conserving an additional foot of saturated thickness in these policies is a direct effect of saturated thickness depletion and NPV for each scenario. Andrews, Howard, and Roosevelt Counties for example showed either no or a small amount of aquifer depletion in the baseline; therefore, the cost of conserving an additional foot of saturated thickness is relatively high in those counties. The cost of an additional foot of saturated thickness conservation in Howard County is $2,281.00 for the reason that in the baseline scenario, the saturated thickness increases approximately the same level it does in the 0% policy: the year sixty saturated thickness is only 0.9 feet higher than the baseline scenario in turn causing the significantly high cost. Alternatively, Hale and Lubbock Counties are high water use counties and showed significant levels of depletion in the baseline scenario. Therefore, the cost of an additional acre of foot in these counties is much lower

Table 1 Year 1 and Year 60 Saturated Thickness in Feet by County for the Baseline Scenario

County	Yr. 1 S.T. in ft.	Yr. 60 S.T. in ft.
Andrews	45.00	41.07
Bailey	85.00	36.75
Borden	46.00	47.83
Cochran	59.00	21.07
Crosby	107.00	53.54
Dawson	84.00	76.04
Dickens	119.00	132.03
Floyd	82.00	19.38
Gaines	65.00	13.97
Garza	64.00	54.49
Glasscock	42.00	34.14
Hale	91.00	26.56
Hockley	50.00	10.95
Howard	34.00	34.49
Lamb	92.00	21.10
Lea	65.00	59.89
Lubbock	79.00	13.15
Lynn	49.00	34.30
Martin	62.00	62.88
Midland	51.00	33.47
Motley	11.00	22.51
Roosevelt	85.00	83.95
Terry	46.00	14.43
Yoakum	64.00	19.55

Another interesting characteristic shown in Table 2 is the differences in the costs of conservation between policies. The cost of the 0% drawdown policy is notably higher than both the 50% total and the 75% policies for all counties in the study area. Conversely, the gap in the costs of an additional acre foot of conservation between the 50% total and the 75% policy are often in close proximity to one another. Gaines County for example shows that the cost of an additional acre foot of saturated thickness is only $3.77 more in the 50% policy than in the 75% policy.

Overall, the results of the study indicate that policy impacts vary greatly across the region. The manner in which a policy alternative will impact a county depends on the hydrologic characteristics of the county, the level of current irrigation, and the profitability of the optimal crops.

Regional Results

The 0% Drawdown Policy conserved significant amounts of water in the Southern Ogallala Aquifer; but it also significantly decreased NPV and agricultural economic activity across the region. This restrictive policy is not necessary for most counties in the region, and would likely have detrimental effects to the regional economy. The decrease in economic activity would be similar to the effects expected in the case of total aquifer exhaustion, which is what water conservation policies are attempting to avoid. As stated previously, five counties showed an increase in saturated thickness throughout the planning horizon in the baseline scenario. Many other counties did exhibit aquifer drawdown in the baseline scenario, but not to the extent that a policy as restrictive as this would be required across the region. This policy would be best used in only those counties, or areas of counties, with extensive annual aquifer drawdown, and would be implemented on a portion of total cropland acres within a county.

The 50% Total Drawdown Policy and 75% Drawdown Policy exhibited similar trends. Comparable to the 0% water conservation policy discussed above, neither of these two policies will likely be necessary across the study region. In many counties the 75% drawdown and often the 50% drawdown restrictions were not binding constraints because the levels of saturated thickness underlying those counties in the baseline scenario did not decline to the 50% or 75% drawdown levels.

Table 2: Implicit Cost in Dollars of Water Conservation Per Foot of Saturated Thickness by Policy on a Cropland Acre Basis

