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Agricultural Safety And Health Education Analysis of Texas' First Year Agriculture Teachers

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ABSTRACT

First year agriculture education teachers in Texas were surveyed during the 1998–1999 school year. The number of first year teachers surveyed was 118 and 74 (63%) participated. Of the 74 respondents, 57 were males and 17 were females with the mean age being 27.3 years. Fifty-seven percent of the teachers taught safety and health as separate independent units of instruction while the most common type of technology used was TV/VCR's and overhead projectors. It was determined that the most useful formats for new educational materials were videotapes with study guides. Over half of the teachers (51.4%) had received CPR training and 52.8% had received first-aid training. Only 22.2% held current CPR certifications while 21.1% had current first-aid certifications. Generally teachers have a solid understanding of safety and health issues but fail to "practice what they preach."

This study recommends that teacher education programs place a much higher emphasis on safety and health issues during teacher preparation. Furthermore, professional development workshops and seminars need to be implemented to help teachers develop necessary skills and educational materials that are easily useable in modern classrooms. A compilation of easy-to-use, interactive agricultural education safety education media materials needs to be developed and disseminated.

KEYWORDS: Agricultural Safety, Agricultural Education, Safety

Within our nation's public schools, concerns for the health and safety of student populations have recently grown in importance. Unfortunately, this attention has grown out of increasing instances of premeditated violent acts. One outcome of these tragedies has been revision of school and campus safety policies by administrators and has created a sense of urgency to improve general student safety. Commonly overlooked in these policies however are non-violent, unintentional injuries and personnel safety training. This is notably consequential, as the cause of greatest concern for the health of children and adolescents has become unintentional injuries (U.S. Department of Health and Human Services [DHHS] 1990).

In 1995, the National Safety Council reported there were 24 deaths per 100,000 agricultural workers and 140,000 disabling farm-related injuries (National Safety Council, 1996). This situation presents a special challenge for vocational education programs that are linked with dangerous occupations, such as agricultural education is to agriculture. Considering teachers and administrators stand to a limited degree *in loco parentis* to students under their supervision, it is a necessity for agriculture teachers to model safe practices and behaviors, and to create a positive safety climate. This is important for reducing preventable injuries, not only while the student is in school but also as they prepare to enter the workforce.

School administrators must be encouraging while diligently developing a positive school safety climate. Ullrich (1997) recommended that to promote a sense of urgency for safety, education administrators should develop a written safety plan and a detailed documentation system. Additionally, Lawver and Fraze (1996) recommended Texas agriscience teachers receive more preservice and inservice education in the areas promoting positive safety attitudes. These two efforts may yield dividends in eliminating preventable injury in agricultural education programs.

Safety and health education for agricultural education teachers has received increased consideration (Ford and Walson, 1997). In 1989, Johnson found that eleven of the top 18 agricultural mechanics laboratory competencies were safety-based. Swan (1993) recommended designating local and federal funds for use in improving safety and emergency equipment and instruction available to instructors and students. The importance of safety topics in preservice and inservice educational programs (Swan, 1993; Hubert, 1996) along with basic first aid and cardiopulmonary resuscitation (CPR) training / certification for agriculture teachers (Bear and Hoerner, 1978; Laird and Kahler, 1995 and Ullrich 1997) has been suggested and offered periodically. However, in most cases it is left to individual school districts to require faculty to obtain and/or keep certifications current.

Healthy People 2000 (DHSS, 1990) recommended education aim at both reducing injury risk and in preparing students to be knowledgeable members of the adult community. This recommendation corresponds with goals of youth leadership organizations such as FFA. If agricultural education students are promoted as future leaders, then training and modeling of proper agricultural safety measures is desirable. This is important, especially for Texas with secondary agricultural education enrollments of almost 90,000 including 58,000 FFA members (Texas Education Agency, 1999).

Agriculture has had the dubious distinction of being ranked first or second in industry work death rate [each year] since 1981 (Pierson and Murphy, 1996). Since a premise of agricultural education programs is to prepare students for careers in agriculture, the issue of reducing injuries, illnesses, and fatalities is essential to their training. The development of a positive and continuous safety climate within an agricultural education program is directly influenced by the personal attitudes and beliefs of the teachers managing that program. As such, a need has been established to determine the scope of health and safety education preparation for agriculture teachers including teaching resources used in secondary agricultural education programs.

PURPOSE AND OBJECTIVES

The purpose of this descriptive study was to provide benchmark data for the assessment of the knowledge, attitudes, and perceptions regarding agricultural safety issues and curricula held by Texas agriculture teachers with less than two full years of teaching experience. The study was supported by CDC/NIOSH funds from Cooperative Agreement # U07/CCU612017. Four objectives were developed to guide this study of Texas agricultural science teachers with less than two full years of teaching experience.

1. Identify selected demographic characteristics.

2. Determine curricula and teaching materials used to address agricultural safety and health.
3. Ascertain most preferred and usable types of curricula as perceived by the surveyed group.
4. Describe the emergency care preparedness of the surveyed group.
5. Determine personal beliefs, practices, and attitudes regarding common agricultural safety and health issues.

MATERIALS AND METHODS

The target population was Texas agriculture teachers with less than two years of agriculture teaching experience and was selected from a database of over 1400 Texas Agricultural Science teachers. The Vocational Agricultural Teachers Association of Texas (VATAT) database of first year teachers served as the frame with 98 teachers identified. Duplicates and foreign elements were removed. Missing elements were identified from university entry-year teacher lists and added which adjusted the frame to 118 identified teachers.

Descriptive research methodology was used to collect data. The instrument design was a booklet style questionnaire. The instrument contained six sections: (I) demographics, (II) agricultural curricula and teaching materials, (III) classes taught 1998-99, (IV) personal health and safety training, (V) personal beliefs, and (VI) personal practices. This manuscript will only address the responses for Sections I-II and IV-VI. Six teacher educators, and seven state agricultural education staff from Texas and Oklahoma served as a panel of experts to review the instrument for face and content validity. Appropriate revisions were completed based on comments. To insure reliability, the instrument was administered to twelve agricultural science teachers in southeast Texas. They were selected because of their location, accessibility, and concern for safety issues. Following review and revision, the instrument was distributed. To ascertain internal consistency, Cronbach's alphas for Sections IV (personal health and safety training), V (personal beliefs) and VI (personal practices) were calculated with results being .71, .62 and .57, respectively. The relatively low internal consistency for the personal practices may be because the items included statements that, while individually important as safety practices, may be unrelated to each other (e.g "I was ___ when I first operated a tractor equipment alone") or due to small numbers of response items in this section.

Data were collected over an eight-week period during the spring of 1999. The instrument, cover letter, self-addressed, postage-paid envelopes and detailed instructions were mailed during first week of April 1999. After approximately two weeks, reminder postcards were sent to those failing to respond. Two weeks later a second survey was mailed. All non-respondents from both mailings were phoned. A final attempt to secure data on the target population was conducted via recruitment and curricula distribution booths at the 1999 Texas FFA convention and VATAT Professional Improvement Conference.

Completed instruments were collected from 74 of the identified 118 agriculture teachers, or a 63% response rate. Descriptive statistics, means, standard deviations and percentages were used to analyze all data. Results were analyzed at the .05 level of significance.

RESULTS AND DISCUSSION

Of the 74 teachers meeting the entry year qualification, there were 57 males (77.0 %) and 17 females (23.0%). This was a larger percentage of females than the current female percentage of 9.0 percent for Texas agricultural education teachers (TEA, 1999). The mean age was 27.3 years. For data analyses teachers were placed in two groups by age: a traditional age group "20-25 years old" (n=40) and a non-traditional age group of "26 years or greater" (n=32) and two were non respondents. Males were evenly distributed between the two groups (29 and 28 respectively) while almost twice the numbers of females were in the younger grouping (11 and 6 respectively).

Teachers were well distributed throughout the VATAT areas that follow the area structure established by the Texas FFA Association. The ten Texas Areas are illustrated in Figure 1.

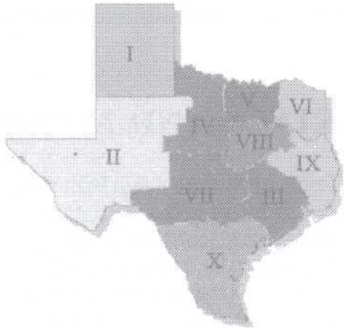

Figure 1. Vocational Agriculture Teachers Assoc.of Texas (VATAT) Areas.

The highest frequency of respondents was in Areas III (14, 18.9%), IX (10, 13.5%), and X (8, 10.8%). The remaining seven Areas had between four (5.4%) and seven (9.5%) respondents per area (Table I).

Table 1. Texas entry-year teacher distribution by FFA Area (1998-99).

	FFA Area										
	I	II	III	IV	V	VI	VII	VIII	IX	X	N
Number of teachers	4	7	14	7	5	6	6	7	10	8	74

To determine distribution by school size, respondents were asked to identify the enrollment size of their school by University Interscholastic League (UIL) conference. The division levels for Texas high school competitions are based on enrollments and are divided as follows: 5A (1,780 students or greater), 4A (780-1,779 students), 3A (345-779 students), 2A (160-344 students), and 1A (159 students or fewer) (UIL, 1999). Data indicated a mean of 146.2 students enrolled in these agricultural education programs (range 16-625) of which 91.2 were FFA members (range 5 to 350). The distribution of teachers by UIL conference / school enrollment are presented in Table 2. The numbers of respondents based on conference classification are as follows: 1A and 2A, 15 respondents each; 3A, 19 respondents; 4A, 13 respondents; 5A, 10 respondents; and two did not complete the classification section of the survey.

Table 2. Entry-year teacher distribution by UIL conference (1998-99).

	Conference Classification						
	1A	2A	3A	4A	5A	N/A	N
Number of teachers	15	15	19	13	10	2	74

Teachers were asked to identify if they addressed agricultural safety and health topics as separate, individual units of instruction or as subjects within instructional units. Thirty-two teachers (43.2%) indicated that they taught safety as a separate unit with the remaining 42 teachers (56.7%) addressing safety and health as specific subjects within larger units such as "cattle handling safety" while covering cattle production.

Teachers indicated from a provided list which technologies they had available at their respective schools. The most common technology identified by all teachers was televisions with videotape players and overhead projectors. Sixty-six (90.4%) had slide projectors, while 63 (85.1%) confirmed that a computer with Internet accessibility was available. Over 60 percent (62.2) checked CD-ROM availability. The least available equipment were laserdisc players (17.6%) and one teacher declared having a laptop computer for presentations. No statistical significant differences were found based on any demographic.

As shown in Table 3, teachers ranked the types of new teaching resources according to greatest value and use (1=most useful— 6=least useful). It was determined that the most useful formats for new materials were videotapes with study guides ($\bar{X}$=1.90, SD=1.00). Secondary preference was indicated for demonstrations/simulations ($\bar{X}$=2.51, SD=1.36). Within the two age groupings, the preferred resource type was videotape and study guide but there was a significant difference in the perceived usefulness of transparencies. The non-traditional group ranked transparencies as more useful ($\bar{X}$=3.59, SD=1.39), a significantly different value from the age 20-25 group ($\bar{X}$=4.25, SD=1.10).

Emergency care preparedness of new teachers was also a health topic of this study and is presented in Table 4. Over half of the respondents (37/72, 51.4%) had received cardiopulmonary resuscitation (CPR) training. Twenty of those teachers (54.1%) were in the age 20-25 grouping. However, only 16 of the 72 teachers (22.2%) kept certifications current.

Seventy-two teachers responded to inquiries of first aid training. Similar to CPR training, 38 (52.8%) teachers revealed having had first-aid training, with 20 (52.6%) responses coming from the younger group. Only eight (21.1%) of these 38 teachers had current certification in first-aid.

Table 3. Entry-year teacher age group comparison of teaching resources.

	Age 20-25		Age 26 +		Aggregate			
	Mean	SD	Mean	SD	Mean	SD	F	P
Videotape and study guide	1.83	0.93	2.00	1.08	1.90	1.00	0.55	0.4623
Class demonstration / Simulation activities	2.32	1.38	2.75	1.32	2.51	1.36	1.75	0.1907
Individual student booklets	3.75	1.48	3.38	1.58	3.58	1.53	1.07	0.3037
Transparencies	4.25	1.10	3.59	1.39	3.96	1.27	5.00	0.0286*
Interactive media	4.33	1.87	3.84	2.00	4.11	1.93	1.10	0.2969
Slides	4.20	1.49	4.19	1.62	4.19	1.53	0.00	0.9729

Note: 1=most useful — 6=least useful
* significant at P = .05

Lastly, information was sought as to identify completion of a general health and/or safety related course. Forty-three (58.9%) of the 73 teachers recorded that they had taken and completed a health class prior to teaching. Twenty-six (60.5%) of the 43 represented the age 20-25 group with the remaining 39.5 percent from the age 26 or greater group. The health and/or safety course was a requirement of graduation for just less than one third of all respondents.

Teachers were asked to give their opinions to a series of questions concerning their personal beliefs and attitudes regarding common agricultural safety and health issues. On a forced response four point Likert-type scale (1 = highly agree, 2 = agree, 3 = disagree and 4 = highly disagree) respondents were highly agreeable that all shops should have a properly working fire extinguisher (X=1.22), and that a clean well-organized shop reflects a safe working environment (X=1.25). Teachers also perceived that wearing proper protective equipment was very important (X=1.30), having emergency numbers posted by the phone were slightly less important (X=1.40), and that seatbelts should be worn and that

Table 4. Emergency care preparedness and safety training of new teachers.

	Age 20-25			Age 26 or greater			Aggregate		
	Yes	No	Certified Currently Required	Yes	No	Certified Currently Required	Yes	No	Certified Currently
Cardio Pulmonary Resuscitation Trained (n=72)	20	19	8	17	16	8	37	35	16
First Aid Trained (n=72)	20	19	5	18	15	3	38	34	8
Private Industry - Safety Training (n=70)	11	27	NA	16	16	NA	27	43	NA
Health Class (n=73)	26	13	16	17	17	8	43	30	24

safety devices in place when operating tractors and farm machinery (X=1.48). Respondents agreed that fences around farm ponds and stock tanks and lagoons are effective safety precautions (X=1.9). To a lesser degree teachers agreed (X=2.06) that mandatory age requirements should be established to operate tractors and / or equipment (Table 5).

The answers to questions concerning personal safety practices of entry-year teachers are reported in Table 6 and are indicators of teacher attitudes about a positive safety climate. Considering the teachers that responded to the question asking if they wear a seatbelt when driving a tractor, 22 or 34.9% indicated that they did while 65.10% did not. Eleven of the respondents indicated that the question was not applicable. An overwhelming majority (82.3%) indicated that they made sure that when they operated a tractor that the PTO shields were in place; 17.74% did not follow this basic safety precaution, while eight teachers identified that this question was not applicable. When asked if their home shop had a properly working and accessible fire extinguisher 69.40% stated that they did, 30.60% did not and twenty-four of the teachers did not have a home shop.

Two additional questions were asked to identify if the teachers were prepared for emergencies at their homes. Fifty-one (69.8%) of the 74 respondents stated that they did not have emergency phone numbers posted by all phones while 22 (30.1%) had phone numbers posted. Only ten (13.5%) of the teachers had directions to their home / property posted by phones for emergency use.

Table 5. Texas agriculture teachers' personal beliefs and attitudes.

	Mean	SD	N
All shops should have a properly working fire extinguisher.	1.22	.71	73
A clean and well-organized shop reflects a safe environment.	1.25	.59	73
Proper protective equipment should always be worn when doing agricultural work.	1.30	.73	73
Emergency numbers posted by the phone are a good idea.	1.40	.79	73
Seatbelts should be worn and safety devices in place when operating tractors and farm machinery.	1.48	.66	73
Fences around farm ponds / stock tanks and lagoons are an effective safety precaution.	1.90	.80	72
Mandatory age requirements should be established to operate tractors and / or equipment.	2.06	.73	73

Note: 1= highly agree, 2=agree, 3=disagree, 4=highly disagree

Table 6. Personal safety practices of entry-year Texas agriculture teachers.

	Yes (%)	No (%)	N	N/A	N
When operating a tractor I wear a seatbelt.	22 (34.9%)	41 (65.1%)	63	11	74
When operating a tractor I make sure PTO shields are in place.	51 (82.3%)	11 (17.7%)	62	8	70
My shop at home has properly working and accessible fire extinguishers.	34 (69.4%)	15 (30.6%)	49	24	73
I have emergency phone numbers posted by all phones.	22 (30.1%)	51 (69.9%)	73	-	73
I have directions to our house/property posted by all phones for use in an emergency.	10 (13.5)%	64 (86.5%)	74	-	74

In Table 7, data on entry-year teachers' age and opinions on age requirements are noted. The researchers were interested in determining the age of responding teachers when they first operated a tractor or piece of agricultural equipment alone. The average age was found to be 11.8 years, the range was from 21 years old to 47 years old with a standard deviation of 6.63. These teachers allow trained drivers with a mean age of 14.9 while they began driving tractors and farm machinery when they were 11.8 years old. Furthermore, teachers felt children should be 11.0 years old to assist when working with livestock.

Table 7. Teacher safety information and opinions on age.

	Mean	SD	N
How old were you when you first operated a tractor or equipment alone?	11.80	6.63	73
I allow trained drivers age _____ and older to drive tractors and farm equipment alone.	14.87	2.15	73
Children must be _____ years old to assist when working with livestock.	11.02	3.30	73

*Mean is calculated as years of age.

Table 8. Personal safety practices of teachers.

	Always	Almost Always	Rarely	Never	Mean	SD	N
While doing agricultural work, I _____ wear the appropriate protective equipment. **	17 22.4%	52 68.4%	7 9.21%	1 1.31%	1.90	.60	70
I _____ follow recommended directions when mixing chemicals for application. **	60 77.9%	14 18.9%	0 0%	0 0%	1.22	.42	74

**Note: 1=Always, 2=Almost Always, 3=Rarely and 4=Never

Additional personal safety practices were evaluated. Respondents always wear appropriate protective equipment while working, at a rate of 22.4% and almost always 68.4% of the time. Few teachers rarely (9.2%) and never (1.3%) wear protective equipment. Similarly, these teachers always or almost always followed recommended directions when mixing chemicals. This data is illustrated in Table 8.

SUMMARY

There are several areas of concern and interest documented by the findings of this study of Texas' entry year teachers. The demographic data indicated that increasing numbers of females have entered this traditionally male-dominated career field. Females made up almost one quarter of the new teachers during the 1998-99 academic year in the agricultural education classrooms across Texas. This was a substantially higher percentage as compared to the percentage of female agriculture teachers in Texas overall (nine percent). The average age of these new teachers was just over 27 years old and although considerably higher than expected, it may reflect the current practice of recruiting pre-service teachers from the ranks of college graduates in other disciplines or others returning to school following a few years of work experience in other fields.

A large portion of teachers that did not teach safety and health topics within larger educational curriculum units may substantiate a lack of continuous safety education integration in a program and a weakness in the establishment of an overall safe climate. This study also reveals an element of weakness in curricula utilized by the teacher, and in the teacher preparation programs failing to prepare these individuals for the challenge of integrating safety and health concepts throughout the curriculum.

A large percentage of teachers had access to computers with Internet access and CD-ROM's, as well as the more traditional audio/video equipment in slide projectors, televisions and VCRs. It was interesting that even though these teachers largely had access to modern computer technology, they did not find interactive media whether from CD-ROM's or Internet as useful teaching tools. In comparison, they also tended to rank traditional resources such as videotapes and class demonstration / simulation activities highly. This could be indicative of not receiving adequate training on the use of newer, interactive media as teaching tools during their pre-service training programs or, this could be an indication that teachers feel that the older teaching tools are more effective. This appears contradictory to research that indicates students enjoy and learn well when these resources are included in teaching methodologies. Another factor to be considered regarding the lower ranking of interactive media is that easy to use, inexpensive interactive media teaching resources may not be available or accessible to these teachers.