County	0%	50% Total	75%
Andrews	800.98	435.07	340.28
Bailey	21.38	10.12	7.11
Borden	341.89	N/A	N/A
Cochran	54.82	27.75	20.99
Crosby	25.43	11.90	8.24
Dawson	79.88	20.60	10.56
Dickens	70.03	N/A	N/A
Floyd	49.96	34.68	28.62
Gaines	29.56	20.81	17.04
Garza	119.78	55.00	37.11
Glasscock	43.41	8.91	4.29
Hale	38.60	33.81	29.56
Hockley	58.70	41.27	35.30
Howard	2281.00	N/A	N/A
Lamb	20.11	14.34	11.92
Lea	427.32	226.68	164.24
Lubbock	21.04	16.36	14.31
Lynn	82.68	29.43	14.30
Martin	473.23	N/A	N/A
Midland	112.42	47.32	27.87
Motley	80.17	N/A	N/A
Roosevelt	343.90	110.89	63.37
Terry	83.98	59.58	48.78
Yoakum	58.35	34.70	27.65

Both the 50% total drawdown policy and the 75% drawdown policy caused a decrease from the baseline NPV and both conserved water in the aquifer relative to the baseline. The 75% policy had a slightly higher NPV than the 50% policy whereas the 50% drawdown policy conserved 25% more water than did the 75% policy.

These two policies were the most restrictive in high water use counties. Hale County, the highest water use county in the study area, showed a NPV 16% lower than the baseline for the 50% policy while the 75% policy NPV was 7% lower than the baseline. However, the 50% policy conserved an additional 16 feet more saturated thickness than did the 75% policy. Alternatively, Midland County is a low water use county. The NPV for the 50% total policy in this scenario was 7% less than the baseline whereas the 75% policy NPV was 2% below the baseline. However, in this case, the 50% policy conserved 4 feet of saturated thickness relative to the baseline and the 75% policy conserved 3 feet of saturated thickness relative to the baseline. Therefore, these water policy alternatives are likely not necessary for Midland County.

The 50% Annual Drawdown Policy, as with previously discussed scenarios, did not work well for low water use counties due to the fact that water use was so small in the baseline scenario that restricting a county to half the baseline amount caused the discontinuation of irrigation practices. This policy alternative did conserve significant amounts of water in the high water use counties. Hale County for example, conserved 55 feet of saturated thickness relative to the baseline while the NPV was 37% lower than the baseline. However, the cost of implementing this annual policy will likely be much greater than the cost of implementing a similar sixty year policy.

DISCUSSION

The results from this study indicate that because of the significant differences in hydrologic characteristics and current irrigation levels across the study area, blanket water conservation policies for the Southern sub-region as a whole are likely to be inefficient. Under the baseline scenario, there are many counties in the study area that do not deplete saturated thickness to a level that warrants a conservation policy. As shown in the results section, the cost of conserving an additional acre foot of water in low water use counties is extremely high. Legislative time and tax money would be more efficiently spent enacting policies to conserve water in those counties that significantly utilize the aquifer underlying the county. After analyzing the water use practices and aquifer levels in each county, this study concludes that for the Southern portion of the Ogallala Aquifer, water conservation policies should focus on counties that deplete the aquifer to less than 30 feet of saturated thickness in the baseline scenario; where the implicit cost of conserving a foot of saturated thickness is relatively low. By focusing water conservation on these nine heavily irrigated counties, policy makers can conserve water for future irrigation where it is most vital to the regional economy.

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Economic Analysis of Optimal Nitrogen Application in Corn Production

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ABSTRACT

Identifying the fertilizer-output relationship for a crop would be an important tool for determining optimal rate of fertilization and hence maximum profit. Proper nutrient management also minimizes environmental degradation. The model described in this paper is useful to forecast the production and productivity for corn based on optimal nitrogen application. An empirical production function was estimated using SAS GLM model that best describes the data. The economically optimal level of nitrogen fertilization was obtained by maximizing the profit function. It was observed that the current level of corn production in U.S. Corn Belt is slightly below the optimal. It is suggested to increase the present level of nitrogen use from 143.22 lb to 153.35 lb per acre to obtain maximum possible profit. The net revenue is estimated to be $316.47 from each acre of corn with the optimal rate of nitrogen fertilization at the current price structure. Both the net revenue and the incremental profit are expected to be much larger if the price structure remains as in earlier years.

KEY WORDS: Production Function, Crop Forecasting, Production Modeling, Corn Production, Modeling

INTRODUCTION

One of the most important cereal crops produced in the United States is corn, in terms of both acreage and production. The United States grows around 78 to 80 million acres and produces around 9 to 11 billion bushels of corn annually (National Agricultural Statistics Service (USDA-NASS, 2006). In 2005, total corn production stood at 81.76 million acres and production reached 11.11 billion bushels. The trend for the last five year indicates that both the acreage and yield are constantly increasing (USDA-NASS, 2006). The U.S. Corn Belt is located in the north central plains, and includes Iowa, Illinois, southern Minnesota, southeast South Dakota, eastern Nebraska, northeast Kansas, northern Missouri, Indiana, and western Ohio (Forcella et al., 1992). Most of the U.S. corn is produced in this area. Corn has been one of the most important crops for in U.S. agriculture. It is a major constituent of animal feed. Furthermore, the importance and hence the demand of corn is estimated to escalate due to its increasing use for producing ethanol (Pimentel and Patzek, 2005; Dailyfutures.com, 2006).

Corn is a voracious nutrient-requiring crop and must have adequate amount of nitrogen and phosphorus for profitable production (Alley et al., 1997; Heckman et al., 1996; Morris et al., 1993; and Yu et al., 2000). Determining the fertilizer-output relationship can provide a means to proper fertilizer management by selecting economically optimal rates of fertilization that have direct implications on crop profitability. Fertilization beyond optimal results in inefficient use of the resources, while fertilization below optimal would be a compromise in total production potential. Nitrogen and phosphorus are also the nutrients that result in eutrophication in surface water when concentration increases beyond certain critical levels (Alley et al., 1997). Thus, proper nutrient management reduces the impact on environmental degradation and also minimizes the energy use in manufacturing these nutrients. Further, the relationship can be used as a tool to forecast the production and productivity of a crop in a given scenario. This would be an important tool for planners.

The objectives of this study are: (1) to estimate the maximum potential corn yield in the U.S. Corn Belt, (2) to find the economically optimal rate of nitrogen fertilization for corn production in the U.S. Corn Belt that maximizes profit, and (3) to evaluate the sensitivity of the variation of prices of corn and nitrogen to the rate of nitrogen fertilization. The nitrogen fertilizer optimization is chosen because of the facts that it the most important plant nutrient and highly volatile in the soil and thus needs constant replenishments (Alley et al., 1997).

An agricultural production function is generally defined as a bio-physical relationship between inputs and an output where a physical quantity of crop production can be attained for a given sets of inputs used at given treatments (Griliches, 1964). In other words,

$$Y = f(X_1, X_2, \ldots\ldots\ldots\ldots\ldots\ldots X_K \mid X_L \ldots\ldots\ldots X_N) \qquad (1)$$

where, Y represents the crop yield. X_1 …. X_N are the quantities of the inputs used in the production in which X_1, X_2, …… X_K represent the variable factors, while X_L …... X_N represent the fixed factors.

The construction of an agricultural production function is considered to be complex because of the existence of the interaction effect among the various inputs and uncontrollable natural exogenous factors. Despite these phenomena, attempts have been made to develop crop production models that can provide a means to forecast the production and productivity of a crop at a given bio-physical relationship (Challinor et al., 2003; Ozsabuncuoglu, 1998; Baier, 1977, and Barreto and Westerman, 1987). There has been a continuous attempt to improve forecasting of models by incorporating factors like weather, irrigation, fertilization, soil fertility, and use of techniques like remote sensing etc. Development of such models is also important for forecasting crop production which then serve as instruments for agriculture planners to respond in a timely manner to impending shortages (Chopak, 2000; and FAO, 2002). Such planning permits (or enables) preparation for harsh consequences and/or to develop early warning systems.

Crop models can be characterized by two different approaches: (1) process based models, which seek to represent many processes of crop growth and development, and (2) empirical or mathematical models, which use observed relationships to predict the variable of interest, usually crop yield (Challinor et al., 2003). Each approach has its advantages and disadvantages. Thus, a compromise must be sought between the volume of data (inputs) required and the precision of the forecast generated.