Glaring concerns exist related to maintaining emergency care preparedness certifications and health and safety education training. Improvements are needed in this area since only a relative small percentage of the teachers are currently certified in CPR and first-aid and less than one-third of these teachers having been exposed to a required a health or safety course.

In general these teachers have strong personal safety beliefs and safety attitudes. When reviewing the data, nearly all highly agreed or agreed with the safety statements indicating that they have an understanding of what is required in a well-defined safety climate.

It is also obvious that these same teachers who possess an excellent awareness of what is required to have a well-defined safety climate do not follow appropriate personal safety practices. Furthermore, it is interesting to note that not all of these teachers, always wear appropriate protective equipment when doing agricultural work or when mixing chemicals. This is indicative of an attitude of "do like I say, not like I do." As role models for students in agricultural education programs this is an ethical dilemma that cannot be ignored. The researchers' concern is that the teachers seem to understand the safety concerns but do not always follow the safety practices that will protect them from injury.

Basic safety issues such as wearing seatbelts when operating a tractor, posting emergency phone numbers and directions were largely ignored. To a lesser degree these teachers had a somewhat acceptable compliance of checking PTO shields when operating a tractor and of having fire extinguishers in their home shop facility. Yet again many of these teachers failed in their ethical and moral obligations by modeling improper safety attitudes and practices.

It is also noteworthy that these respondents recognize the dangers of allowing children to operate tractors and farm equipment. This is indicated by the differences in the age at which they first operated tractors and equipment, compared to the age at which they now allow children to be involved in the same activity.

RECOMMENDATIONS

It is imperative that all teachers, both new and veteran groups, involved with extracurricular activities receive CPR certification and it is highly recommended that CPR certification and first-aid training be incorporated into all agriculture teacher education programs to create a sense of urgency and a positive safety climate. It is further recommended that CPR certification and first aid training workshops be offered at the annual Professional Development Conference for Texas' agriculture teachers in order to help meet the recent state mandate for such training.

This study found that even though a vast majority of schools with entry-year agriculture teachers have access to computer technology, teachers do not rate the use of interactive media very highly as a teaching tool. It is recommended that teacher education programs place additional emphasis on developing these skills to use media in teacher education programs.

A compilation of easy-to-use, interactive agricultural safety education media materials need to be developed for use specifically for agriculture teachers. For best results, these multimedia materials should be available at low or no cost to agricultural education programs through the use of state or federal funds. Furthermore, safety education and injury prevention teaching materials and resources should to be developed to specifically meet the needs of agricultural education students and teachers.

As a means of improving teachers' awareness of the importance of modeling proper safety attitudes and actions teacher preparation programs should place a much larger emphasis on instilling and enforcing these attitudes and skills on pre-service teachers. Additionally, workshops on safety education including topics concerning modeling safety attitudes and actions should be organized and offered during the annual Professional Improvement Conference.

Further research may be necessary to address unique concerns of females in agricultural education. Additional investigation into the female perspective of safety and health issues could reveal topics not previously considered as high priority. Another issue for review is the finding that these teachers' were older than those considered traditional. Similar research should be undertaken to address safety and health attitudes of all agriculture teachers and in the safety climate perceptions of agricultural education programs overall. This study should be replicated annually in Texas, as well as in other states, to provide the data necessary for the longitudinal analysis of safety education. Longitudinal analysis will enable us to accurately determine the benefits and outcomes of safety education programs.

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Effect of Diet on Vitreous Humor and Serum in Black-tailed Jackrabbits

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ABSTRACT

The responses of serum and vitreous humor constituents to two levels of nutrition were compared in 23 adult, male black-tailed jackrabbits (*Lepus californicus*). The vitreous humor constituents were similar or linearly correlated to serum constituents for urea nitrogen, triglycerides, and glutamic-oxaloacetic transaminase. The remaining vitreous humor constituents were neither similar nor predictive of serum constituents. Vitreous humor glucose, cholesterol, albumin, total protein, and gamma glutamyltransferase, and serum urea nitrogen, triglycerides, cholesterol, total protein, albumin, and gamma glutamyltransferase were affected by 25% feed restriction. Vitreous humor has potential as a source for biochemical indicators of nutritional intake only if additional baseline vitreous humor constituent values are determined.

KEY WORDS: condition, jackrabbit, *Lepus californicus*, nutrition, serum, stress, vitreous humor

Knowledge of nutrition is essential to gain insight on the interaction of wildlife and their habitat. Blood characteristics used to assess the nutritional status of wildlife (LeResche et al. 1974, Warren and Kirkpatrick 1978) may be influenced by collection stress (Jacobson et al. 1978). In addition, in cases of sudden death, hematologic evaluation is limited because of coagulation (Coe 1972). Although obtaining a vitreous humor sample typically involves euthanasia, the vitreous humor can be an alternative source for measuring certain metabolites such as urea nitrogen and creatinine (Lane and Lincoln 1985, DeLiberto et al. 1988). Vitreous humor is easily accessible and less subject to chemical changes than serum (Coe 1972), may retain its quantifiable constituent levels longer than serum following death (Schoning and Strafuss 1981, Henke and Demarais 1992), and has been shown in humans to be less susceptible than serum to acute physical changes (Jaffe 1962). Urea nitrogen in vitreous humor and serum were correlated in cattle (Lane and Lincoln 1985), domestic rabbits (Henke and Demarais 1992), and white-tailed deer (*Odocoileus virginianus*) (DeLiberto et al. 1988). The effect of specific condition levels on vitreous humor must be determined (LeResche et al. 1974) before the vitreous humor can be accepted as a reliable alternative to serum as a source of biochemical nutritional indices. If successful, then vitreous humor would offer a postmortem diagnostic source of animal condition. For example, eyes could be obtained at hunter check stations from recently-hunted animals to assess their nutritional condition rather than having to be immediately present at the kill site to obtain blood samples before coagulation occurs.

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Therefore, we evaluated the potential use of vitreous humor as a source for biochemical indicators of nutritional intake. Black-tailed jackrabbits (*Lepus californicus*) were selected as an animal model for other wild animal applications because they had large eyes that contained an adequate sample of vitreous humor, were numerous in the surrounding area, and were easily captured. Specific objectives included to 1) compare serum and vitreous humor values between rabbits placed on *ad libitum* diets and 75% of their *ad libitum* intake, 2) determine the effect of nutritional intake on serum and vitreous humor values, 3) estimate predictability of serum values using vitreous humor values, and 4) establish baseline physiological values for black-tailed jackrabbits in northwest Texas.

METHODS

Twenty-three adult, male black-tailed jackrabbits were caught by the drive corral method (Henke and Demarais 1990*a*) within the city limits of Lubbock, Texas during 30 April-8 May, 1988. Animals were individually housed indoors in stainless steel rabbit cages. A grid rack allowed urine and feces to fall out. Jackrabbits were provided *ad libitum* water and Purina Rabbit Chow Complete blend (Ralston Purina Co., St. Louis, MO) and allowed to adapt to confinement and feed. The amount of feed that each jackrabbit consumed was determined by the daily difference of the amount of feed given and amount of feed remaining. Jackrabbits were considered adapted when their daily feed consumption stabilized. Consumption was considered stable when feed consumption remained within 10% of the 7-day running mean for a 7-day period. After the adaption period, jackrabbits were assigned randomly to 1 of 2 diets, either *ad libitum* or 75% of their *ad libitum* intake, for a 2-week period. Feed intake reduced by 25% resulted in jackrabbits with lower post-trial body weight and kidney fat indices, enlarged spleens and adrenal cortex widths, increased bilirubin and cortisol concentrations, and depressed immune function (Henke and Demarais 1990*b*).

Euthanasia was accomplished with a 1.5cc intraperitoneal injection of T61 euthanasia solution (Taylor Pharmaceuticals, Decatur, IL). The time period between removal from the cage and death was < 3 minutes. A blood sample was taken via a heart puncture with a 12cc syringe and a 18 gauge needle and centrifuged at 1,400 rpm for 15 minutes. Serum was collected and used for chemistry analysis.

Both eyes of each jackrabbit were removed from their sockets and washed free of blood. The vitreous humor was collected, centrifuged at 1,400 rpm for 15 minutes; the gelatinous portion was discarded, and the liquid phase was collected and used for chemistry analysis. Animals were aged using eye lens weights to verify adult status (Rongstad 1966).

Vitreous humor and serum samples were analyzed for urea nitrogen (UN), glucose, triglycerides, cholesterol, total protein, albumin, lactic dehydrogenase (LDH), creatine phosphokinase (CPK), glutamic-oxaloacetic transaminase (GOT), and gamma glutamyltransferase (GGT) using the MultiStat III-plus fluorescence light scattering microcentrifugal analyzer (Instrumentation Laboratory, Lexington, MA). Reagents and standards were obtained from the manufacturer. Controls analyzed with each run consisted of two commercially-produced human samples (Fisher Scientific, Inc., Springfield, NJ) and the appropriate pooled animal samples. Concentrations of standards had to be within 3% of their known concentration for the chemical analysis to be accepted.

Statistical analyses were performed on log-transformed data due to non-normality of distributions. Distribution of residuals were retested using the Shapiro-Wilk test at $P < 0.05$ to ensure normality of log-transformed data (SAS Institute 1989). Because relationships between serum constituents and animal condition are known, mean serum and vitreous humor constituents within treatments were compared using similarly as serum. Each variable's association between serum and vitreous humor paired Student's t-test (SAS Institute 1989) to determine if vitreous humor reacted wasdetermined using Pearson's correlation coefficients (SAS Institute 1989). Equations predicting concentrations of serum constituents from concentrations of vitreous humor constituents were developed by use of least-squares linear regression (SAS Institute 1989). The effect of diet was tested separately within the serum and vitreous humor samples with Student's t-test (SAS Institute 1989). Statistical analyses were considered to have potential biological significance at $P \leq 0.10$ (Tacha et al. 1982).

RESULTS

The time period for death to occur did not differ ($P = 0.89$) between treatment groups. Corresponding right and left vitreous humor samples were similar ($P > 0.23$) for all constituents in both treatment groups so vitreous humor data were averaged within animals for supplemental analyses.

Urea Nitrogen (UN)

Urea nitrogen was lower ($P < 0.004$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction increased UN in serum ($P = 0.001$) but did not affect vitreous humor ($P = 0.19$) (Table 1). A linear relationship ($r = 0.63$, $P = 0.03$) was observed between vitreous humor UN and serum UN in the control group (Table 2). The predictive equation of log-transformed UN using vitreous humor is: Serum UN = 1.40 + 0.59 (Vitreous humor UN).

Glucose

Glucose was lower ($P < 0.0001$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction did not affect glucose levels in the serum ($P = 0.26$), but did affect vitreous humor levels ($P = 0.05$) (Table 1). There were no linear relationships between serum and vitreous humor glucose for either treatment group (Table 2).

Triglycerides

Triglyceride levels were similar between serum and vitreous humor ($P > 0.29$) for both treatment groups (Table 1). Feed restriction increased triglyceride levels in serum ($P = 0.002$) but did not affect vitreous humor levels ($P = 0.24$) (Table 1). A linear relationship ($r = -0.64$, $P = 0.03$) was observed between vitreous humor and serum triglycerides in the stressed group (Table 2). The predictive equation of log-transformed triglycerides using vitreous humor of nutritionally stressed jackrabbits is: Serum Triglycerides = 5.65 - 0.16 (Vitreous humor Triglycerides). However, for this equation to be meaningful, the nutritional condition of jackrabbits must be assessed first (see Henke and Demarais 1990*b*).

Cholesterol

Cholesterol was lower ($P < 0.0001$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction increased cholesterol in serum and vitreous humor ($P < 0.0001$) (Table 1). There were no linear relationships between serum and vitreous humor cholesterol for either treatment group (Table 2).

Total Protein

Total protein was greater ($P < 0.0001$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction decreased total protein levels in the serum and vitreous humor ($P < 0.0001$) (Table 1). There were no linear relationships between serum and vitreous humor total protein for either treatment group (Table 2).

Albumin

Albumin was lower ($P < 0.0001$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction decreased albumin levels in the vitreous humor ($P = 0.04$) and serum ($P = 0.0002$) (Table 1). There were no linear relationships between serum and vitreous humor albumin for either treatment group (Table 2).

Table 1. The effect of source (serum vs. vitreous humor) and treatment (control vs. nutritional stress) on blood chemistry values for adult male black-tailed jackrabbits.

	Serum				Vitreous Humor				P-Values			
	Control (N=12)		Stress (N=11)		Control (N=12)		Stress (N=11)		Stress Effect		Source Effect	
Constituents	0	SE	0	SE	0	SE	0	SE	Serum	Vit. Humor	Control	Stress.
Urea Nitrogen (mg/dl)	23.1	1.0	29.5	1.2	18.8	0.9	21.4	1.7	0.001	0.19	0.004	0.001
Glucose (mg/dl)	215.3	15.0	193.9	6.6	98.2	8.6	76.6	6.2	0.26	0.05	0.0001	0.0001
0Triglyceride (mg/dl)	84.9	8.8	140.6	12.6	85.7	23.0	235.7	114.5	0.002	0.24	0.29	0.48
Cholesterol (mg/dl)	41.9	1.5	67.4	3.7	15.4	1.0	22.0	0.9	0.0001	0.0001	0.0001	0.0001
Total Protein (g/dl)	24.9	0.4	16.5	0.7	58.0	0.4	46.7	2.3	0.0001	0.0001	0.0001	0.0001
Albumin (g/dl)	4.3	0.1	3.6	0.1	1.4	0.2	0.9	0.1	0.0002	0.04	0.0001	0.0001
GGT (IU/L)[a]	4.2	0.6	6.0	0.7	0.7	0.1	1.7	0.4	0.05	0.001	0.0001	0.0001
LDH (IU/L)[a]	228.5	24.9	193.4	29.6	73.0	35.0	90.5	42.5	0.22	0.52	0.0001	0.002
CPK (IU/L)[a]	289.0	43.1	240.1	42.5	145.0	47.6	166.8	43.2	0.38	0.60	0.004	0.09
GOT (IU/L)[a]	82.4	20.2	59.6	7.4	58.3	17.4	48.7	11.3	0.38	0.99	0.10	0.17

[a] GGT, gamma glutamyltransferase; LDH, lactic dehydrogenase;CPK, creatinephosphokinase; GOT, glutamic-oxaloacetic transaminase.

Table 2. Pearson's correlation coefficients on log-transformed data for serum and vitreous humor in 23 adult, male black-tailed jackrabbits on two levels of nutrition.

	Treatments			
	Non-stress		Stress	
Constituents	rho	P	rho	P
Urea nitrogen	0.63	0.03	0.03	0.92
Glucose (mg/dl)	0.18	0.57	0.49	0.13
Triglyceride (mg/dl)	0.49	0.10	- 0.64	0.03
Cholesterol (mg/dl)	-0.15	0.64	0.29	0.39
Total Protein (g/dl)	-0.22	0.48	- 0.18	0.59
Albumin (g/dl)	0.24	0.45	-0.31	0.35
GGTa (IU/L)	-0.06	0.84	-0.18	0.61
LDHa (IU/L)	-0.20	0.54	0.50	0.12
CPKa (IU/L)	0.20	0.53	-0.29	0.38
GOTa (IU/L)	0.76	0.004	-0.47	0.14

[a]GGT, gamma glutamyltransferase; LDH, lactic dehydrogenase; CPK, creatine phosphokinase; GOT, glutamic-oxaloacetic transaminase.

Gamma Glutamyltransferase (GGT)

Gamma glutamyltransferase was lower ($P < 0.0001$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction increased GGT in vitreous humor ($P = 0.001$) and in serum ($P = 0.05$) (Table 1). There were no linear relationshipsbetween serum and vitreous humor GGT for either treatment group (Table 2).

Lactic Dehydrogenase (LDH)

Lactic dehydrogenase was lower ($P < 0.002$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction did not affect LDH levels in the serum ($P = 0.22$) or vitreous humor ($P = 0.52$) (Table 1). There were no linear relationships between serum and vitreous humor LDH for either treatment group (Table 2).

Creatine Phosphokinase (CPK)

Creatine phosphokinase levels were lower ($P < 0.09$) in vitreous humor than in serum for both treatment groups (Table 1). Feed restriction did not affect CPK levels in the serum ($P = 0.37$) or vitreous humor ($P = 0.60$) (Table 1). There were no linear relationships between serum and vitreous humor CPK for either treatment group (Table 2).

Glutamic-oxaloacetic Transaminase (GOT)

Glutamic-oxaloacetic transaminase levels were similar between vitreous humor and serum ($P > 0.10$) for both treatment groups (Table 1). Feed restriction did not affect GOT levels in the serum ($P = 0.38$) or vitreous humor ($P = 0.99$) (Table 1). A linear relationship (r = 0.76, P = 0.004) was observed between vitreous humor GOT and serum GOT in the control group (Table 2). The predictive equation of log-transformed GOT using vitreous humor is: Serum GOT = 2.51 + 0.47 (Vitreous humor GOT).

DISCUSSION

Vitreous humor constituents were poor predictors of serum values. Because biochemical indicators of nutritional condition in blood are sensitive to antemortem stress, hemolysis, and postmortem interval (Mautz et al. 1980, Henke and Demarais 1992), vitreous humor has been suggested as a potential alternative medium for certain metabolites due to the vitreous barrier, which may nullify the problems associated with hematological analysis (Coe 1972). However, the vitreous barrier caused the vitreous humor to be insensitive to short-term dietary differences, which explains the dissimilarity between serum and vitreous humor values for all variables except triglycerides and GOT. Differences in penetration of chemically-related substances into the vitreous body of New Zealand white rabbits (*Oryctolagus cuniculus*) were attributed to a vitreous barrier, which was selective to lipoid solubility and to the electrical charge of molecules (Bleeker et al. 1968). In addition, because the vitreous humor and serum reacted differently to feed restriction, the predictive equations offered for UN, triglycerides, and GOT are only meaningful if the nutritional condition of the animal is assessed first. However, such an assessment is not always possible, which would render the predictive equations without merit.

Glucose, UN, CPK, and GOT in the vitreous humor and serum were correlated in winter-captured black-tailed jackrabbits (Henke 1989). The differential response of several constituents in the vitreous humor between the present study and previous research with black-tailed jackrabbits (Henke 1989) suggested that either the vitreous humor can react erratically for the same biochemistry within the same animal model, or a seasonal variation within the sources exist. A similar phenomenon was observed in white-tailed deer where only winter serum and vitreous humor glucose were correlated in summer and winter-captured deer (DeLiberto 1987).

Serum and vitreous humor UN were not affected by feed restriction. The increased serum UN with feed restriction was most likely caused by tissue catabolism because the feed-restricted jackrabbits also lost weight (Henke and Demarais 1990*b*). Warren and Kirkpatrick (1978) attributed elevated serum UN levels in feed-restricted cottontail rabbits (*Sylvilagus floridanus*) to a similar process. Vitreous humor UN was not indicative of recent nutritional intake by jackrabbits.

Serum glucose was not affected by the 25% feed restriction, which suggested that the feed restriction either was not severe enough or long enough for the jackrabbits to use up their glucose reserves (Collins 1982). Vitreous humor was sensitive of recent carbohydrate intake by jackrabbits though.

Increased triglycerides suggest that fats were being mobilized from peripheral lipid deposits due to low caloric intake (Collins 1982). Because vitreous humor triglycerides were unaffected by the feed restriction, the vitreous humor would not be an adequate source to assess triglycerides in jackrabbits.

Increased levels of cholesterol suggest that dietary protein was insufficient for liver synthesis of lipoproteins (Collins 1982). Decreased protein intake can result in a decreased utilization of total protein and albumin (Watson and Sodeman 1985).