Since there is no fundamental theoretical model to represent the effect of inputs on crop yield, the selection of a particular mathematical model is generally made on the basis of observation, experience, and ease of calculation (Barreto and Westerman, 1987). General theoretical knowledge about production functions is readily available in many text books (e.g., Heady and Dillion, 1961). Literature shows that empirical models like linear, multi-linear and polynomial functions (including quadratic, square root, linear von Liebig, Mitscherlich-Baule, nonlinear von Liebig, Cob-Douglas, and transcendental) are commonly used to construct input-output relationships in agriculture. Further, the studies conducted by Colwell (1978) and Melsted and Peck (1997) stated that fertilization-yield relationship varied with crop, fertilizer, soil, management practices, and the growing season variables. Thus, a model should be simple and use minimum, readily available information that has a potential to predict with a certain given precision. Some factors are more important for yield than others (Baier, 1977). Attempts have been made to identify and incorporate factors into the model that are likely to have statistical significance in corn production.

METHODS AND PROCEDURES

In this study, a corn production function was derived based on the corn production data from the U.S. Corn Belt. Then, the optimal amount of input needed to achieve crop profit maximization was calculated. The goal of any commercial producer would be maximizing the profit rather than maximizing the production. Thus, economical optimal level of nitrogen can be obtained by maximizing the profit function. Assuming perfectly competitive markets and a crop production function with only one variable input, Y = *f*(N), the profit function can be postulated as:

$$\pi = P_c\, Y - P_N\, N \qquad (2)$$

where, π represents profit. P_c is the output price. P_N is the input price. And N is the amount of input used in the production process.

In order to maximize profit, the first order derivative of equation (2) was taken with respect to variable N (nitrogen),

$$\frac{\partial \pi}{\partial N} = P_c * \frac{\partial Y}{\partial N} - P_N = 0 \qquad (3)$$

$$\frac{\partial \pi}{\partial N} = P_c * MPP - P_N = 0 \qquad (4)$$

$$or \qquad \text{VMP} = \text{MIC} \qquad (5)$$

where, MPP = $\frac{\partial Y}{\partial N}$, represent the marginal physical productivity of the factor and VMP represent value of the marginal physical product for a given price (i.e. VMP = Pc * MPP). The marginal input cost (MIC) is the additional cost incurred due to addition of one more unit of the input. Thus, for a perfect market situation, it's a price of the input. Solving equation (5) for single variable factor N would give the optimal rate of input use that would maximize the profit (Beattie and Taylor, 1993).

Data for this research were collected from NASS and Economic Research Service (ERS) at USDA websites. The data include corn yield, average corn price, nitrogen, phosphorus and potash application rates, and their annual retail prices. The data were collected for all nine U.S. Corn Belt states for 37 years (i.e. from 1967 to 2003). To generate lag value for the corn price, the previous year's price was taken. Similarly, to estimate average annual nitrogen price, the price of 30% nitrogen solution was considered in the study. Table 1 gives a short summary about the variables that used in this study.

Table 1: Summary of the Corn Yield, Fertilizer Application and Average Corn and Nitrogen Price in U.S. Corn Belt (1967-2003).

Parameters	**Average**	**Minimum**	**Maximum**	**Standard Deviation**
Yield (bushel/acre)	103.98	59.50	139.33	23.40
Applied Nitrogen (lb./acre)	121.69	57.00	143.22	19.36
Applied Phosphorus (lb/acre)	56.97	38.44	64.11	4.63
Applied Potash (lb./acre)	64.12	30.33	84.50	11.14
Corn Price ($/bushel)	2.09	1.03	3.28	0.62
Nitrogen Price[1] ($/lb)	0.18	0.08	0.28	0.05

[1.] The price of nitrogen was calculated from price of 30% Nitrogen solution.

Thus keeping aforementioned factors in mind, the study attempts to design a simple mathematical model to predict the corn yield which can be postulated as

$$Y_c = f\,(N, P, K, T) \qquad (6)$$

where, Y_c represents corn yield. *T* is the time, *N* is the rate of nitrogen application. *P* is the phosphorus application rate. *K* is the rate of potassium application. The time *T* is inserted in the model to capture the trend. Trend in increasing yield over time exist due to factors, such as crop variety improvement, increased and more efficient irrigation and fertilizer use, and improved pest and disease control management (Challinor et al., 2003) or any stochastic climatic conditions.

Highly calibrated, comprehensive models are currently used for research, teaching, and studying crop management and prediction. Frequently these models need large amount of input data, but such data may have inherent uncertainties or not be available if spatial in nature (Challinor et al, 2003). Thus the estimated model has to be as simple as possible while taking account of the most important factors first and then gradually incorporating the other factors.

SAS generalized linear model (GLM) procedure was used in different function formats to determine the best fit, beginning with simple linear regression. Each time the fit of the model was evaluated on the basis of coefficient of multiple determination (R^2) and significance of the *t* statistics for the regression coefficients of each variable. The same procedure was repeated for the multiple regression model and then non-linear regression models by inserting contradictory, interactive, and finally, cubical terms into the model. This was done attempting several combinations separately and sequentially.

Running linear and non-linear models for various combinations of factors resulted in estimation of parameters as well as for goodness of fit for each model. The goodness of fit of the model was evaluated from the R^2 values. It was observed that the R^2 tended to increase as more variables were added. However, some of them were not included in the model because they were statistically insignificant.

RESULTS AND DISCUSSION

Several predefined functional forms including linear, multi-linear, quadratic, cubical, Cobb-Douglas, and other polynomial forms were tried by introducing contradict and interaction terms in the model. The following polynomial form was found to best fit the statistical observed data:

$$Y_c = 114.26 - 2.60*10^{-2}N^2 - 8.43K + 5.73*10^{-2}N*P + 1.2*10^{-2}N*K - 1.00*10^{-2}N*P*K + 1.20T \quad (7)$$

(0.34) (0.28) (0.22) (0.23) (0.20) (0.18) (0.02)

$R^2 = 0.7722$

where, Y_c represents corn yield in bushels/ acre; *N* is amount of nitrogen application in lb/acre; *P* is the phosphorus application rate in lb/acre; *K* is the rate of potassium application in lb/acre; and *T* represents the time ranged from 1 to 37. The model explains 77.22% (R^2 value) of variation in corn yield in terms independent variables included in the model. The values in the parenthesis below the coefficients are the *p*-values and reflect the level of significance of the estimated coefficients.

The estimated production function suggests that there are significant interaction effects among nitrogen, potassium, and phosphorus fertilizers in explaining corn yield variation. It was observed that the average nitrogen application was 143.22 lb/acre, which produced 143.21 bushels of corn in 2003. These were below both potential and optimal levels. The model indicated that maximum potential yield can be obtained by increasing nitrogen use to 153.35 lb/acre resulting in a yield of 145.89 bushels/acre.

Assuming a corn price of $2.42 per bushel and a nitrogen price of $0.24 per pound (price of 2003; USDA-ERS, 2006), the optimum level of corn production was estimated to be 145.79 bushels/acre resulting in a profit of $316.47 per acre. The current level of nitrogen use (i.e., 143.22 lb/acre in 2003) is estimated to yield 143.21 bushels of corn per acre and hence the profit of $312.22 per acre. It is eminent that current level of operation is below the optimum level and thus operating at optimum level can bring an incremental profit of $4.25 per each acre.

The sensitivity analysis for optimal nitrogen fertilization on corn and the net revenue for different levels of corn and nitrogen prices are presented in the Table 2. The top portion of table depicts the optimal levels of nitrogen applications for the alternative nitrogen-corn price combinations. And the bottom portion of the tables depicts the associated net per-acre present value of returns. It can be seen that the optimal fertilization rate decreases to 143.74 lb/acre if the price of nitrogen rises to $0.50 per lb and price of corn falls to $1.00 per bushel, which generates $71.62 per acre of net return. Similarly, the optimal nitrogen fertilization rate is as high as 152.97 lb/acre if the nitrogen price falls to $0.10 per lb and corn price rises to $5.00 per bushel, which increases the net returns to $714.12 per acre. The fertilizer-corn price ratio is highest on the upper left corner, which gradually decreases along the diagonal to reach its minimal on the bottom right corner. It is eminent from the table that the lower fertilizer-corn price ratio, higher optimal fertilization rate. The higher the fertilizer-corn price ratio the lower the optimal fertilization rate is.