Increased levels of vitreous humor GGT in the feed restricted group suggested that vitreous humor GGT may be a sensitive indicator of recent nutritional intake. Liver damage due to caloric and protein malnutrition can increase GGT (Iber and Latham 1985)

Increased levels of LDH, CPK, and GOT would indicate severe and/or long-term liver damage (Iber and Latham 1985). However, because the feed restriction was only for two weeks, hepatiosis was not expected and did not occur.

The use of vitreous humor will not replace serum as the standard medium for biochemical analysis. However, vitreous humor may have potential as a source for some biochemical indicators of nutritional intake. Vitreous humor glucose, cholesterol, total protein, albumin, and GGT were sensitive indicators of feed restriction. Vitreous humor total protein, albumin, and GGT of black-tailed jackrabbits also were not affected by acute handling stress (Henke 1989). The range of Anormal values for these vitreous humor constituents needs to be addressed prior to the vitreous humor having practical application. The serum and vitreous humor constituent levels presented can be used as baseline values for *ad libitum*-fed and feed-restricted black-tailed jackrabbits.

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Blood Parasite Survey of Inca Doves from a South Texas Urban Environment

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ABSTRACT

Inca doves (*Columbina inca*) are a native species of southern and central Texas, which are locally abundant in urban areas. Unfortunately, little is known about the factors that may impact their populations such as predation, disease, and parasites. To learn more about factors that may influence the health of this species, we initiated a survey to determine if Inca doves in south Texas have blood parasites. Inca doves were live trapped on the Texas A&M University-Kingsville campus and surrounding City of Kingsville, aged and sexed, banded, sampled via leg vein puncture, and released. Two blood smears from each bird were made on microscope slides, preserved, stained, and examined under 1000x magnification. Forty-one Inca doves were captured from 5 July to 10 October, 2000. No blood parasites were observed on the smears. Our findings suggest that Inca doves were not infected or at least they were not demonstrating active infections in peripheral blood during late summer and early fall 2000.

KEYWORDS: Blood parasites, *Columbina inca*, Inca dove, South Texas

Blood parasites have been known to cause morbidity and mortality in various avifauna (Herman et al., 1975; Atkinson, 1991; Forrester, 1991). Much of the focus has been on game species due to the emphasis on evaluating factors that influence population densities. Information about less high profile species has often been lacking.

One such species, the Inca dove (*Columbina inca*), is a resident of southern and central Texas and is locally abundant in urban habitats. Currently, none of the published studies that examined Inca doves for blood parasites have sampled more than one individual each and were birds sampled from populations occurring outside of the U.S. (Beltran, 1942; Beltran and Pardinas, 1953; Saunders, 1959; Winchell, 1978). Such lack of sampling for this species precludes health assessments at the host population level and points to a need for surveying Inca dove populations in Texas and across their geographic range. To learn more about factors that may influence the health of Inca doves, a survey was initiated to determine if Inca doves in a south Texas urban environment have blood parasites and, if they do, determine prevalence and density of infection.

METHODS

Inca doves were live trapped using wire cages baited with grain at six different sites in the City of Kingsville and Texas A&M University-Kingsville campus in Kleberg County, Texas (27° 31'N, 97° 51'W). Sites were baited for three days and traps were put near the bait for two days before traps were set. Trapping began on 5 July 2000 and continued until 10 October 2000. At the time of capture, Inca doves were aged and sexed according to descriptions of Baptista et al. (1997) and Goodwin (1977), banded and Wildlife Service aluminum leg bands to avoid resampling previously captured birds, and sampled via leg vein puncture. After the blood sample was taken, a Kimwipe® or clean paper towel was

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compressed on the leg until blood flow ceased, after which the bird was released. Two blood smears from each bird were made on glass microscope slides. Smears were preserved in 100% methanol and stained using Diff-Quik®. Each smear was examined for 15 minutes (30 minutes per bird) at 1000x magnification using a microscope. Standard observation times have not been established for examining blood smears at particular magnifications; however, recent studies have examined individual smears for a short as 10 minutes (DeJong and Muzzall, 2000) up to 20-30 minutes (Fedynich et al., 1998) at 1000x magnification.

Inca doves were trapped and handled according to the protocols of the U.S. Department of the Interior, U.S. Geological Survey, Bird Banding Laboratory Permit No. 23051 and Texas Parks and Wildlife Department Scientific Permit No. SPR-0498-949. This study was approved by the Texas A&M University-Kingsville Animal Care and Use Committee, authorization No. Y2K-6-2.

RESULTS AND DISCUSSION

Forty-one Inca doves (three adult males, three adult females, 23 juvenile females, and 12 juvenile males) were captured and sampled. No blood parasites were observed in each of the blood smears. Early stages of either Haemoproteus sp. or Plasmodium sp. were suspected in four birds. In each case, a more advanced-stage specimen needed to determine that a parasite was actually present could not be found after additional examination of the two smears of the bird in question. Consequently, these birds were considered negative.

Findings of this study are surprising, given that up to three blood parasite species (*Haemoproteus columbae*, *Haemoproteus sacharovi*, *Leucocytozoon* sp.) have been found in other columbid species in Texas (Stabler, 1961; Godfrey et al., 1990; McClinton, 1998) including south Texas (Glass, 1999). Absence of infections in a localized host population and presence in another population of the same host species have been reported in mourning doves (*Zenaida macroura*) and pigeons (*Columbia livia*) (Knisley and Herman, 1967), which suggests that lack of infection is the result of a breakdown of the host-vector-parasite transmission cycle rather than some intrinsic host factor such as immunity or resistance.

A dysfunctional host-vector-parasite transmission cycle may be the result of a lack of vectors or insufficient vector density. Although it was beyond the scope of this study to trap and identify possible vectors, we did observe several hippoboscid flies on Inca doves, which are known vectors for *H. columbae* and *H. sacharovi* (Atkinson, 1991). Fedynich and Small (1996-1998, unpublished data) found fledged juvenile and adult eastern white-winged doves (*Zenaida asiatica asiatica*) from Kingsville, Texas were infected with *H. columbae* during October-November 1996 (n = 12), July 1997 (n = 6), and May 1998 (n = 5), which indicates that at least this host species is infected within the locality where we sampled Inca doves. It is possible that the population dynamics of vectors during our particular sampling period was such that there was insufficient densities to sustain infections in Inca doves.

We sampled a high proportion of fledged hatch-year birds, possibly reducing our chances of observing blood protozoa. It takes 12-16 days for Inca dove nestlings to fledge (Baptista et al., 1997) and the prepatent phase (time from actual infection of host to observation of gametocytes in blood) of H. columbae ranges from 14-28 days (Garnham, 1966). Knisley and Herman (1967) summarized several studies in which no blood parasites were observed in nestling mourning doves (fledge in 11-15 days) and white-winged doves (fledge in 13-16 days). However, Farmer (1960) found mourning dove nestlings infected with *H. sacharovi* and *Leucocytozoon* sp., which suggests that gametocytes for these parasite species are capable of being observed in host blood prior to fledging. Relatively high prevalences of *H. columbae* have been found in 62 of 78 (79%) fledged hatch-year mourning doves sampled in early September on the Rolling Plains and Southern High Plains of Texas (Godfrey et al., 1990) and in 10 of 16 (62%) fledged hatch-year white-winged doves sampled June-September in south Texas (Glass, 1999), which suggests that fledged hatch-year Inca doves have sufficient time to acquire and demonstrate infections in blood.

In this study, 41 Inca doves were not infected or at least did not have active infections in the peripheral blood during summer-fall 2000. Although these findings do not unequivocally indicate that Inca doves were free of infection (certain stages of blood protozoa occur in host tissue), it does suggest that the host-vector-parasite transmission cycle was not operating during summer 2000.

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Evaluation of Twenty-six Buffalograss Cultivars and Accessions for Use as Turfgrass on the High Plains of West Texas

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ABSTRACT

The development of high quality buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.] is depended on the texture, density, length of growing season and overall turfgrass quality. Twenty-six buffalograss cultivars and accessions were evaluated for their potential as a high quality turfgrass at the Texas Tech University located in Lubbock, TX. The top five turfgrasses that consistently had the best turfgrass quality grown on the High Plains of West Texas were TTU-227, TTU-196, 378, TTU-12 and TTU-232.

KEYWORDS: *Buchloe dactyloides* (Nutt.) Engelm., cultivar evaluation, turfgrass quality

Buffalograss, *Buchloe dactyloides* (Nutt.) Englem., is a stoloniferous, sod forming, perennial, warm season grass native to North America. Buffalograss is the dominant short grass in the Great Pains and is extremely tolerant to drought, disease, temperature extremes and requires minimal fertilization (Waddington et al., 1992; Wenger, 1943). These traits along with the ability to withstand moderate traffic have led to an increase in the use of buffalograss as a turfgrass (Leuthold, 1982; Riordan, 1991). Buffalograss has been increasingly evaluated for its potential as a low maintenance turfgrass (Englke and Hickey, 1983; Kneebone, 1984; Pozarnsky, 1983; Wu et al. 1984).

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Buffalograss has typically been described as dioecious, with a few isolated moneocious plants (Savage, 1934). The staminate plant of buffalograss is characterized by a flag-like inflorescence that protrudes an inch or two above the main canopy. The pistillate plants inflorescence is shorter and held in the canopy among the leaves (Beard, 1973). The staminate inflorescence is one of the reasons buffalograss has not been used extensively as a turfgrass. Some new buffalograss cultivars however are comprised of only pistillate plants or have low numbers of staminate flowers.

Buffolagrass's tolerance to environmental stresses lies in its ability to go dormant (Shantz, 1911). The onset of dormancy can be induced by temperature (chilling), drought, or photoperiod. Although dormancy has ensured buffalograsses survival in harsh environments it has limited its use as a turfgrass. Buffalograsses have been evaluated that green up early in the spring and enter dormancy later to provide a longer growing season (Kenworthy, 1996, Morris, 2000).

Research has shown that buffalograss requires less irrigation and fertilization than other warm season turfgrasses (Wu et al., 1989). In arid and semiarid climates where water resources are limited buffalograss provides a turfgrass that requires less water and has the ability to withstand periods of drought. Similarly, protection of water resources from nitrate leaching is essential. Buffalograss has a low fertility requirement of 0.0 to 0.4 lbs./nitrogen (N)/month during the growing season as compared to 0.5-1.5 lbs/N/month for bermudagrass (Beard, 1973). The low irrigation, fertility and pesticide requirements of buffalograss save important natural resources and limits environmental contamination. The objective of this study is to evaluate buffalograss cultivars and accessions that produce a high quality turfgrass for use on the High Plains of West Texas.

MATERIALS AND METHODS

Twenty-six buffalograss cultivars and accessions were planted July 1996 at the Texas Tech University Erskine Research Farm in Lubbock, Texas (Table 1). The first 14 cultivars were part of the National Buffalograss Test-1996. The remaining 12 accessions were selected from 273 accessions of native buffalograss collected across the lower Great Plains (Kenworthy, 1996). The soil type was an Amarillo fine sandy soil (fine-loamy, mixed thermic, Aridic Paleustalf). Treatments were arranged as a randomized block design with three replications. Each cultivar or accession was grown in a 10 ft. x 10 ft. area with a 1 ft. border on all sides. The plots were irrigated with sprinklers during establishment and flood irrigated thereafter. Five cultivars were established from seed with the remaining 21 cultivars established vegetatively with four 2 inch plugs per plot (Table 1). Plots were fertilized at a rate of 2-3 lbs. of N/1000ft^2/year, mowed at a height of 2 inches every 7 to 10 days irrigated to prevent stress weekly during the growing season.

The twelve accessions evaluated in this study from the Texas Tech University buffalograss germplasm collection had been collected at twelve extremely diverse sites across the lower Great Plains (Table 2). Two of the accessions were diploids (2N=20), three of the accessions were tetraploids (4N=40) and seven accessions were hexaploids (6N=60). These twelve accessions had been phenotypically selected for turfgrass quality during the collection process and again in replicated plots at Lubbock, Texas during 1995 and 1996 (Kenworthy, 1996). These twelve accessions exhibited the best turfgrass quality of the 273 accessions in this collection.

Turfgrass quality was determined by evaluating leaf texture (1 = coarse to 9 = fine), density (1 = bare to 9 = maximum density) and percent living ground cover (0 to 99). Turfgrass quality ratings were taken monthly from April through August 1997, April through October, 1998, and March through October 1999 and 2000. Turfgrass quality rating are based on a scale of 1 = dormant to 9 = maximum quality turfgrass. All evaluations were based on standards use by the National Turfgrass Evaluation Program (NTEP). Data were analyzed by analysis of variance and means were separated with Fisher's Protected Least Significant Difference Test at the 0.05 level of probability using SAS (SAS, 1989).

RESULTS AND DISCUSSION

Turfgrass is a crop that is evaluated based on its aesthetic qualities over a number of years. The cultivars in this experiment were evaluated over a four-year period evaluating leaf texture, density, percent ground cover and overall turfgrass quality. Leaf texture was taken in the first year after planting in April 1997 (Table 3). There were no significant differences in leaf texture for any of the cultivars or accessions.

Turfgrass density was taken in 1997-99 (Table 3). In 1997, all seeded cultivars, Bam-1000, Bison, Cody, Tatanka and Texoka, had a significantly greater turfgrass density than the vegetative cultivars. This would be attributed to the seeds being spread over the entire 10 ft. x 10 ft. area at planting whereas the vegetative cultivars were established from 4 plugs per plot and had to spread via stolons. The higher density ratings of the vegetative cultivars are an indication of cultivar vigor. All vegetative cultivars and accessions exhibited similar growth rates except Bonnie Brae, 378, TTU-227, TTU-12, TTU-232, TTU-62 and TTU-43 that had a significantly lower density. In 1998, cultivars and accessions TTU-43, 91-118, TTU-232, TTU-175B, TTU-46 and TTU-196 had the greatest density, but only accession TTU-12 and cultivars Texoka and 378 had significantly lower density than the other cultivars. In 1999, Bonnie Brae, 91-118, Stampede, TTU-175B, 86-120, 378, TTU-94B, and UCR-95 had the greatest density, but only Midget, Bam-1000, Bison and Texoka had a significantly lower density than other cultivars and accessions. For the three-year average Cody, Tatanka and Bison had the greatest density. Percent living ground cover was taken in the fall of 1997 through 1999 (Table 3). In 1997, both Bam-1000 and Bison had the highest living ground cover rating at 96%. By the fall of 1997, twelve of the cultivars and accessions had a living ground cover of less than 80%. In 1998, however all but accessions TTU-12, TTU-232, TTU-43 and TTU-62 had similar ground cover rating of greater than 90%. In 1999, all cultivars and accessions had greater than 80% living ground cover except Tatanka, Bonnie Brae and UCR-95. Over the three-year period Cody, Bam-1000, Bison, Texoka, 86-120,TTU-94B, TTU-230A, TTU-84, TTU-17, TTU-175B and TTU-227 had greater than 90% living ground cover.

Turfgrass quality ratings were collected from April through August in 1997 (Table 4). Four of the five seeded cultivars were rated the best overall quality during the first growing season. This could be attributed to the greater density of these cultivars during the first growing season. The highest rated cultivars in 1997 were Cody and Bam-1000. Four of the top five rated cultivars and accessions were seeded. Quality rating in the first year may be of minimal value as the cultivars and accessions were still being established. After the first growing season quality ratings in 1998 were taken from April through October (Table 5). The highest rated cultivars and accessions in descending order were TTU-227, TTU-196, TTU-175B, UCR-95 and 609. These cultivars and accessions had the highest overall average for the entire growing season. Many of these cultivars and accessions were still receiving high quality rates in October compared to other cultivars and accessions that were beginning to go dormant. In 1999, data were taken from March through October (Table 6). The top five rated cultivars and accessions in descending order were TTU-227, 378, TTU-12, TTU-196 and 609. The March quality rating indicates that some cultivars and accessions were beginning to green-up compared to others that were still dormant. Similarly, in October many of the top cultivars and accessions were still green when others were already dormant. In 2000, cultivars and accessions that had the highest average quality rating in descending order were TTU-196, TTU-227, 378, TTU-12 and Bison (Table 7). The cultivars and accessions that have the highest average quality ratings tended to green-up earlier in the spring and retain color later into the fall. An infestation of white grubs in the fall of 1999 may have influenced individual plot ratings in 2000. These data indicate that over a three year period from 1998 though 2000 that TTU-227, TTU-196, TTU-12 and TTU-232 had similar or better overall quality compared to the standard 378 that was the highest rated standard in this study (Table 8).

The performance of twelve accessions was comparable with the fourteen commercially developed cultivars (Table 8). It was interesting to note that four of the top five accessions were hexaploids. Hexaploids often have longer and coarser leaves but establish dense, vigorous stands. Because ploidy levels were not readily available on the commercial cultivars, direct comparison based on ploidy was not possible. The high turfgrass quality ratings of accessions such as TTU-227 and TTU-196 indicate there is still useful genetic variation for turfgrass quality in buffalograss available in native populations of this grass.

CONCLUSION

This study indicates that accessions TTU-227, TTU-196, TTU-12 and TTU-232 produced a high quality turfgrass for this geographical location as compared to the standard cultivars of Bison, Texoka, 378 and 609. These accessions provide a fine texture and dense turfgrass suited for commercial use. Similarly, these accessions had a long growing season and the highest quality turfgrass. It was interesting that in these evaluations many of the hexaploid accessions produced the highest quality turfgrasses compared to diploid and tetraploid accessions. These accessions have shown great promise grown on the High Plains of West Texas. Further research will be necessary to evaluate these cultivars grown under different environmental conditions such as the NTEP Test.

Table 1. Entry, genotype, propagation method and sponsor of 26 buffalograss cultivars and accessions evaluated at Lubbock TX from 1996 to 2000.

Entry	Genotype	Propagation method	Sponsor
1.	Bam-1000	Seeded	Bambert Seed Company
2.	Bison	Seeded	Standard entry
3.	Cody	Seeded	Native Turf Group, Inc.
4.	Tatanka	Seeded	Native Turf Group, Inc.
5.	Texoka	Seeded	Standard entry
6.	Bonnie Brae	Vegetative	Horizon Turfgrass
7.	Legacy	Vegetative	Todd Valley Farms, Inc
8.	Midget	Vegetative	Horizon Turfgrass
9.	Stampede	Vegetative	Turfgrass America
10.	UCR-95	Vegetative	Frontier Hybrids
11.	86-120	Vegetative	University of Nebraska
12.	91-118	Vegetative	University of Nebraska
13.	378	Vegetative	Standard entry
14.	609	Vegetative	Standard entry
15.	TTU-12	Vegetative	Texas Tech University
16.	TTU-17	Vegetative	Texas Tech University
17.	TTU-43	Vegetative	Texas Tech University
18.	TTU-46	Vegetative	Texas Tech University
19.	TTU-62	Vegetative	Texas Tech University
20.	TTU-84	Vegetative	Texas Tech University
21.	TTU-94B	Vegetative	Texas Tech University
22.	TTU-175B	Vegetative	Texas Tech University
23.	TTU-196	Vegetative	Texas Tech University
24.	TTU-227	Vegetative	Texas Tech University
25.	TTU-230A	Vegetative	Texas Tech University
26.	TTU-232	Vegetative	Texas Tech University

Table 2. Chromosome number, ploidy, collection site and proximity of twelve accessions of Buffalograss evaluated for turf quality at Lubbock, Texas from 1997 to 2000.