Table 2. Optimal Nitrogen Fertilization Rate and Profit Levels for Different Nitrogen-Corn Price Combinations.

a. Optimal Rate of Nitrogen Fertilization (unit: lb/acre)

		Price of Corn ($ per bu)			
		1.00	2.00	3.00	4.00
Price of Nitrogen ($ per lb)	0.50	143.74	148.54	150.15	150.14
	0.40	145.66	149.51	150.79	151.43
	0.30	147.58	150.47	151.43	151.91
	0.20	149.51	151.43	152.07	152.39
	0.10	151.43	152.40	152.71	152.87

b. Net Returns from Corn Production (unit: $ per acre)

		Price of Corn ($ per bu)			
		1.00	2.00	3.00	4.00
Price of Nitrogen ($ per lb)	0.50	71.62	216.30	361.79	507.41
	0.40	86.09	231.20	376.83	522.59
	0.30	100.75	246.20	391.94	537.76
	0.20	115.60	261.30	407.12	552.97
	0.10	130.65	276.49	422.36	568.24

However, Table 2 gives a discrete picture and may not always suit the real-life situation (Yu et al., 1999). Thus, estimation of the relationship, i.e. the optimal fertilization rate based on continuous relative prices of nitrogen and corn as defined in Equation (8) would be more useful.

$$e^N = \alpha * P_r^{\beta} * \varepsilon \qquad (8)$$

where, e is the exponential, P_r is the nitrogen-corn price ratio; N represents the optimal nitrogen fertilization rate for given price ratio; α and β are the parameters to be estimated; and ε is the error term. Regressing, the 19 optimal fertilization rates with respect to the nitrogen-corn price ratios (after excluding the six repeated price ratios), the following equation was estimated:

$$N = \underset{(209.25)}{144.723} - \underset{(-9.03)}{2.5274} \ln(P_r) \qquad (9)$$

$R^2 = 0.8273$

where, the variables are defined as above. The values on the parenthesis below represent their associated *t*-value. All the parameters were found to be significant at 0.0001 levels. The graphical presentation of the Equation (9) is given in Figure 1. The optimal amount of nitrogen ranges from 146 to 155 lb/acre for price ratio ranging from 0.5 to 0.02.

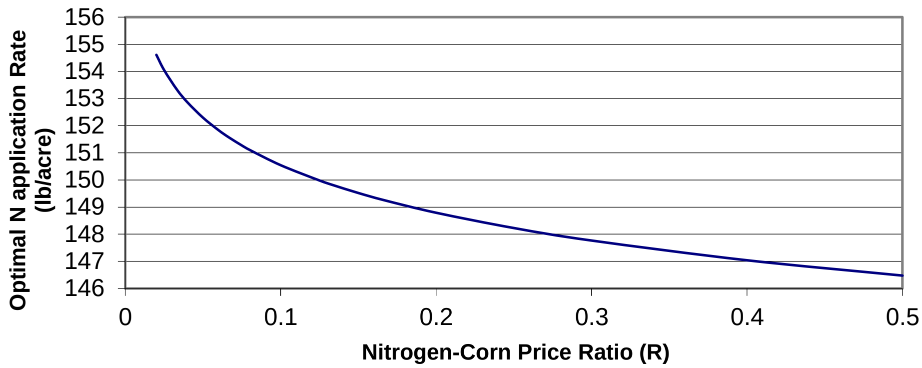

Figure 1: Continuous Form of Optimal Nitrogen Application Rate for Different Nitrogen-Corn Price Ratios.

CONCLUSIONS

The current level of corn production in U.S. Corn Belt is slightly below the optimal. Thus, operating at the maximum profitable level of corn production was estimated to bring an increment of $ 4.03 profit from each acre of corn field at the 2003 price structure. It was suggested that increasing level of nitrogen use from 143.22 lb to 153.35 lb per acre would increases net revenue from $312.22 to $316.47 per acre. Both the net revenue and the incremental profit are expected to be much larger if the price of nitrogen falls or alternatively the price of corn rises. Although, these results are more useful to policy maker (or the development planner); it could prove valuable to a producer to check if he/she is producing at optimal level.

The change in input-output price ratios alters marginal revenue and hence optimal fertilization rate. It was estimated that for nitrogen-crop price ratios ranging from 0.02 to 0.5, the optimal nitrogen application rates would range from 143.74 to 152.97 lb/acre.

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