Genotype	Chromosome Number ---n---	---Ploidy---	Collection Site Latitude	Collection Site Longitude	---Proximity---
TTU-12	60	Hexaploid	36°37′	100°30′	Canadian, TX
TTU-17	60	Hexaploid	38°01′	100°21′	Cimarron, OK
TTU-43	60	Hexaploid	34°04′	102°20′	Littlefield, TX
TTU-46	20	Diploid	34°56′	102°24′	Hereford, TX
TTU-62	40	Tetraploid	38°06′	102°55′	Lamar, CO
TTU-84	20	Diploid	34°34′	103°12′	Clovis, NM
TTU-94B	40	Tetraploid	34°58′	104°51′	Santa Rosa, NM
TTU-175B	40	Tetraploid	30°30′	101°09′	Cornstock, TX
TTU-196	60	Hexaploid	27°35′	98°38′	Freer, TX
TTU-227	60	Hexaploid	29°59′	97°53′	Kyle, TX
TTU-230A	60	Hexaploid	30°26′	98°21′	Johnson City, TX
TTU-232	60	Hexaploid	31°07′	98°04′	Lampasas, TX

Table 3. Mean leaf texture rating, density rating and percent living ground cover of 26 buffalograss cultivars and accessions evaluated at Lubbock, TX from 1997 to 1999.

Cultivar	Texture	Density				Percent living ground cover			
		1997	1998	1999	Avg.	1997	1998	1999	Avg.
	-rating-	rating				%			
Cody	7.0a	7.0a	8.3a-c	7.7a-d	7.7a	89ab	99a	86a-c	91.7a
Tatanka	6.3a	6.7a	8.3a-c	8.0a-c	7.7a	83ab	99a	77bc	86.7a-d
Bam-1000	7.3a	7.0a	8.3a-c	7.0cd	7.3ab	96a	99a	89a-c	94.7a
Bison	7.7a	7.7a	8.3a-c	7.0cd	7.7a	96a	98a	86a-c	93.3a
Texoka	8.0a	7.3a	7.7c	6.7d	7.0a-c	90ab	99a	86a-c	92.0a
91-118	4.7a	4.0b-d	9.0a	8.7a	7.0a-c	23gh	99a	89a-c	70.7ef
86-120	6.0a	4.0b-d	8.3a-c	8.7a	7.0a-c	86ab	99a	93ab	92.7a
Legacy	6.3a	3.3b-e	8.3a-c	8.3ab	6.7b-d	63b-f	98a	99a	86.7a-d
Bonnie Brae	7.0a	3.0c-e	8.3a-c	8.7a	6.7b-d	43d-h	96ab	73c	70.7ef
Midget	5.3a	4.0b-d	8.7ab	7.3b-d	6.7b-d	43d-h	96ab	86a-c	75.3de
Stampede	7.0a	3.3b-e	8.7ab	8.7a	7.0a-c	63b-f	95ab	96a	84.7a-d
UCR-95	6.7a	3.3b-e	8.7ab	8.7a	6.7b-d	13h	99a	73c	62.0f
609	5.3a	4.7b	8.7ab	8.3ab	7.3ab	70a-e	99a	99a	89.3ab
378	6.3a	3.0c-e	7.7c	8.7a	6.3cd	70a-e	96ab	99a	88.3a-c
TTU-94B	7.7a	4.3bc	8.3a-c	8.7a	7.0a-c	90ab	98a	89a-c	92.3a
TTU-230A	7.7a	4.0b-d	8.7ab	8.0a-c	6.7b-d	90ab	94ab	99a	94.3a
TTU-84	7.0a	4.0b-d	8.3a-c	8.0a-c	6.7b-d	87ab	99a	89a-c	91.7a
TTU-17	7.0a	3.7b-d	8.3a-c	8.3ab	7.0a-c	90ab	99a	93ab	94.0a
TTU-232	6.7a	2.0ef	9.0a	8.0a-c	6.3cd	83ab	88c	93ab	88.0a-c
TTU-175B	7.7a	3.3b-e	9.0a	8.7a	6.7b-d	73a-d	99a	99a	90.7ab
TTU-12	8.0a	2.0ef	8.0bc	8.0a-c	6.0d	40e-h	91bc	99a	76.7c-e
TTU-196	8.0a	22b-d	9.0a	8.3ab	7.0a-c	40e-h	99a	99a	79.0b-e
TTU-46	8.0a	4.0b-d	9.0a	8.3ab	7.0a-c	83ab	96ab	83a-c	87.3a-c
TTU-62	7.3a	2.0ef	8.3a-c	8.3ab	6.3cd	50c-g	72d	90a-c	70.3ef
TTU-43	7.7a	1.0ef	9.0a	8.3ab	6.0d	37f-h	87c	89a-c	71.0ef
TTU-227	7.3a	2.7de	8.3a-c	8.0a-c	6.3cd	77a-c	99a	99a	91.7a
LSD (0.05)	NS	1.30	0.81	1.19	0.7	32.4	5.9	16.4	8.5
Coefficient of Variation		20.2%	5.9%	8.9%	6.6%	29.0%	3.8%	11.0%	11.8%

Means within column not followed by the same letter differ at the 0.05 level of probability by Fisher's Least Significant Difference Test.
Texture rating = 1= coarse to 9= fine texture.
Density rating = 1= bare to 9= maximum density.

Table 4. Turfgrass quality ratings of 26 cultivars and accessions of buffalograss evaluated at Lubbock, TX in 1997.

Cultivar	Turfgrass quality rating					
	Apr.	May	Jun.	Jul.	Aug.	Avg.
	----------	----------	----------	rating	----------	----------
Texoka	7.0ab	8.3a	9.0a	8.0ab	9.7a	8.4a
Bam-1000	7.3a	8.0ab	9.0a	8.0ab	9.7a	8.4a
Cody	6.7a-c	8.0ab	9.0a	8.0ab	9.7a	8.3ab
Bison	7.3a	7.3bc	9.0a	8.0ab	9.3ab	8.2a-c
TTU-230A	6.7a-c	7.3bc	9.0a	8.3a	9.0a-c	8.1a-c
TTU-46	6.7a-c	7.3bc	9.0a	8.0ab	9.0a-c	8.0a-c
TTU-84	7.0ab	7.0cd	8.3a-c	8.0ab	9.0a-c	7.9a-d
Tatanka	5.3a-e	8.0ab	9.0a	8.0ab	9.0a-c	7.9a-d
TTU-175B	6.0a-d	6.7c-e	8.3a-c	8.0ab	9.3ab	7.7a-e
TTU-94B	5.3a-e	7.0cd	8.7ab	8.3a	9.0a-c	7.7a-e
TTU-17	6.7a-c	6.7c-e	7.7b-d	7.7a-c	8.3b-d	7.4b-f
TTU-227	5.0a-e	6.7c-e	7.7b-d	8.0ab	9.0a-c	7.3c-g
Midget	4.3b-f	6.7c-e	7.7b-d	7.7a-c	8.7a-d	7.0d-h
86-120	5.7a-d	6.3d-f	7.3c-e	8.0ab	7.3ef	6.9d-i
378	5.0a-e	6.3d-f	7.0d-f	7.3b-d	8.7a-d	6.7e-j
Legacy	4.7a-f	6.0e-g	7.3c-e	7.7a-c	8.0c-f	6.7e-j
91-118	3.7d-f	6.3d-f	7.7b-d	7.7a-c	8.3b-d	6.7e-j
TTU-196	2.7ef	6.0e-g	7.0d-f	8.0ab	9.0a-c	6.5g-k
609	5.0a-e	4.7h	6.7d-f	7.7a-c	8.7a-d	6.5g-k
Bonnie Brae	4.0c-f	5.7fg	7.0d-f	7.0cd	8.0c-f	6.3g-k
TTU-232	4.0c-f	6.0e-g	6.0f	7.0cd	8.0c-f	6.2h-k
TTU-12	4.0c-f	5.7fg	6.3ef	7.0cd	7.7d-f	6.1h-k
Stampede	4.3b-f	6.0e-g	6.0f	6.7d	7.7d-f	6.1h-k
TTU-62	3.3d-f	5.7fg	6.7d-f	7.3b-d	7.0f	6.0i-k
UCR-95	2.0f	5.3gh	6.3ef	7.3b-d	8.7a-d	5.9jk
TTU-43	2.7ef	5.7fg	6.0f	6.7d	7.0f	5.6k
LSD (0.05)	2.67	0.99	1.08	0.79	1.01	0.95
Coefficient of Variation	32%	9.3%	8.6%	6.3%	7.2%	8.2%

Means within column not followed by the same letter differ at the 0.05 level of probability by Fisher's Least Significant Difference Test.
Turfgrass rating = 1=dead or dormant to 9=maximum turfgrass quality

Table 5. Turfgrass quality ratings of 26 cultivars and accessions of buffalograss evaluated at Lubbock, TX in 1998.

Cultivar	Turfgrass quality ratings							
	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Avg.
	rating							
TTU-227	8.7a	8.7a	9.0a	8.7ab	9.0A	8.7a	3.7a-c	8.0a
TTU-196	7.3c-e	8.0ab	9.0a	8.7ab	8.0bc	8.7a	5.0a	7.8ab
TTU-175B	7.7b-d	8.3ab	9.0a	9.0a	8.0bc	7.7a-c	3.0b-d	7.6a-c
UCR-95	6.7ef	7.7bc	8.7ab	9.0a	8.0bc	8.0ab	5.0a	7.5a-d
609	8.3ab	8.0ab	8.0b-d	7.3de	8.0bc	8.0ab	4.3ab	7.4b-e
Bison	7.3c-e	7.7bc	8.7ab	8.3a-c	7.7b-d	7.3b-d	5.0a	7.4b-e
TTU-94B	7.7b-d	8.0ab	8.7ab	8.3a-c	7.7b-d	7.3b-d	3.0b-d	7.3b-d
Texoka	7.7b-d	7.7bc	8.7ab	8.3a-c	7.7b-d	7.0b-d	4.3ab	7.2c-f
TTU-46	8.3ab	8.3ab	8.3a-c	8.0b-d	7.3c-e	7.0b-e	2.3c-e	7.2c-g
TTU-12	8.0a-c	8.0ab	8.7ab	8.3a-c	7.7b-d	6.3de	3.0b-d	7.2c-g
TTU-232	7.7b-d	8.0ab	8.3a-c	7.7c-e	8.3ab	7.3b-d	3.0b-d	7.1c-h
Midge	t7.3c-e	8.0ab	8.3a-c	8.3a-c	7.0de	7.3b-d	3.7a-c	7.1c-h
Bam-1000	8.0a-c	8.0ab	8.7ab	8.0b-d	8.0bc	6.7c-e	3.0b-d	7.1d-i
TTU-84	8.3ab	8.0ab	8.3a-c	8.3a-c	7.3c-e	6.7c-e	2.3c-e	7.0d-h
Cody	8.0a-c	8.0ab	8.7ab	8.3a-c	7.7b-d	6.3de	2.3c-e	7.0d-h
Tatanka	8.3ab	8.0ab	8.3a-c	8.3a-c	7.7b-d	6.3de	1.7de	6.9d-j
378	7.7b-d	7.7bc	8.0b-d	7.7c-e	7.7b-d	6.7c-e	2.3c-e	6.8f-k
Legacy	7.3c-e	7.7bc	8.0b-d	7.7c-e	7.3c-e	6.7c-e	3.0b-d	6.8f-k
TTU-17	7.0de	8.0ab	8.0b-d	8.0b-d	7.7b-d	6.0e	3.0b-d	6.8f-k
TTU-230A	7.0de	7.7bc	8.0b-d	8.3a-c	7.3c-e	6.7c-e	1.7de	6.7g-k
Stampede	7.3c-e	7.7bc	7.7cd	7.3de	7.3c-e	6.7c-e	2.3c-e	6.7g-k
Bonnie Brae	6.7ef	8.0ab	8.0b-d	7.7c-e	7.7b-d	6.7c-e	2.3c-e	6.6h-k
91-118	8.0a-c	7.7bc	7.7cd	8.0b-d	7.7b-d	6.0e	1.7de	6.6i-k
TTU-62	7.0de	7.0c	7.7cd	7.3de	7.0de	6.3de	3.0b-d	6.5j-l
86-120	7.7b-d	7.7bc	7.7cd	7.3de	7.3c-e	6.0e	1.0e	6.4kl
TTU-43	6.0f	7.0c	7.3d	7.0e	6.7e	6.0e	2.3c-e	6.0l
LSD (0.05)	0.98	0.80	0.85	0.88	0.79	1.03	1.65	0.42
Coefficient of variation	7.9%	6.2%	6.2%	6.7%	6.3%	9.0%	33.8%	4.6%

Means within column not followed by the same letter differ at the 0.05 level of probability by Fisher's Least Significant Difference Test.
Turfgrass rating = 1=dead or dormant to 9=maximum turfgrass quality

Table 6. Turfgrass quality ratings of 26 cultivars and accessions of buffalograss evaluated at Lubbock, TX in 1999.

Cultivar	Turfgrass quality ratings								
	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Avg.
	rating								
TTU-227	2.0ab	5.0c	6.3de	8.0a	9.0a	7.7ab	4.7a	2.3a	5.6a
378	2.0ab	6.3a	7.7ab	7.7ab	8.3bc	8.0a	2.3b-d	1.0b	5.4ab
TTU-12	2.0ab	6.0ab	7.7ab	8.0a	9.0a	7.7ab	1.3de	1.0b	5.4a-c
TTU-196	2.0ab	5.0c	6.0e	7.7ab	9.0a	8.0a	3.3b	2.3a	5.4ab
609	2.0ab	5.0c	6.0e	8.0a	8.3bc	7.0a-c	3.3b	2.3a	5.3a-d
TTU-232	2.0ab	5.7a-c	7.0b-d	7.7ab	8.0c	7.3ab	2.7bc	1.0b	5.2a-e
Legacy	2.0ab	6.0ab	7.7ab	7.3bc	8.0c	7.3ab	1.0e	1.0b	5.1a-f
TTU-17	1.7bc	6.0ab	7.3a-c	7.7ab	8.0c	7.0a-c	1.7c-e	1.0b	5.1a-f
86-120	2.0ab	6.0ab	8.0a	7.0c	8.0c	6.7a-d	1.0e	1.0b	5.0b-f
Bonnie Brae	2.0ab	6.0ab	8.0a	8.0a	8.3bc	5.0a-e	1.3de	1.0b	5.0b-f
TTU-84	2.0ab	5.7a-c	7.0b-d	7.7ab	8.3bc	6.3a-d	1.7c-e	1.3b	5.0b-f
TTU-175 B	1.0d	5.7a-c	7.0b-d	7.7ab	9.0a	6.7a-d	1.7c-e	1.0b	5.0b-f
Cody	2.0ab	5.7a-c	7.0b-d	8.0a	9.0a	5.0a-e	1.7c-e	1.0b	4.9b-f
Texoka	2.0ab	5.7a-c	7.0b-d	8.0a	8.7ab	5.0a-e	1.3de	1.0b	4.9b-g
91-118	1.0d	5.7a-c	7.0b-d	8.0a	8.0c	6.0a-d	2.3b-d	1.0b	4.9b-g
TTU-230A	1.0d	5.0c	6.3de	8.0a	8.0c	7.7ab	2.0c-e	1.3b	4.9b-g
TTU-62	2.3a	5.a-c7	6.7c-e	8.0a	8.0c	5.3a-d	2.3b-d	1.0b	4.9b-g
Tatanka	2.0ab	6.0ab	7.7ab	8.0a	8.3bc	4.0c-e	1.0e	1.0b	4.8d-g
Bam-1000	2.0ab	6.0ab	7.0b-d	7.7ab	8.7ab	5.0a-e	1.3de	1.0b	4.8c-g
TTU-46	2.0ab	6.0ab	7.0b-d	7.3bc	8.7ab	3.7de	1.3de	1.0b	4.7e-g
Bison	2.0ab	5.0c	6.3de	8.0a	8.3bc	5.0a-e	2.0c-e	1.0b	4.7d-g
Stampede	1.7bc	5.3bc	6.7c-e	8.0a	8.3bc	4.7b-e	2.0c-e	1.0b	4.7d-g
TTU-94B	1.0d	6.0ab	7.0b-d	7.7ab	8.3bc	5.3a-d	1.3de	1.0b	4.7d-g
TTU-43	1.3cd	6.0ab	7.3a-c	8.0a	8.0c	3.7de	1.0e	1.0b	4.5f-h
UCR-95	1.0d	4.0d	6.0e	7.3bc	8.3bc	5.7a-d	1.3de	1.0b	4.3gh
Midget	2.0ab	5.0c	6.0e	7.3bc	8.0c	2.0e	1.0e	1.0b	4.0h
LSD (0.05)	0.37	0.83	0.83	0.61	0.59	3.04	1.11	0.41	0.60
Coefficient of variation	12.8%	9.0%	7.3%	4.8%	4.3%	31.6%	36.7%	21.5%	7.4%

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

Turfgrass rating = 1=dead or dormant to 9=maximum turfgrass quality

Table 7. Turfgrass quality ratings of 26 cultivars and accessions lines of buffalograss evaluated at Lubbock, TX in 2000.

Cultivar	Turfgrass quality ratings								
	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Avg.
	rating								
TTU-196	2.0a	3.0a-c	6.3ab	6.7ab	6.7ab	7.0a	6.3a	5.3a	5.4a
TTU-227	2.0a	3.3ab	6.3ab	6.7ab	7.0a	6.3ab	6.0ab	5.0ab	5.4a
378	1.7ab	3.7a	6.7a	7.0a	6.3a-c	5.7a-d	5.0a-e	4.0b-d	5.0ab
TTU-12	1.0b	3.0a-c	5.7a-d	6.3a-c	6.7ab	6.0a-c	5.7a-c	5.0ab	4.9ab
Bison	1.7ab	2.7a-d	4.3b-g	5.0a-e	6.3a-c	6.3ab	5.7a-c	4.3a-c	4.6a-c
TTU-232	2.0a	3.7a	6.0a-c	6.0a-d	5.7b-e	5.3b-d	4.7b-e	3.7cd	4.6a-c
Texoka	1.3ab	2.3b-e	5.0a-f	5.3a-e	6.7ab	6.3ab	5.0a-e	4.0b-d	4.5a-c
Cody	1.3ab	2.7a-d	4.7a-g	5.3a-e	6.3a-c	5.7a-d	5.0a-e	4.0b-d	4.4b-d
TTU-175 B	1.3ab	2.3b-e	4.7a-g	5.3a-e	6.3a-c	5.7a-d	5.3a-d	4.3a-c	4.4b-d
TTU-17	1.7ab	3.0a-c	5.3a-e	6.0a-d	5.3c-f	4.7cd	4.3c-e	3.7cd	4.3b-d
TTU-230A	1.3ab	2.7a	5.0a-f	5.0a-e	5.3c-f	5.3b-d	4.3c-e	4.3a-c	4.2b-d
TTU-46	1.0b	2.0c-e	4.3b-g	5.0a-e	6.3a-c	5.7a-d	5.3a-d	4.3a-c	4.2b-d
Bam-1000	1.0b	2.0c-e	3.7d-g	4.3c-f	6.0a-d	6.3ab	5.3a-d	4.0b-d	4.1b-d
91-118	1.0b	3.3ab	5.7a-d	6.0a-d	5.7b-e	4.3d	3.7e	3.3cd	4.1b-d
Stampede	1.7ab	2.7a-d	4.3b-g	4.7b-f	5.0d-f	5.3b-d	5.0a-e	4.0b-d	4.1b-d
609	2.0a	3.0a-c	5.3a-e	5.7a-d	5.7b-e	4.7cd	3.7e	3.0d	4.1b-d
Tatanka	1.7ab	2.3b-e	4.3b-g	4.7b-f	5.7b-e	5.0b-d	4.3c-e	3.7cd	4.0c-e
86-120	1.0b	2.7a-d	5.0a-f	5.3a-e	5.3c-f	4.7cd	4.3c-e	3.7cd	4.0c-e
TTU-84	1.3ab	2.3b-e	4.7a-g	4.7b-f	5.3c-f	5.0b-d	4.7b-e	4.0b-d	4.0c-e
Legacy	1.0b	2.3b-e	4.7a-g	5.3a-e	5.3c-f	4.3d	4.3c-e	3.7cd	3.9c-e
Midget	1.0b	2.0c-e	3.3e-g	4.0d-f	5.3c-f	5.7a-d	5.0a-e	4.3a-c	3.8c-f
TTU-62	2.0a	2.3b-e	4.3b-g	4.3c-f	5.0d-f	4.3d	4.3c-e	3.3cd	3.8c-f
TTU-94B	1.0b	2.3b-e	4.0c-g	4.3c-f	5.0d-f	4.3d	4.0ed	3.3cd	3.5d-f
TTU-43	1.3ab	1.7de	3.3e-g	4.0d-f	4.7e-g	5.0b-d	4.3c-e	3.7cd	3.5d-f
UCR-95	1.0b	1.3e	3.0fg	3.3ef	4.3fg	4.7cd	4.0ed	3.0d	3.1ef
Bonnie Brae	1.0b	1.3e	2.7g	2.7f	3.7g	5.0b-d	4.0ed	3.0d	2.9f
LSD (0.05)	0.77	1.22	2.1	2.1	1.1	1.5	1.5	1.2	0.91
Coefficient of variation	33.4%	29.4%	26.9%	25.0%	12.2%	16.8%	18.9%	19.3%	11.6%

Means within column not followed by the same letter differ at the 0.05 level of probability by Fisher's Least Significant Difference Test.
Turfgrass rating = 1=dead or dormant to 9=maximum turfgrass quality

Table 8. Turfgrass quality ratings of 26 cultivars and accessions of buffalograss evaluated at Lubbock, TX from 1997 to 2000.

Cultivar	Turfgrass quality ratings					
	1997	1998	1999	2000	1997 to 2000	1998 to 2000
	rating					
TTU-227	7.3c-g	8.05a	5.6a	5.4a	6.2a	5.8a
TTU-196	6.5g-k	7.8ab	5.4ab	5.4a	5.9ab	5.7ab
378	6.8e-j	6.8f-k	5.4ab	5.0ab	5.7b-d	5.3bc
TTU-12	6.1h-k	7.2c-g	5.4a-c	4.9ab	5.5b-g	5.3bc
TTU-232	6.2h-k	7.1c-h	5.2a-e	4.6a-c	5.5c-g	5.2cd
TTU-175B	7.7a-e	7.6a-c	5.0b-f	4.4b-d	5.8a-d	5.2c-e
Bison	8.2a-c	7.4b-e	4.7d-g	4.6a-c	5.9ab	5.1c-g
Texoka	8.4a	7.2c-f	4.9b-g	4.5a-c	5.9ab	5.1c-g
609	6.5g-k	7.4b-e	5.3a-d	4.1b-d	5.5c-g	5.1c-f
Cody	8.3ab	7.0d-h	4.9b-f	4.4b-d	5.8a-c	5.0c-h
TTU-17	7.4b-f	6.8f-k	5.1a-f	4.3b-d	5.6b-f	5.0c-h
Bam-1000	8.4a	7.1d-i	4.8c-g	4.1b-d	5.8a-d	4.9d-i
TTU-84	7.9a-d	7.0d-h	5.0b-f	4.0c-e	5.7b-e	4.9c-i
TTU-46	8.0a-c	7.2c-g	4.7e-g	4.2b-d	5.7b-e	4.9d-i
Tatanka	7.9a-d	6.9d-j	4.8d-g	4.0c-e	5.6b-f	4.8e-j
91-118	6.7e-j	6.6i-k	4.9b-g	4.1b-d	5.3e-i	4.8d-i
Legacy	6.7e-j	6.8f-k	5.1a-f	3.9c-e	5.3f-h	4.8d-j
TTU-230A	8.1a-c	6.7g-k	4.9b-g	4.2b-d	5.6b-f	4.8d-j
86-120	6.9d-i	6.4kl	5.0b-f	4.0c-e	5.3f-j	4.7f-k
Stampede	6.1h-k	6.7g-k	4.7d-g	4.1b-d	5.1h-j	4.7g-k
TTU-94B	7.7a-e	7.3b-d	4.7d-g	3.5d-f	5.4d-h	4.7f-k
TTU-62	6.0i-k	6.5j-l	4.9b-g	3.8c-f	5.0i-k	4.7h-k
Midget	7.0d-h	7.1c-h	4.0h	3.8c-f	5.2g-j	4.6h-k
Bonnie Brae	6.3g-k	6.6h-k	5.0b-f	2.9f	4.9i-k	4.5jk
UCR-95	5.9jk	7.5a-d	4.3gh	3.1ef	4.9jk	4.5h-k
TTU-43	5.6k	6.01	4.5f-h	3.5d-f	4.6k	4.3k
LSD (0.05)	0.95	0.42	0.60	0.91	0.37	0.40
Coefficient of variation	8.2%	4.4%	7.4%	11.6%	4.1%	5.0%

Means within column not followed by the same letter differ at the 0.05 level of probability by Fisher's Least Significant Difference Test.
Turfgrass rating = 1=dead or dormant to 9=maximum turfgrass quality

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Emergence and Height of Plants Seeded in Crude Oil Contaminated Soil

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ABSTRACT

Accidental contamination of soils with petroleum hydrocarbons results from oil production and shipping. Growing plants in these soils may enhance the rate and extent of remediation of these soils reducing their potential to contaminate surface and ground water. The objective of this study was to identify plants that are native, naturalized, or that have been successfully introduced to north central Texas which will emerge and grow in crude oil contaminated soil. A greenhouse study was conducted in seed flats with the dimensions of 55 x 28 x 3.2 cm (L x W x H) containing 20 individual rows. Rows were filled with a Windthorst sandy clay loam soil amended with 0 (control), 0.5, 5, or 10% unweathered crude oil (soil dry weight basis). Soil moisture was maintained near – 30kPa. Nineteen plant varieties were seeded in separate rows at a rate of ten seeds per row. Treatments were conducted in triplicate in a completely randomized design. Emergence and plant height were measured on days 7, 14, 21, and 28. After 28 days emergence had decreased by 79%, 90%, and 98% in soils with 0.5%, 5%, and 10% respectively when compared to controls. Decreases in plant height were 72%, 86% and 96% in soils with 0.5%, 5% and 10% crude oil respectively. Plant species with the greatest emergence and plant height in soil with crude oil were Kenaf #2 (*Hisbiscus cannabinus* var. *tainvng #2*) and Kenaf #3 (*Hisbiscus cannabinus* var. *sf 459*), which were the only seedlings that emerged in the treatment with 10% crude oil. These two varieties are recommended for use on crude oil spills of 10% or less (soil dry weight basis) in north central Texas. Delaying seeding for a few days following a spill and tilling the contaminated soil may remove toxic volatile components of the crude oil from soil and improve seedling emergence, plant growth, and enhance phytoremediation.

KEYWORDS: Germination, Survival, Bioremediation, Phytoremediation, Petroleum Hydrocarbons

INTRODUCTION

Texas leads the United States in crude oil production. According to the year 2000 statistics, Texas has approximately 160,000 oil wells that annually produce over 400,000,000 barrels of oil. (Railroad Commission of Texas, 2001). Due the high level of production in the state, there is an increased risk of accidental contamination of soil from production and shipping. Contaminated soils are an environmental concern because it is a potential

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source for surface and ground water contamination that can endanger humans, wildlife, and area vegetation. The soils in areas of contamination require remediation to return them to a non-hazardous state. Remediation often involves excavation and transporting contaminated soil to an incinerator or landfill. However these options are relatively expensive. The cost to remediate one ton of soil by incineration is $200-1500 while landfilling ranges from $100 – 400 (Schnoor, 1997). Another remediation option is to treat the contaminated soil on-site. This remediation technique is much less expensive and typically cost between $10-35 per ton (Schnoor, 1997). One type of on-site remediation uses plants, which is called phytoremediation, and has been described as an economic, potentially effective, low-maintenance approach to treating soils contaminated with crude oil (Banks et al., 2000).

Phytoremediation is still a relatively new technology, but has been shown to enhance the disappearance of crude oil from soil. A study in Germany found ryegrass significantly reduced the concentration of petroleum hydrocarbons compared to an unvegetated control in a laboratory study (Günther, 1996) and in a field study phytoremediation significantly accelerated the disappearance of petroleum hydrocarbons compared to unvegetated controls (Schwab and Banks, 1999). However, phytoremediation is not always successful. In field lysimeters, phytoremediation using Johnsongrass, ryegrass, and a Johnsongrass-ryegrass rotation did not enhance the disappearance of a mixture of hydrocarbons from soil (Corapcioglu et al., 1999). A limitation of phytoremediation is that plant emergence and growth can be inhibited by contaminants. For example germination of tall fescue decreased from approximately 85% in uncontaminated soil to 35% in a nutrient solution containing 60 mg TNT L^{-1} while shoot growth decreased from 4.4 mm d^{-1} to approximately 0.2 mm d^{-1} (Peterson et al., 1996). For phytoremediation to be successful there is a need to identify plants that are capable of growing in crude oil contaminated soil.

The objective of this study was to identify plants that are native, naturalized, or that have been successfully introduced to north central Texas which will emerge and grow in crude oil contaminated soil.

MATERIALS AND METHODS

A Windthorst sandy clay loam soil (Fine, mixed, thermic Udic Paleustalfs) with no known history of crude oil contamination was selected for this study (Table 1). This soil was collected from the Tarleton State University Hunewell Ranch near Stephenville, TX. The soil was air dried and passed through a 2-mm sieve. Soil organic matter content was determined by the Walkley-Black method (Nelson and Sommers, 1982). Soil pH was measured from a 1:1 soil to distilled water solution using a glass electrode and pH meter (McLean, 1982). Particle size distribution was measured by the hydrometer method (Gee and Bauder, 1986).

Table 1. Physicochemical properties of a Windthorst sandy clay loam soil.

Sand[1]	Silt[1]	Clay[1]	OC[2]	pH[3]
%	%	%	%	
50	20	30	2.63	7.2

[1] Hydrometer method

[2] Organic carbon

[3] pH meter using 1:1 soil:distilled H_2O ratio

Experiments were conducted in a greenhouse. Experimental units consisted of 20-row seed flats filled with contaminated soil in every other row. Soil was contaminated with 0 (control), 0.5, 5, or 10% north central Texas Crude oil that was unweathered. The total petroleum hydrocarbon content, considered the toxic portion of the crude oil was found to be 80.7% using EPA method 418.1 modified for soil (EPA, 1979). Plants that thrive in north central Texas were selected for this study (Table 2). Seeds were obtained from Turner Seeds of Breckenridge, TX and from the Texas A&M University Stephenville Research and Extension Center. Plants were seeded at a rate of 10 seeds per row. One species was seeded per row. Seeds were sown from just below the soil surface to approximately 2 cm deep with the larger seeds being sown at the deepest depth. Soils were kept at near field capacity (-30 kPa) by subsurface irrigation. Treatments were completely randomized and conducted in triplicate. The number of emerged seed and plant height were measured on days 7, 14, 21, and 28. Means emergence and plant height were separated using Duncan's multiple range test with means considered significantly different at $\alpha = 0.05$.

Table 2. Species screened to identify emergence and growth as measured by plant height in crude oil contaminated soil

Scientific Name	Common Name
Armadillo burr medic	*Medicago polymorpha*
Buffalograss	*Buchloe dactyloides* var. *texoka*
Hairy vetch	*Vicia villosa*
Hubam sweet clover	*Melilotus albus*
Illinois bundle flower	*Desmanthus illinoensis*
Johnsongrass	*Sorghum halepense*
Kenaf #2	*Hisbiscus cannabinus* var. *tainvng #2*
Kenaf #3	*Hisbiscus cannabinus* var. *sf 459*
Lablab	*Lablab purpureus*
Laredo soybean	*Glycine max* var. *laredo*
Madrid yellow clover	*Melilotus* sp.
Morning glory	*Ipomoea* sp.
Rose Clover	*Trifolium hirtum*
Sorghum triumph	*Sorghum bicolor* var. *triumph*
Sunflower macro	*Helianthus annuus* var. *macrocarpus*
Sunflower mammoth	*Helianthus annuus* var. *mammoth*
Sunflower maximillian	*Helianthus maximiliani*
Tall Jose wheatgrass	*Agropyron elongatum*
Ragweed	*Ambrosia psilostachya*

RESULTS

Emergence

Increasing the soil's concentration of unweathered crude oil from 0 to 10% significantly decreased seedling emergence of the 19 plant species (Tables 3-6). Plant emergence was highly variable across plant species. For example, 76.7% of the Sorghum triumph seeds emerged and were still surviving 28 days after planting compared to 26.7% for Lablab in the controls (Table 6). In the 0.5% crude oil treatment emergence was reduced by approximately 80% relative to the control during the 28 days after planting and only 9 of the species emerged. The treatment with 5% crude oil decreased emergence by approximately 90% relative to the control and the number of species emerging was 6. In the 10% crude oil treatments, emergence decreased by approximately 98% relative to the control and only two species, Kenaf #2 and Kenaf #3, emerged.

In the 0.5% crude oil treatment, Kenaf #2 had the greatest percentage seedling emergence (Tables 3-6). Kenaf #2 emergence was 36.7% on day 7 and remained at that percentage during the remainder of the 28 day experiment. Kenaf #3 had the second greatest percentage emergence of 23.3%, which was observed at each time period. Lablab also had 23.3% germination on day 7 and 28, but was 20.0% on day 14 and 21

Table 3. Seedling emergence 7 days after seeding in crude oil contaminated soil.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	Emergence (% of sown seeds)[b]						
Kenaf #2	20.0 cdfg	36.7a	13.3a	0.0	28.6	-2.86	0.76
Lablab	30.0 bcd	23.3b	13.3a	0.0	27.3	-2.76	0.97
Kenaf #3	26.7 bcdf	23.3b	3.3ab	0.0	23.9	-2.74	0.88
Sunflower mammoth	26.7 bcdf	16.6bc	3.3ab	0.0	20.9	-2.39	0.82
Laredo soybean	13.3 dfgh	3.3d	3.3ab	0.0	8.48	-0.91	0.54
Tall Jose wheatgrass	60.0 a	6.7cd	0.0b	0.0	31.8	-3.91	0.39
Johnsongrass	6.7 gh	3.3d	0.0b	0.0	4.71	-0.57	0.69
Sorghum triumph	63.3 a	0.0d	0.0b	0.0	30.4	-3.76	0.31
Sunflower macro	35.0 bc	0.0d	0.0b	0.0	16.8	-2.08	0.31
Morning glory	40.0 b	0.0d	0.0b	0.0	19.2	-2.38	0.31
Hubam sweet clover	36.7 bc	0.0d	0.0b	0.0	17.6	-2.18	0.31
Illinois bundle fllower	13.3 dfgh	0.0d	0.0b	0.0	6.39	-0.79	0.31
Buffalograss	33.3 bc	0.0d	0.0b	0.0	16.0	-1.98	0.31
Hairy vetch	13.3 dfgh	0.0d	0.0b	0.0	6.39	-0.79	0.31
Madrid yellow clover	13.3 dfgh	0.0d	0.0b	0.0	6.39	-0.79	0.31
Armadillo burr medic	10.0 fgh	0.0d	0.0b	0.0	4.80	-0.59	0.31
Rose clover	6.7 gh	0.0d	0.0b	0.0	4.80	-0.40	0.31
Ragweed	3.3 gh	0.0d	0.0b	0.0	1.59	-0.20	0.31
Sunflower max	0.0 h	0.0d	0.0b	0.0	na	-0.00	na
Average	23.8	6.0	1.9	0.0	14.5	-1.69	0.53
Average decrease in emergence relative to control	——	74.9	91.9	100.0			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 4. Seedling emergence 14 days after seeding in crude oil contaminated soil.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	Emergence (% of sown seeds)[b]						
Kenaf #3	26.7def	23.3b	10.0b	6.7a	24.4	-1.99	0.90
Kenaf #2	26.7def	36.7a	23.3a	0.0b	33.6	-3.09	0.86
Lablab	26.7def	20.0b	10.0b	0.0b	23.7	-2.45	0.96
Sunflower mammoth	26.7def	6.7cd	3.3c	0.0b	16.4	-1.88	0.53
Sorghum triumph	76.7a	0.0d	3.3c	0.0b	37.4	-4.50	0.31
Tall Jose wheatgrass	63.3ab	13.3bc	0.0c	0.0b	36.4	-4.45	0.48
Laredo soybean	53.3bc	6.7cd	0.0c	0.0b	28.6	-3.52	0.41
Sunflower macro	35.0de	3.3cd	0.0c	0.0b	18.3	-2.25	0.38
Johnsongrass	20.0efg	3.3cd	0.0c	0.0b	11.1	-1.36	0.44
Morning glory	40.0cd	0.0d	0.0c	0.0b	19.2	-2.38	0.31
Buffalograss	40.0cd	0.0d	0.0c	0.0b	19.2	-2.38	0.31
Hubam sweet clover	36.7cd	0.0d	0.0c	0.0b	17.6	-2.18	0.31
Hairy vetch	20.0efg	0.0d	0.0c	0.0b	9.61	-1.19	0.31
Madrid yellow clover	13.3fgh	0.0d	0.0c	0.0b	6.39	-0.79	0.31
Armadillo burr medic	13.3fgh	0.0d	0.0c	0.0b	6.39	-0.79	0.31
Illinois bundle fllower	13.3fgh	0.0d	0.0c	0.0b	6.39	-0.79	0.31
Sunflower max	6.7gh	0.0d	0.0c	0.0b	6.39	-0.79	0.31
Rose clover	6.7gh	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Ragweed	3.3h	0.0d	0.0c	0.0b	1.59	-0.20	0.31
Average	28.9	6.0	2.6	0.4	14.4	-1.69	0.48
Average decrease in emergence relative to control	——	79.3	90.9	98.8			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 5. Seedling emergence 21 days after seeding in crude oil contaminated soil.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	Emergence (% of sown seeds)[b]						
Kenaf #2	2.67 def	36.7a	23.3a	3.3ab	33.3	-2.78	0.85
Kenaf #3	23.3 ef	23.3b	13.3b	6.7a	23.4	-1.73	0.98
Sunflower mammoth	26.7def	6.7cd	3.3c	0.0b	16.4	-1.88	0.53
Sunflower macro	40.0 cd	3.3cd	3.3c	0.0b	21.3	-2.49	0.38
Johnsongrass	26.7 def	3.3cd	3.3c	0.0b	14.9	-1.70	0.41
Sorghum triumph	76.7 a	0.0d	3.3c	0.0b	37.4	-4.50	0.31
Lablab	26.7 def	20.0b	0.0c	0.0b	21.8	-2.62	0.79
Tall Jose wheatgrass	63.3 ab	13.3bc	0.0c	0.0b	36.4	-4.45	0.48
Laredo soybean	53.3 bc	6.7cd	0.0c	0.0b	28.6	-3.51	0.40
Madrid yellow clover	36.7 de	3.3cd	0.0c	0.0b	19.1	-2.35	0.38
Buffalograss	70.0 a	0.0d	0.0c	0.0b	33.6	-4.16	0.31
Morning glory	40.0 cd	0.0d	0.0c	0.0b	19.2	-2.38	0.31
Armadillo burr medic	20.0 fg	0.0d	0.0c	0.0b	9.61	-1.19	0.31
Hairy vetch	16.7 fgh	0.0d	0.0c	0.0b	8.02	-0.99	0.31
Illinois bundle flower	13.3 fgh	0.0d	0.0c	0.0b	6.39	-0.79	0.31
Rose clover	6.7 gh	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Sunflower max	6.7 gh	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Ragweed	6.7 gh	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Hubam sweet clover	3.4 h	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Average	30.7	6.1	2.6	0.5	1.63	-0.20	0.47
Average decrease in emergence relative to control	——	80.0	91.5	98.3			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 6. Seedling emergence 28 days after seeding in crude oil contaminated soil.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	Emergence (% of sown seeds)[b]						
Kenaf #2	26.7def	36.7a	30.0a	6.7a	34.1	-2.34	0.71
Kenaf #3	23.3ef	23.3b	10.0b	6.7a	22.7	-1.79	0.91
Rose clover	6.7g	0.0d	6.7bc	0.0b	4.4	-0.28	0.11
Johnsongrass	26.7def	6.7cd	3.3bc	0.0b	16.4	-1.88	0.53
Sunflower macro	40.0cd	3.3d	3.3bc	0.0b	21.3	-2.49	0.38
Sorghum triumph	76.7a	0.0d	3.3bc	0.0b	37.4	-4.50	0.31
Lablab	26.7def	23.3b	0.0c	0.0b	23.3	-2.79	0.81
Tall Jose wheatgrass	50.0c	13.3c	0.0c	0.0b	30.0	-3.66	0.52
Sunflower mammoth	26.7def	6.7cd	0.0c	0.0b	15.8	-1.93	0.51
Laredo soybean	53.3bc	3.3d	0.0c	0.0b	27.1	-3.34	0.35
Buffalograss	66.7ab	0.0d	0.0c	0.0b	32.0	-3.96	0.31
Morning glory	40.0cd	0.0d	0.0c	0.0b	19.2	-2.38	0.31
Madrid yellow clover	33.3de	0.0d	0.0c	0.0b	16.0	-1.98	0.31
Armadillo burr medic	20.0efg	0.0d	0.0c	0.0b	9.61	-1.19	0.31
Hairy vetch	16.7fg	0.0d	0.0c	0.0b	8.02	-0.99	0.31
Hubam sweet clover	15.0fg	0.0d	0.0c	0.0b	7.21	-0.89	0.31
Sunflower max	6.7g	0.0d	0.0c	0.0b	7.21	-0.89	0.31
Ragweed	6.7g	0.0d	0.0c	0.0b	3.22	-0.40	0.31
Illinois bundle flower	5.0g	0.0d	0.0c	0.0b	2.40	-0.30	0.31
Average	29.8	6.1	3.0	0.7	17.5	-1.97	0.47
Average decrease in emergence relative to control	——	79.4	90.0	97.6			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

In the treatments with 5% crude oil, Kenaf #2 had the largest percentage germination during the 28 days after planting (Tables 3-6). Its germination percentage on days 7, 14, and 21 was 23.3%, which increased to 30.0% on day 28. Kenaf #3 had the second greatest percentage emergence on days 14, 21, and 28 with 10, 13.3, and 10 % emergence respectively. Lablab had the third highest percent emergence with 13.3 and 10 % on days 7 and 14 respectively. However, it was unable to survive in the 5% crude oil treatment and died by day 21.

Only the two Kenaf varieties emerged in the treatments with 10% crude oil (Tables 3-6). Their emergence was delayed relative to the control treatment as neither one had emerged on day 7. By day 14, 6.7% of Kenaf #3 had emerged where it remained for the duration of the experiment. Kenaf #2 first showed emergence on day 21 with 3.3%, which increased to 6.7% on day 28.

Linear regression was fit to the data to show correlations between soil crude oil concentration and emergence (Tables 3-6). In general, correlation (r^2) shows a good fit for treatments where emergence was observed in contaminated soil. For example, the correlation coefficient for Kenaf #2 and Kenaf #3 was 0.71 and 0.91 respectively on day 28 (Table 6). Correlation was poor for varieties that did not emerge in oil contaminated soil. Slopes (ß) of the regression lines are shown in Tables 3-6 for each plant species and may be useful in predicting emergence of a given species in soil with a known crude oil content.

Plant Height

Plant height decreased as the crude oil content of soil increased (Tables 7-10). For example, when averaging plant height across all plant species and comparing soil treated with 0.5, 5 or 10% crude oil to controls, plant height decreased by 72.0, 75.0, and 96.2 % respectively.

Plant species with the greatest plant height varied during the 28 day trial (Tables 7-10). In the treatments with 0.5% crude oil, Lablab showed the greatest plant height followed by Kenaf #2 and Sunflower mammoth. On day 7, in treatments with 5% crude oil, plant height was greatest in Lablab followed by Kenaf #3 and Kenaf #2. On day 14, Lablab and Kenaf #2 had the tallest plant height followed by Kenaf #3. Although Lablab had the greatest height on day 14, it had only grown 3 mm during the previous 7 days and its leaves were becoming necrotic. Lablab died in the 5% treatment by day 21, resulting in Kenaf #2 having the greatest height followed by Kenaf #3 and Sorghum triumph. This order remained through day 28. Only the two Kenaf varieties were able to grow in the 10% crude oil treatment. By day 14, Kenaf #3 was the only species to grow in the 10% crude oil treatment, but by day 21 Kenaf #2 had also emerged and had the greatest plant height through day 28.

A fitted regression analysis, plotting crude oil content vs. plant height, showed good correlation for most species that germinated in crude oil contaminated soils. For example the correlation coefficient (r^2) for Kenaf #2 ranged from 0.68 (day 28) to 0.93 (day 14). Slopes (ß) of the regression lines are shown in Tables 7-10 for each plant species and may be useful in predicting plant height of a given species growing in soil with a known crude oil content.

DISCUSSION

Because Texas law considers soils with 5% petroleum hydrocarbons or less no longer in need of remediation, some reduction in seedling emergence and plant height was expected, but not to the extent that was found. Other studies have observed more modest reductions in emergence (Salanitro et al., 1997, Günther et al., 1996, and Banks et al., 2000). A likely explanation for the low seedling emergence and plant height was the use of unweathered crude oil in this study. Commonly in lab studies, crude oil is heated to artificially weather the crude oil, which removes the more volatile fraction, including

Table 7. Influence of soil crude oil concentration on plant height 7 days after seeding.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	PlantHeight (mm)[b]						
Lablab	41.8a	49.1a	45.0a	0.0	50.4	-4.25	0.75
Kenaf #3	20.7cde	20.1c	16.3b	0.0	22.0	-1.99	0.91
Kenaf #2	22.5bcd	39.5b	10.5b	0.0	30.5	-3.20	0.77
Sunflower mammoth	43.2a	32.3b	3.3c	0.0	35.9	-4.18	0.83
Tall Jose wheatgrass	28.3bcd	9.7d	0.0c	0.0	18.0	-2.18	0.58
Johnsongrass	9.3efg	7.0de	0.0c	0.0	7.62	-0.92	0.79
Laredo soybean	9.4efg	1.7de	0.0c	0.0	5.28	-0.65	0.45
Sorghum triumph	34.4ab	0.0e	0.0c	0.0	16.5	-2.04	0.31
Morning glory	31.8abc	0.0e	0.0c	0.0	15.3	-1.89	0.31
Sunflower macro	26.6bcd	0.0e	0.0c	0.0	12.8	-1.58	0.31
Hairy vetch	17.0def	0.0e	0.0c	0.0	8.17	-1.01	0.31
Hubam sweet clover	8.3efg	0.0e	0.0c	0.0	3.99	-0.49	0.31
Madrid yellow clover	7.1fg	0.0e	0.0c	0.0	3.41	-0.42	0.31
Illinois bundle flower	6.9fg	0.0e	0.0c	0.0	3.31	-0.41	0.31
Armadillo burr medic	5.9fg	0.0e	0.0c	0.0	2.83	-0.35	0.31
Buffalograss	5.0fg	0.0e	0.0c	0.0	2.40	-0.30	0.31
Ragweed	5.0fg	0.0e	0.0c	0.0	2.40	-0.30	0.31
Rose clover	3.8g	0.0e	0.0c	0.0	1.83	-0.23	0.31
Sunflower max	0.0g	0.0e	0.0c	0.0	na	na	na
Average	17.2	8.4	4.0	0.0			0.77
Average decrease in height relative to control	—	50.7	75.0	100.0			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 8. Influence of soil crude oil concentration on plant height 14 days after seeding.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] $ß_0$	$ß_1$	r^2
	PlantHeight (mm)[b]						
Kenaf #3	55.3de	28.6d	30.0b	4.8a	44.4	-3.80	0.74
Lablab	106.8b	90.8a	48.0a	0.0a	101.0	-10.2	0.99
Kenaf #2	61.0de	58.5b	46.1a	0.0a	64.1	-5.86	0.93
Sorghum triumph	148.6a	0.0f	10.7c	0.0a	73.3	-8.65	0.31
Sunflower mammoth	118.2b	54.8b	3.3d	0.0a	82.1	-9.81	0.68
Laredo soybean	80.3c	35.8cd	0.0d	0.0a	54.7	-6.63	0.66
Sunflower macro	111.8b	32.7d	0.0d	0.0a	68.4	-8.34	0.54
Tall Jose wheatgrass	65.7cd	17.0e	0.0d	0.0a	39.2	-4.79	0.52
Johnsongrass	30.4fg	11.7e	0.0d	0.0a	19.9	-2.41	0.61
Morning glory	78.3c	0.0f	0.0d	0.0a	37.6	-4.65	0.31
Hairy vetch	47.0ef	0.0f	0.0d	0.0a	22.6	-2.80	0.31
Illinois bundle flower	24.4gh	0.0f	0.0d	0.0a	11.7	-1.45	0.31
Madrid yellow clover	19.6ghi	0.0f	0.0d	0.0a	9.41	-1.17	0.31
Buffalograss	15.2ghi	0.0f	0.0d	0.0a	7.30	-0.90	0.31
Hubam sweet clover	15.2ghi	0.0f	0.0d	0.0a	7.30	-0.90	0.31
Armadillo burr medic	9.7hi	0.0f	0.0d	0.0a	4.66	-0.58	0.31
Ragweed	8.0hi	0.0f	0.0d	0.0a	3.84	-0.48	0.31
Rose clover	8.0hi	0.0f	0.0d	0.0a	3.84	-0.48	0.31
Sunflower max	5.7i	0.0f	0.0d	0.0a	2.74	-0.34	0.31
Average	53.1	17.4	7.3	0.3	34.6	-3.90	0.60
Average decrease in height relative to control		67.3	86.3	99.5			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 9. Influence of soil crude oil concentration on plant height 21 days after seeding.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] β_0	β_1	r^2
	PlantHeight (mm)[b]						
Kenaf #2	86.0d	81.2b	87.7a	22.7a	91.4	-5.67	0.72
Kenaf #3	80.3de	34.5cd	57.1b	20.3a	62.3	-3.67	0.42
Sorghum triumph	222.7a	0.0f	34.3c	0.0b	113.3	-12.6	0.30
Sunflower macro	167.4bc	43.7c	18.3d	0.0b	103.5	-11.9	0.54
Sunflower mammoth	169.0b	70.8b	6.0e	0.0b	114.2	-13.6	0.65
Johnsongrass	55.0ef	17.0df	6.0e	0.0b	35.2	-4.04	0.58
Lablab	144.3bc	115.3a	0.0f	0.0b	121.3	-14.5	0.80
Laredo soybean	157.1bc	71.7b	0.0f	0.0b	107.8	-13.1	0.66
Tall Jose wheatgrass	80.5de	19.1cdf	0.0f	0.0b	47.3	-5.78	0.50
Madrid yellow clover	25.5gh	3.0f	0.0f	0.0b	13.6	-1.67	0.40
Morning glory	146.6bc	0.0f	0.0f	0.0b	70.4	-8.71	0.31
Hairy vetch	137.3c	0.0f	0.0f	0.0b	66.0	-8.16	0.31
Illinois bundle flower	41.2fg	0.0f	0.0f	0.0b	19.8	-2.45	0.31
Buffalograss	27.6fgh	0.0f	0.0f	0.0b	13.3	-1.64	0.31
Hubam sweet clover	23.9gh	0.0f	0.0f	0.0b	11.5	-1.42	0.31
Ragweed	20.7gh	0.0f	0.0f	0.0b	9.94	-1.23	0.31
Sunflower max	12.7gh	0.0f	0.0f	0.0b	6.10	-0.75	0.31
Rose clover	12.5gh	0.0f	0.0f	0.0b	6.00	-0.74	0.31
Armadillo burr medic	10.4h	0.0f	0.0f	0.0b	5.00	-0.62	0.31
Average	85.3	24.0	11.0	2.3	53.4	-5.91	0.54
Average decrease in height relative to control	——	71.8	87.1	97.3			

[a]Constant (β_0), slope (β_1), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Table 10. Influence of soil crude oil concentration on plant height 28 days after seeding.

Plant Species	Crude Oil (%) 0	0.5	5	10	Regression[a] β_0	β_1	r^2
	PlantHeight (mm)[b]						
Kenaf #2	110.9d	100.9b	112.0a	46.3a	114.0	-5.53	0.68
Kenaf #3	111.8d	40.1cde	75.5b	28.5b	82.3	-4.74	0.34
Sorghum triumph	250.2a	0.0f	42.0c	0.0c	127.9	-14.1	0.30
Sunflower macro	215.0b	52.7	34.3c	0.0c	133.3	-14.9	0.53
Johnsongrass	84.9e	32.0de	9.7d	0.0c	57.0	-6.54	0.64
Rose clover	20.8f	0.0f	9.3d	0.0c	11.7	-1.08	0.26
Lablab	148.0c	174.7a	0.0d	0.0c	149.8	-17.8	0.79
Sunflower mammoth	208.2b	87.0b	0.0d	0.0c	139.2	-16.9	0.64
Laredo soybean	208.3b	43.3cd	0.0d	0.0c	119.6	-14.6	0.47
Tall Jose wheatgrass	105.5de	22.8e	0.0d	0.0c	61.0	-7.45	0.48
Morning glory	168.7c	0.0f	0.0d	0.0c	81.0	-10.0	0.31
Hairy vetch	148.8c	0.0f	0.0d	0.0c	71.5	-8.85	0.31
Buffalograss	37.2f	0.0f	0.0d	0.0c	17.9	-2.21	0.31
Illinois bundle flower	37.0f	0.0f	0.0d	0.0c	17.8	-2.20	0.31
Madrid yellow clover	35.5f	0.0f	0.0d	0.0c	17.1	-2.11	0.31
Sunflower max	27.7f	0.0f	0.0d	0.0c	13.3	-1.65	0.31
Ragweed	25.7f	0.0f	0.0d	0.0c	12.3	-1.53	0.31
Hubam sweet clover	19.8f	0.0f	0.0d	0.0c	9.51	-1.18	0.31
Armadillo burr medic	14.6f	0.0f	0.0d	0.0c	7.01	-0.86	0.31
Average	104.1	29.1	14.9	3.9	65.4	-7.07	0.53
Average decrease in height relative to control		72.0	85.7	96.2			

[a]Constant (β_0), slope (β_1), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

many of the phytotoxic compounds found in crude oil (Rhykerd et al., 1998, Rhykerd et al., 1999). By not weathering the crude oil used in this study, exposure of seeds to this volatile fraction of crude oil may have reduced emergence relative to other studies.

The crude oil contaminated soil in this study drastically reduced plant growth. This increases the time required to establish a plant canopy, which is an important component of successful phytoremediation. The plant canopy decreases the impact of raindrops on soil and reduces the potential of surface runoff and erosion that can contribute to surface water contamination (Cunningham et al., 1995).

Delaying seeding following crude oil spills and tilling contaminated soils may improve seedling emergence, plant growth, and enhance remediation. Delaying seeding may enhance seedling emergence because the majority of volatile compounds, many of which are phytotoxic, escape from soil within 24-48 hours following a spill. Additionally, tillage, which has been shown to increase bioremediation of crude oil contaminated soils (Rhykerd et al., 1999), may further enhance the removal of volatile compounds from soil exposing volatile compounds that had been trapped in the soil.

CONCLUSIONS

Vegetative cover on contaminated soil is necessary to promote phytoremediation and reduce surface runoff and erosion. However, this study found seedling emergence and plant height were significantly reduced in soils with increasing crude oil content. Of all the species tested in this study, Kenaf #2 (*Hisbiscus cannabinus* var. *tainvng #2*) and Kenaf #3 (*Hisbiscus cannabinus* var. *sf 459*) showed the greatest seedling emergence and plant height. These species are therefore recommended for use to establish vegetation and promote phytoremediation on soils with up to 10% crude oil contamination. To improve seedling emergence and plant growth, it is recommended that following a spill, seeding be delayed to allow for volatilization of a majority of the phytotoxic fraction of crude oil. Tilling the contaminated soil during this delay is further recommended to enhance the rate and extent of volatilization.

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Combined Effects of Dietary Carbohydrates and Preslaughter Flushing with Magnesium Sulfate on Cecal Coliform Colonization in Chicks

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ABSTRACT

Day-old broiler chicks were fed a corn-soybean meal based diet containing either 2% lactose or 0.05% mannanoligosaccharide (MOS) per kg of feed. Lactose-fed chicks at 7 and 14 d of age had significantly fewer cecal coliforms ($\log_{10}$ 3.90 cfu/mL) than MOS-fed ($\log_{10}$ 4.57 cfu/mL) and untreated control chicks ($\log_{10}$ 5.88 cfu/mL). Chicks at 21 d of age were given magnesium sulfate ($MgSO_4$) in the drinking water for 12 h prior to sacrifice. Chicks given MOS followed by $MgSO_4$ in the drinking water had fewer cecal coliforms (cfu mL) than chicks in the remaining treatment groups. Compared to the other treatments the combination of MOS and $MgSO_4$ resulted in greater reduction in cecal bacterial population in pre-slaughter chicks at 21 d of age.

KEYWORDS: Lactose, Mannanoligosaccharide, Coliforms, Magnesium sulfate, Chicks

INTRODUCTION

Control of intestinal foodborne pathogens continues to be of interest to poultry producers and researchers. Among the foodborne pathogens *Salmonella* and *Campylobacter spp* (especially *Campylobacter jejuni*) are among the most important pathogenic organisms (White et al., 1999; Saleha et al., 1998). *Salmonella* contamination of processed poultry and meat products has been shown in some cases to be as high as 35% (Houston, 1987). In 1998, 849 cases of campylobacteriosis were reported in Georgia (Georgia Department of Human Resources, 1999). *Campylobacter* has been associated with poultry carcasses and poultry products that have been processed further (White et al., 1999; Saleha et al., 1998). Despite advances in processing and storage practices, consumer concerns have not diminished in recent years regarding the contamination of processed poultry meat by *Salmonella typhimurium* and *Campylobacter*.

Studies conducted with pigs and mice stated that in order for enteric pathogens to colonize the gastrointestinal (GI) tract, they must first be able to gain attachment to mucosal epithelial cell surfaces within the GI tract where they can grow to sufficient numbers to produce clinical signs of the disease (Oyofo et al., 1989).

Interference with the ability of bacteria to adhere to epithelial cells has been shown, *in vitro* as well as *in vivo*, to prevent bacterial colonization and subsequent pathogenesis (Fuller, 1978). If attachment does not occur, the organisms are expelled by mucous secretions and by peristalsis (Morton, 1993). The adherence of pathogens to the intestinal wall can be inhibited by different sugars (Oyofo et al., 1989). Lactose (Corrier et al., 1990), mannanoligosaccharide (MOS)[7] (Sisak, 1994) and mannose (Oyofo et al. 1989) as feed additives or in the drinking water have been shown to reduce enteric pathogen colonization.

The movement of the unattached bacteria from the GI tract depends on the viscosity of the contents. Bedford et al. (1991) demonstrated that weight gain in broiler chicks correlated closely with the reduction in intestinal viscosity. Magnesium sulfate, a mild and inexpensive laxative, reduces intestinal viscosity and is closely correlated with the reduction of colifoms in cecal and colon contents of broiler chicks (Stanley et al., 1991). The objective of the present study was to examine the combined effects of lactose and MOS, followed by pre-slaughter flushing of the GI tract with $MgSO_4$, on the reduction of cecal coliform bacterial population in broiler chicks.

MATERIALS AND METHODS

A total of 360, 1-day-old male broiler chicks (Cornish Rocks) were obtained from a local commercial hatchery. The chicks were divided into three treatment groups of 40 chicks per group with each treatment group replicated three times. The chicks were maintained in wire cages with incandescent lighting and were fed a commercial, unmedicated corn-soybean meal-based diet. The diet contained or exceeded levels of critical nutrients recommended by the National Research Council (NRC, 1994). The birds were not inoculated with *Salmonella*; however, evaluation for *Salmonella* was made on the cecal contents. MOS [7](Alltech Biotechnology Laboratory, Lexington, Kentucky) was added at 0 and 0.05%/kg of feed for three treatment replications. Lactose was applied at 0 and 2%/kg of feed to three additional replicate groups. Chicks in the three replicates remaining (control) did not receive either lactose or MOS[7] in the feed.

Ten chicks, 7 and 14 d of age, respectively, were randomly selected from each treatment group and sacrificed by cervical dislocation. Ceca were removed aseptically and the contents were collected, weighed wet, serially diluted in 9 mL of bacterial free distilled water, and plated. Coliform counts were obtained by using pour plates of plate count agar (PCA) that were overlaid with violet red bile agar [Food and Drug Administration (FDA), 1984]. The numbers of colony forming units (CFU) were determined after the plates were incubated aerobically at 35 C for 12 h. Isolation and identification of coliform bacteria were completed using methods described by the FDA (1984).

At 21 d of age the remaining 20 chicks in each group were divided into two groups of 10 and given $MgSO_4$ in the drinking water at 0 or 5.5 g/liter for 12 h before the chicks were sacrificed (Stanley et al., 1991). Chicks receiving the $MgSO_4$-free water in each treatment group were used as control groups. The chicks were weighed before being treated with $MgSO_4$ and before they were sacrificed to evaluate the effect of $MgSO_4$ on body weight.

Data on cecal bacterial population were transformed to logarithms and subjected to a one-way analysis of variance using general linear models procedures as programed by SAS software (SAS Institute, 1988). Duncan's multiple range test (Duncan, 1955) was conducted to detect differences between means ($P< 0.05$).

RESULTS AND DISCUSSION

At 7 d of age chicks given a diet containing 2% lactose/kg of feed had 1.20 log units fewer (P < 0.05) cecal coliforms than did ceca from control chicks, whereas chicks fed 0.05% MOS per kg of feed had 1.3 log fewer (P < 0.05) coliform population, compared to the control chicks (Table 1). The mean $\log_{10}$ coliform (cfu/g) of cecal contents increased at 14 d and again at 21 d of age in chicks in the lactose and MOS treatment groups. These values were not different from those obtained for chicks in the control group.

Table 1. Mean cecal coliform population after dietary MOS and lactose in broiler chicks at 7, 14, and 21 d of age.

	Coliform (log 10 cfu/g) of cecal content		
Treatments	7[1]	14[1]	21[1]
Control	5.88a	5.59a	6.51a
Lactose[2]	3.89b	4.80a	5.37a
MOS[3]	4.57b	5.10a	5.85a
SEM	1.65	1.37	1.51

[a,b]Means with no common superscript differ significantly (P>0.05).

[1]Three replications, forty chicks per replication (n=30).

[2]Lactose was fed continuously at 2% kg of feed.

[3]MOS=Mannanoligosaccharide, fed continuously at 0.05%/kg of feed.

Lactose is a disaccharide sugar found in milk and when added to broiler feed has considerable beneficial effects in preventing the growth of harmful bacteria (Schaible, 1970; Corrier et al., 1994). MOS derived from yeast is a source of mannose (Sisak, 1994).administration of mannose to chicks resulted in a significant reduction in *Salmonella typhimurium* colonization in broiler chickens (Oyofo et al., 1989). Many species of cecal bacteria have lectin-like appendages (fimbriae) that bind the receptors on to epithelial cells (Oyofo et al., 1989). Ofek et al. (1977) stated that epithelial cell receptors are probably coated with mannose. Dietary mannose, and mannose-containing feed additives, block the adherence of bacteria that have mannose-sensitive fimbriae (Ofek et al., 1977; Eshdat et al., 1978). MOS appears to have an additional mode of action in the reduction of intestinal bacteria in chicks. Bedford et al. (1991) indicated that increased dietary fiber in MOS is related to reduction in intestinal viscosity. Because of its high fiber content of 30%, MOS is thought to decrease the viscosity of the contents of the GI tract, as it is slow to degrade and passes intact through the GI tract (Sisak, 1994).

Lactose-fed chicks at 21 d of age had significantly (P<0.05) lower cecal coliforms than chicks in the control group or MOS-fed chicks. The addition of $MgSO_4$ to the drinking water at 21 d during the last 12 h prior to sacrifice resulted in a significant (P<0.05) decrease in the cecal coliforms in all treatment groups (Table 2). Ceca taken from chicks fed diet containing MOS followed by $MgSO_4$ in the drinking water 12 h before sacrifice had the lowest cecal coliforms when compared with the untreated or the chicks given only $MgSO_4$.

Table 2. Mean cecal coliform populations before and after $MgSO_4$ of chicks at 21 d of age treated with MOS and lactose.

Treatments	Coliform (log_{10} cfu/g) of cecal content	
	Without[1] $MgSO_4$	With[1] $MgSO_4$
Control	6.51a	4.01b
Lactose2	5.32a	3.65b
MOS3	5.85a	3.12b
SEM	1.15	1.26

[a,b]Means within row with no common superscript differ significantly (*P<0.05*).

[1]Three replications, twenty chicks per replications (n=30).

[2]Lactose was fed continuously at 2%/kg of feed.

[3]MOS=Mannanoligosaccharide, fed continuously at 0.05%/kg of feed.

Chicks given lactose also had their coliforms lowered after receiving $MgSO_4$. Magnesium sulfate has been demonstrated to decrease the viscosity of the ingesta in the GI tract of chickens (Stanley et al., 1991). Therefore, $MgSO_4$ and MOS, had a combined effect on the coliform population in the GI tract suggesting that the increase of the ingesta viscosity and the inability of the bacteria to bind the receptor in the epethielial cells were responsible for the reduction in the bacteria count. Being trapped in the ingesta, the bacteria failed to attach to the epithelial cells and were expelled (Morton, 1993). By increasing the persistatic movement of the GI tract with $MgSO_4$ less fecal contents were recovered 12 h after the administering $MgSO_4$ (Stanley et al., 1991).

Mannanoligosaccharide of lactose added to the feed had no significant effect on the pH levels of the cecal contents from chicks in all groups. The pH of the cecal contents was relatively the same for the control, lactose, and MOS-fed groups (5.51, 4.77, and 5.38), respectively, indicating that the reduction in the cecal coliforms from the combined effect of MOS and $MgSO_4$ was not due to the changes in the pH of cecal contents but due to the combined effect of increased viscosity and the blocking effect of MOS. Additionally, $MgSO_4$ administered 12 h prior to processing did not adversely affect the BW of the chicks in all groups (477 vs 470g for control, 451 vs 449 g for lactose, and 462 vs 460 g for MOS). Stanley et al. (1991) reported that the coliform population in the ceca was lowered significantly when the level of $MgSO_4$ exceeded 5.5 g/L of drinking water without any significantly effect on body weight of the broiler chickens. Also, they reported that a positive correlation existed between cecal coliform reduction in broiler chickens and decreased bacterial population on the carcass when $MgSO_4$ was administered to the drinking water 12 h before the birds were sacrificed. Further, no withdrawal period is necessary for $MgSO_4$. Magnesium sulfate is a low-cost additive and is relatively simple to administer. Treatment of chicks with MOS fed continuously followed with pre-slaughter flushing of the G.I. tract with $MgSO_4$, 12 h prior to sacrifice was highly effective in reducing cecal coliforms population. The combined use of MOS followed by $MgSO_4$ 12 h prior to processing could be a useful integrated management practice in reducing the levels of bacteria in the digestive tracts of pre-slaughter chickens and the potential for reducing carcass contamination during processing.

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Effects of Early Harvest PGR on Peanut (*Arachis hypogaea* L.) Growth, Yield, and Quality

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ABSTRACT

Field studies were conducted from 1996 to 1999 to determine peanut response to Early Harvest PGR, a commercial hormonal growth regulator consisting of 0.09% cytokinins as kinetin, 0.03% gibberellic acid, 0.045% indole butyric acid and 99.835% inert ingredients. Early Harvest was applied either as a seed treatment, an in-furrow treatment, and as a foliar spray. Regardless of application timing, Early Harvest did not improve peanut yield across any varieties and resulted in increased peanut plant height or grade in only one year of the study.

KEYWORDS: Grade, groundnut, growth, plant growth regulator.

Early Harvest PGR is a commercial hormonal plant growth regulator registered for us in peanut (*Arachis hypogaea* L.), corn (*Zea mays* L.) grain sorghum [*Sorghum bicolor* (L.) Moench], cotton (*Gossypium hirsutum* L.), and a number of other agronomic and horticultural crops (Early Harvest PGR specimen label, Griffin Corp., Valdosta, GA). Early Harvest contains 26.8 mg cytokinins, 13.4 mg indole butyric acid, and 8.9 mg gibberellic acid per fluid ounce.

Other reported research with hormonal plant growth regulators on various crops has been with PGR-IV (Micro Flo Co., Lakeland, FL), which contains 0.9 mg gibberellic acid and 0.8 mg indole butyric acid per fluid ounce. Most of the reported research has been with cotton. Effects of PGR-IV on cotton yield have been variable. Yield increases ranging from 8 to 18% have been reported in several studies. (Cothren, 1995; Oosterhuis and Zhao, 1994 a,b; Weir et al., 1995; Hickey and Landivar, 1997). Hickey and Landivar (1997) reported that 2 oz/A at pinhead square, early bloom, and early bloom plus 2 wk has shown a trend for increased cotton yields.

The cotton response has sometimes been inconsistent across locations (Weir et al., 1995). In other studies, PGR-IV did not affect yield (Locke et al., 1994; Robertson and Cothren, 1995) while yield decreases have occasionally been reported (Abaye et al., 1995; Weir et al., 1994).

Yield increases are thought to be associated with increases in early season plant growth resulting from in-furrow applications of PGR-IV and increased leaf photosynthesis, nutrient partitioning, and boll set resulting from foliar applications (Hickey 1994; Oosterhuis and Zhao, 1993). Other physiological responses attributed to PGR-IV include enhanced root growth and more efficient carbohydrate translocation (Oosterhuis and Zhao, 1994b; Cadena and Cothren, 1996).

Cotton yield increases associated with PGR-IV applications appear to happen most often when the crop experiences nutritional or environmental stresses (Cadena and Cothren, 1995; 1996; Cadena et al.,1994; Zhao and Oosterhuis, 1995). Application of PGR-IV in-furrow increased tap root length, root dry weight, number of lateral roots, and total root length (Cadena et al., 1994; Oosterhuis and Zhao, 1994a; Zhao and Oosterhuis, 1995). This increased root growth is claimed to offer insurance against poor early season growing conditions (Oosterhuis et al., 1995).

Under either drought stress or nitrogen deficiency, PGR-IV increased leaf photosynthesis due to increased stomatal conductance (Cadena and Cothren, 1995). There was a trend for greater yield when PGR-IV was applied to drought-stressed or nitrogen-deficient cotton; however, there was no trend observed when cotton was not under drought stress or nitrogen deficient (Cadena and Cothren, 1995). In other field studies, PGR-IV increased the rate of photosynthesis and dry matter production of both flooded and drought-stressed cotton (Zhao and Oosterhuis, 1995).

In peanut, York et al. (1996) reported PGR-IV had no effect on peanut main stem or cotyledon lateral branch length, yield, maturity, percentage of fancy pods, extra large kernels, total sound mature kernels, or net returns with Virginia-type peanut. No research has been reported on the use of Early Harvest in peanut. The objective of this study was to determine if Early Harvest effects growth, yield or market quality of runner-type peanut.

MATERIALS AND METHODS

Field studies were conducted from 1996 to 1999 at the Texas Agricultural Experiment Station near Yoakum, TX. In 1996 through 1998 the soil was a Tremona loamy fine sand (clayey, mixed thermic Aquic Arenic Paleustalfs) with less than 1% organic matter and a pH of 6.8 and in 1999 soil was a Denhawken-Elmendorf complex (fine, motmorillonitic, hyperthermic Vertic Ustochrepts-Argiusfolls) with less than 1% organic matter and a pH of 8.0. Each year a small grain cover crop was shredded and the land was moldboard plowed prior to disking.

Fertilizer was applied each year to the small grain cover crop according to soil test recommendations. The runner peanut variety 'GK-7' was planted at 90 lbs/A in 1996 to 1998, while Georgia Green and Tamrun 96 were planted at 95 lbs/A in 1999. A tank mix of Prowl (pendimethalin) at 2.0 pt/A and Pursuit (imazethapyr) at 1.44 oz/A were applied and incorporated 2 in deep with a tractor-driven power tiller prior to planting. This herbicide combination provides control of annual grasses, broadleaf weeds, and yellow and purple nutsedge. Other management practices recommended by the Texas Agricultural Extension Service for peanut production were followed. Irrigation was applied as needed to supplement rainfall.

The experimental design was a randomized complete block with four replications. Plot size was 2 rows (36 in spacing) by 25 ft long. Early Harvest was sprayed at planting in a 2 in band immediately behind the seed drop-tube. Early Harvest seed treatment was mixed with commercial seed at the rate of 40 g/50 lb seed until seed was lightly coated. Foliar sprays of Early Harvest were applied when peanut were at the 3 to 4 leaf stage (approximately 20 d after planting), pegging (approximately 60 d after planting), 14 d after pegging application, and at pod fill (approximately 90 to 100 d after planting). Foliar sprays were applied with a CO backpack sprayer calibrated to deliver 20 gpa at 30 psi using Teejet 11002 flat fan nozzles (Spraying Systems Co., Wheaton, IL).

Plant height measurements were taken in 1996, 1998, and 1999 seven to eight wk after planting (WAP). Five plants per plot were measured from the ground line to tip of the growing point. Peanuts were dug when mature according to the untreated check. Peanut yields were obtained in 1996, 1997, and 1999. Although peanuts were dug in 1998, substantial rains (approximately 15 in) soon after digging prevented entry into the field in a reasonable time period to harvest pods before deterioration. Yields were obtained by digging each plot separately, air-drying in the field for 5 to 8 d, and harvesting peanut pods from each plot with a combine. Weights were recorded after soil and foreign material were removed from the plot samples. Grades were determined from a 200-g pod sample from each plot following procedures described by the Federal-State Inspection Service (USDA, 1986).

Peanut plant height, yield, and grade were subjected to ANOVA and means were compared using Fisher's protected LSD test at the 5% level of probability. Peanut height data were separated by years in 1996 and 1998 because of treatment by year interaction. Height data were separated in 1999 by variety due to varietal differences. Peanut yield data were combined over years or variety since no year or variety by treatment interactions were observed. Peanut grades were separated in 1996 and 1997 because of a treatment by year interaction while grades were separated by variety in 1999 due to a varietal response.

RESULTS AND DISCUSSION

Peanut height. In 1996, Early Harvest applied in-furrow at planting increased height by 8% over the untreated check while Early Harvest applied in sequential applications in- furrow at planting, three to four leaf stage, 14 d after peg, and pod fill resulted in a 6% decrease in height 7 weeks after planting (WAP) (Table 1). In 1998, no difference in peanut height was noted. When Georgia Green and Tamrun 96 were treated with Early Harvest in 1999, no differences in Early Harvest treatments were observed within variety (Table 2). Only varietal differences in peanut height were observed. York et al. (1996) working with Virginia market types reported that PGR-IV had no effect on peanut main stems and cotyledon lateral branch lengths.

Table 1. Response of GK-7 peanut to Early Harvest applied at various times during the growing season.

Treatment	Rate/A	Appl. timing[a/]	Height (7WAP[b/]) 1996	Height (7WAP[b/]) 1998	Yield	Grade[c/] 1996	Grade[c/] 1997
			----inches----		lbs/A	-----%------	
Check	-	-	7.1	8.7	1877	76.3	63.6
Early Harvest PGR	2.0 fl oz.	Plant	7.7	8.5	2192	76.3	64.8
Early Harvest PGR	2.0 fl oz. 3.2 fl oz 4.8 fl oz	Plant 4-5 ls, peg, 14 d after peg pod fill	6.7	8.3	1993	78.1	65.5
Early Harvest PGR	3.2 fl oz 4.8 fl oz.	3-4 ls, peg, 14 d after peg pod fill	7.2	8.7	2027	77.6	66.9
LSD (0.05)			0.3	NS	NS	1.7	NS

[a/] Plant = in-furrow with seed, ls = leaf stage
[b/] WAP = weeks after planting
[c/] Grade = sound mature kernels (SMK) + sound splits (SS)

Peanut yield. None of the Early Harvest treatments significantly affected peanut yield in any year of the study (Tables 1 and 2). Peanut yields in 1999 with Georgia Green and Tamrun 96 were much higher than GK-7; however, peanuts were free from significant environmental and pest stress development in all years. Our findings with runner market types are in agreement with York et al. (1996) who reported no difference in Virginia-type peanut yield with any PGR-IV treatments. Cotton yield increases with PGR-IV have occurred most often when cotton has experience some type of stress (Cadena and Cothren, 1995; 1996).

Peanut grade. In 1996, Early Harvest applied at plant and during the growing season increased grade over the untreated check (Table 1). In all other years no grade differences were noted. York et al. (1996) reported no grade differences with PGR-IV. They reported that their study may have been dug too soon for optimum yield. However, they concluded that the early harvest should not have affected overall conclusions because of the lack of difference in maturity among treatments.

Table 2. Response of Georgia Green and Tamrun 96 to Early Harvest applied at various times during the 1999 growing season.

			Height (8WAP[b/])			Grade[c/]	
Treatment	Rate/A	Appl. timing[a/]	GA. Green	T-96	Yield	GA. Green	T-96
			---- inches----		lbs/A	--------%--------	
Check	-	-	11.1	14.9	4287	68.8	66.8
Early Harvest PGR	40 g/50 lb	Seed	11.3	13.9	4282	70.1	69.1
Early Harvest PGR	40 g/50 lb 3.2 fl oz	Seed 3-5 ls, peg	2.5	14.4	4541	69.9	67.6
Early Harvest PGR	3.2 fl oz	3-5 ls, peg, 14 d after peg	11.1	14.4	4485	71.8	69.3
LSD (0.05)			NS	NS	NS	NS	NS

[a/] Plant = in-furrow with seed, ls = leaf stage
[b/] WAP = weeks after planting
[c/] Grade = sound mature kernels (SMK) + sound splits (SS)

The results of this study show no significant benefit to using Early Harvest on runner-type peanut. Supplemental irrigation was applied whenever needed and the peanuts were never moisture stressed. Since the greatest response in cotton has been seen when cotton is stressed, the same may be true for peanut.

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Effects of Herbicide and Liquid Nitrogen Fertilizer Application on the Establishment of Wheatgrass Pastures in the Texas Rolling Plains

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ABSTRACT

Introduced wheatgrasses selected for improved productivity, quality, and drought tolerance may be a complementary forage to winter wheat and perennial warm-season grasses, filling a gap in spring forage availability in the semi-arid regions of the Texas Rolling Plains. In this experiment, the effects of herbicides applied with water or liquid nitrogen (N) fertilizer on the establishment of crested wheatgrass cv. Hycrest, hybrid wheatgrass cv. NewHy, intermediate wheatgrass cv. Oahe, pubescent wheatgrass cv. Luna and cv. Manska, and tall wheatgrass cv. Jose were investigated. Wheatgrasses were sown at a location near Guthrie, TX in November 1998. Five months after seeding, 2,4-D (2.0 lb ai/A), metsulfuron (Ally; 0.011 lb ai/A), triasulfuron (Amber; 0.026 lb ai/A), dicamba (Banvel; 0.5 lb ai/A), and picloram (Tordon 22K; 0.5 lb ai/A) were applied in an aqueous solution or with liquid N fertilizer carrier (28% N, ammonium nitrate + urea, UAN). One month after herbicide application, plants were evaluated for chlorosis, necrosis, stunting, and stand coverage. Thirty days later herbage dry matter (DM) yield was determined. Wheatgrasses differed in their responses to individual herbicides; however, the use of sulfonylurea herbicides triasulfuron and metsulfuron, and auxin-type herbicides picloram and dicamba increased or did not affect DM yield when compared to control. Application of UAN in a mixture with these herbicides improved establishment of wheatgrasses compared with herbicides applied in an aqueous solution by reducing leaf and plant injury and increasing DM yield. In contrast, application of the auxin-type herbicide 2,4-D reduced growth of most wheatgrasses when compared to control plants, regardless the carrier type. When compared to untreated plants, application of auxin-like herbicides resulted in a greater incidence of leaf injury and reduction in DM yield than application of sulfonylurea herbicides.

KEYWORDS: Herbicide, Pasture establishment, Wheatgrasses, Cool-season grasses.

Increasing costs, lower crop value, and increased risk associated with dual-purpose or forage wheat (*Triticum* spp.) have led to interest in finding alternative winter forage crops in the Texas Rolling Plains (Redmon, 1997). An alternative source of forage during winter and spring may be cool-season perennial grasses (Reuter et al., 1999). Although winter conditions are favorable for growth and herbage production of most cool-season perennial grass species in this region, water deficits and high temperatures during summer months reduce their survival potential and significantly limit the number of species in consideration (Redmon, 1997). One class of suitable cool-season grasses is the wheatgrasses. Over the past 20 years, the nutritional quality of introduced wheatgrass species has been significantly improved (Vogel and Moore, 1998; Moore et al., 1995), offering an alternate and potentially less expensive forage than winter wheat.

Management practices maximizing production and survival rate of wheatgrasses in the Texas Rolling Plains are not well understood. One of the most important management practices is proper weed control to ensure successful pasture establishment. Little is known about wheatgrass species and variety responses to herbicides used to control weeds in grass pastures, especially when applied in a mixture with liquid nitrogen (N) fertilizer, a common practice to reduce operational costs of pasture management.

The objectives of this experiment were: 1) to test wheatgrass species and variety responses to selected herbicides commonly used for weed control in grasslands; and 2) to determine the effects of liquid N fertilizer/herbicide combinations on plant growth during the establishment year.

MATERIALS AND METHODS

Study Area

This experiment was established 12 miles north of Guthrie, TX (Midway Church, 33° 48' 43" N latitude, 100° 19' 39" W longitude) on Sagerton loam soil (fine mixed thermic Typic Paleustolls) in November 1998. The precipitation and temperature data for 1998 - 2000 at

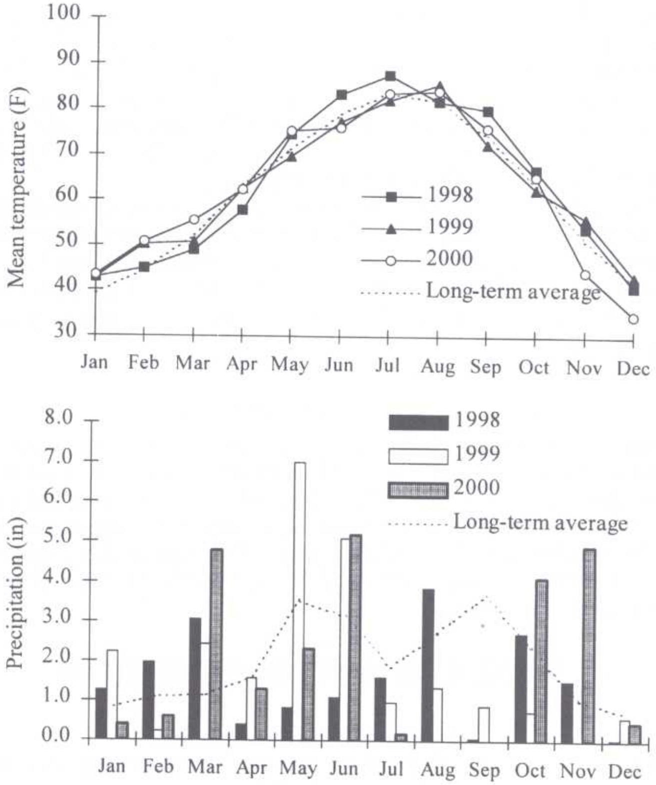

Fig. 1. Mean temperature and precipitation at Guthrie, TX during 1998 - 2000.

this location (N.O.A.A., 1998, 1999, 2000) are presented in Fig. 1. The mean (high + low for 24-hr period) monthly air temperatures were 1.5 F and 0.8 F higher than the long-term average in 1998 and 1999, respectively. In the first half of 2000, the mean air temperature was 2.5 F higher than the long-term average. In 1998 and 1999, precipitation deficits were 5.5 in and 0.7 in, respectively. A severe precipitation deficit (0.7 in) in December 1998 delayed plant germination; however, above normal (156%) rainfall in January - March 1999 resulted in a relatively good plant establishment.

Experimental Design

Wheatgrass species investigated in this experiment included crested wheatgrass [*Agropyron cristatum* (L.) Gaertn. X *A. desertorum* (Fisch. ex Link) J.A. Schultes] cv. Hycrest, hybrid wheatgrass [*Elytrigia repens* var. *repens* (L.) Desv. ex B.D. Jackson X *Pseudoroegneria spicata* (Pursh) Löve] cv. NewHy, intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & Dewey] cv. Oahe, pubescent wheatgrass [*Thinopyrum intermedium* ssp. *barbulatum* (Schur) Barkworth & Dewey] cv. Luna and cv. Manska, and tall wheatgrass [*Thinopyrum ponticum* (Podp.) Barkworth & Dewey] cv. Jose.

The experiment was established as a randomized complete block design replicated four times. Each wheatgrass entry within a block (replication) was planted as a single strip (7 ft by 120 ft) at the seeding rate of 15 lb/A using a Tye Pasture Pleaser double disk drill (AgEquipment Group LP, Lockney, TX). Each strip was divided in six plots (7 ft by 20 ft). Subsequently, each plot was split in half. Half of the plot was treated with herbicide in an aqueous solution and 0.25% nonionic surfactant (NIS), and the other half was treated with herbicide mixed with liquid N fertilizer carrier [UAN, 28% N (ammonium nitrate + urea)] and NIS on April 9, 1999. The herbicide untreated control plots were sprayed with water or UAN fertilizer. Herbicide treatments included 2,4-D [4-(2,4-dichlorophenoxy)butanoic acid, 2.0 lb ai/A], picloram (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid, 0.5 lb ai/A), dicamba (3-,6-dichloro-2-methoxybenzoic acid, 0.5 lb ai/A), metsulfuron {methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate, 0.011 lb ai/A} or triasulfuron{2-(2-chloroethoxy)-N-[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]benzenesulfonamide, 0.026 lb ai/A}.

On May 13, 1999 chlorosis, necrosis, stunted plants, and stand coverage were visually determined based on scale from 0 to 100 (0 = no symptoms or no stand coverage, 100 = severe symptoms or complete stand coverage). Herbage biomass was determined by harvesting plots at a 2-in stubble height on June 19, 1999 (year of establishment) and June 29, 2000 (second growing season). Dry matter (DM) yield was determined after drying samples in a forced-air oven at 149 F for 72 hr.

Statistical Analysis

Before statistical analysis, percentage values describing the occurrence of chlorotic, necrotic, stunted plants, and stand coverage were transformed by the arcsin transformation to ensure normal distribution. Actual data are presented with statistical separation based on transformations. Detailed comparison of means for wheatgrass type and herbicide treatments was performed by using a protected Duncan multiple range test ($P = 0.05$), and the pairwise multiple comparison test (LSD, $P = 0.05$) was applied for comparison of UAN fertilizer application effects.

RESULTS AND DISCUSSION

Leaf and Plant Injuries

Chlorosis. The incidence of chlorosis was significantly affected by herbicide, UAN fertilizer, wheatgrass entry, and an interaction between wheatgrass entry and UAN fertilizer (Table 1). The interaction of wheatgrass entry with UAN on the incidence of chlorosis indicated that wheatgrasses fertilized with N did not significantly differ in chlorosis among each other (Table 2). In contrast, not fertilized pubescent wheatgrass cv. Luna and cv. Manska, and intermediate wheatgrass cv. Oahe had more chlorosis than tall wheatgrass cv. Jose, hybrid wheatgrass cv. NewHy, and crested wheatgrass cv. Hycrest.

Table 1. Analysis of variance summary of herbicide, nitrogen fertilization, wheatgrass entry effects upon developmental and physiological features of wheatgrass.

Source	Chlorosis	Necrosis	Stunted Plants	Stand Coverage	Herbage DM 1999	Herbage DM 2000
Herbicide (H)	*	*	*	*	*	NS
Nitrogen (N)	*	*	*	*	*	NS
Wheatgrass (W)	*	*	*	*	*	*
HxN	NS	NS	NS	NS	NS	NS
WxH	NS	NS	*	NS	NS	NS
WxN	*	NS	NS	NS	*	NS
WxHxN	NS	NS	NS	NS	*	NS

*Significant at the 0.05 probability level.

Table 2. Incidence of chlorosis on Wheatgrass plants in relation to N fertilization, averaged over herbicide treatments (percentage of plants chlorosis syptoms).

N level	cv. NewHy	cv. Luna	cv. Jose	cv. Manska	cv. Oahe	cv. Hycrest
O lb/A	5.0 A c	13.7 A a	7.7 A bc	11.0 A bc	10.5A ab	4.8 A c
28 lb/A	2.9 B a	1.7 B a	0.8 B a	1.9 B a	0.8 B a	1.2 B a

[1] In columns, means followed by the same capital letter are not significatnly different (P<0.05).
[2] In rows,means followed by the same common lettter are not significantly different (P<0.05).

As a main effect, application of UAN reduced chlorosis (1.6%) when compared to not fertilized plants (8.8%). Regardless of herbicide and UAN treatments, chlorosis was most pronounced in pubescent wheatgrass cv. Luna, followed by cv. Manska, intermediate wheatgrass cv. Oahe, tall wheatgrass cv. Jose, hybrid wheatgrass cv. NewHy, and crested wheatgrass cv. Hycrest (Table 3). When averaged over UAN fertilizer and wheatgrass entry treatments, the greatest frequency of chlorosis was observed on plants treated with picloram, whereas plants treated with 2,4-D, metsulfuron, triasulfuron, and dicamba did not differ from control plants (Table 4). Picloram was applied in this experiment at the highest labeled rate (0.5 lb ai/A) recommended for pastures (Ahrens, 1994). At high doses (0.5 - 1.5 lb ai/A) picloram caused leaf injuries in several cool-season grasses including western wheatgrass (*Pascopyrum smithii* [Rydb.] Löve) and smooth bromegrass (*Bromus inermis* Leyss.) (Gesink et al., 1972), orchardgrass (*Dactylis glomerata* L.), crested wheatgrass and red fescue (*Festuca rubra* L.) (Canode, 1974). Such leaf injuries involved chlorosis as well as twisted flag leaves and leaf rolling (Gunsolus, 1999).

Table 3. Incidence of cholorosis, necrosis, and stunting (percentage of plants with symptoms), and stand coverage (percentage of area covered by plants) on wheat grass entries across herbicide and UAN treatments.

Parameter	cv. Hycrest	cv. Jose	cv. Luna	cv. Manska	cv. NewHy	cv. Oahe
Cholorsis	3.0 d1	4.3cd	7.7 a	6.4b	4.0cd	5.7abc
Necrosis	6.0 ab	7.8a	2.7c	3.3c	4.0bc	3.7c
Stunting	49.1 a	25.6c	19.5c	20.2c	40.5b	23.1c
Coverage	80.1 c	87.7b	91.5a	83.5bc	79.4c	81.6c

[1] In rows, means followed by the same common letter are not significantly different ($P<0.05$).

Table 4. Herbicide effects on chlorosis, necrosis, stunting (percentage of plants with symptoms), and stand coverage (percentage of are covered by plants) across wheatgrass entries and UAN fertilizer treatments.

Parameter	Control	2,4-D	Dicamba	Metsulfuron	Picloram	Triasulfuron
Cholorsis	4.6 b1	4.3 b	5.5 b	4.6 b	7.4 a	4.8 b
Necrosis	1.3 c	5.9 ab	4.3 b	3.7 c	8.1 a	3.8 bc
Stunting	15.6 d	35.6 ab	32.7 bc	27.3 c	40.1 a	27.3 c
Coverage	85.8 c	80.4 b	85.0 a	85.5 a	80.7 b	86.2 a

[1] In rows, means followed by the same common letter are not significantly different ($P<0.05$).

Necrosis. The incidence of necrotic leaves was significantly influenced by herbicide, UAN fertilizer, and wheatgrass entry (Table 1). Most necrotic plants occurred in response to treatment with auxin-type herbicides 2,4-D, dicamba, and picloram (Table 4). The incidence of necrosis on plants treated with sulfonylurea herbicides metsulfuron and triasulfuron was not significantly different from that on control plants (Table 4). Some cool-season grasses, i.e., tall fescue (*Festuca arundinacea* Schreb.), might develop leaf injury such as necrosis after application of picloram at 1.25 lb ai/A (Berry and Buchanan, 1975). Wheatgrasses fertilized with UAN had less necrosis (3.6%) than not fertilized plants (5.5%), regardless of herbicide treatment. Averaged over herbicide and UAN fertilization treatments, tall wheatgrass cv. Jose and crested wheatgrass cv. Hycrest had more necrosis than hybrid wheatgrass cv. NewHy, intermediate wheatgrass cv. Oahe, pubescent wheatgrass cv. Manska, and cv. Luna (Table 3). A greater occurrence of necrosis in tall wheatgrass cv. Jose and crested wheatgrass cv. Hycrest, however, might also be related to their development stage; they were more matured than the other wheatgrasses at the time of herbicide application.

Stunted plants. Stunting was influenced by herbicide, UAN fertilizer, wheatgrass entry, and an interaction between herbicide and wheatgrass entry (Table 1). Averaged over wheatgrass entries and UAN fertilization treatments, stunting rate was higher in all herbicide treatments when compared to control (Table 4). A greater number of stunted plants would be expected in grasses treated with sulfonylurea herbicides rather than auxin-type herbicides (Gunsolus, 1999). However, McLain and Evans (1988) reported a higher incidence of plant injuries on dryland cool-season grasses only when metsulfuron was applied at a rate higher than 0.012 lb ai/A, thus higher than that in our experiment (0.011 lb ai/A). Nitrogen fertilization reduced the number of stunted plants (19.4%) when compared with not fertilized plants (40.1%), regardless of herbicide treatment. Among the wheatgrass entries, stunting occurred mostly in crested wheatgrass cv. Hycrest and hybrid wheatgrass cv. NewHy, and the least number of stunted plants were observed in tall wheatgrass cv. Jose, intermediate wheatgrass cv. Oahe, pubescent wheatgrass cv. Manska, and cv. Luna (Table 3).

The interaction between herbicide and wheatgrass entry (Table 4) indicated that the frequency of stunted plants, compared to untreated control, was greater for hybrid wheatgrass cv. NewHy, intermediate wheatgrass cv. Oahe, and crested wheatgrass cv. Hycrest when 2,4-D, dicamba or picloram were applied. Cultivar NewHy and cv. Oahe had also a greater number of stunted plants in response to treatment with sulfonylurea herbicides. The herbicide 2,4-D was not suitable for pubescent wheatgrass cv. Manska nor was dicamba for tall wheatgrass cv. Jose. In contrast, the frequency of stunted plants was not significantly affected by herbicide treatment in pubescent wheatgrass cv. Luna.

Stand coverage. Stand coverage was influenced by herbicide, UAN fertilizer, and wheatgrass entry. Plots treated with dicamba, metsulfuron or triasulfuron did not differ in stand coverage from control plots; however, a reduction in stand coverage resulted from application of 2,4-D and picloram (Table 4). Wheatgrasses fertilized with UAN generally had better stand coverage (86.5%) than not fertilized plots (80.1%), regardless of herbicide application. The best stand coverage was observed in plots with pubescent wheatgrass cv. Luna, followed by tall wheatgrass cv. Jose and pubescent wheatgrass cv. Manska, intermediate wheatgrass cv. Oahe, crested wheatgrass cv. Hycrest, and hybrid wheatgrass cv. NewHy (Table 3).

Dry Matter Production In The Year Of Establishment

Dry matter yield responses of wheatgrasses to herbicide were modified by UAN fertilizer as shown by the complex interaction between these factors (Table 1). Application of 2,4-D in an aqueous solution increased DM yield of tall wheatgrass cv. Jose by 61% and tended ($P < 0.1$) to increase DM yield of hybrid wheatgrass cv. NewHy (27%) when compared to untreated control (Table 6). Yield DM, however, was reduced by application of 2,4-D in pubescent wheatgrass cv. Manska by 44%, intermediate wheatgrass cv. Oahe by 30%, and in crested wheatgrass cv. Hycrest by 24%, which agreed with results by Lym and Kirby (1991) and Beck et al. (1995). The basis for various DM yield responses of wheatgrasses to 2,4-D may be its translocation, which is generally slow in tolerant species, but it may vary among species due to formation of immobile complexes, reduced xylem transport, and anatomical differences (Ahston and Crafts, 1981). Application of 2,4-D with UAN fertilizer reduced DM yield of tall wheatgrass cv. Jose by 45% and tended to reduce DM yield of pubescent wheatgrass cv. Luna (37%) and cv. Manska (28%). The reason for that might be an increased uptake of 2,4-D by grass plants as often reported for some herbicides applied in a mixture with UAN fertilizer and surfactant (Gauvrit and Dufour, 1990).

Table 5. Percentage of stunted wheat grass plants in relation to herbicide treatments, averaged over UAN fertilizer treatments.

Wheatgrass	Control	2,4-D	Dicamba	Metsulfuron	Picloram	Triasulfuron
cv. Hycrest	3.06b	59.3a	57.5a	37.5b	72.5a	39.6b
cv. Jose	16.2b	31.2ab	35.6a	20.6ab	21.2ab	28.8ab
cv. Luna	17.5ab	17.5ab	21.2ab	20.0ab	28.1a	12.5b
cv. Manska	10.0b	27.5a	25.0ab	21.9ab	19.4ab	21.2ab
cv. NewHy	6.2d1	50.6b	31.9c	40.6c	77.5a	36.2c
cv. Oahe	13.1b	27.5a	25.0a	23.1a	21.9a	28.3a

[1]In rows, means followed by the same common letter are not significantly different ($P < 0.05$).

Table 6. Dry matter production (lb/A) of wheatgrasses in relation to nitrogen fertilization and herbicide type in the year of establishment.

Wheatgrass	Control	2,4-D	Dicamba	Picloram	Metsulfuron	Triasulfuron
---------- 0 lb N/A ----------						
cv. Hycrest	255c[1]	193c	444ab	418ab	364abc	465a
cv. Jose	329bc	531a	241c	477ab	519a	514a
cv. Lunda	500b	554b	450b	811a	562b	577b
cv. Manska	494a	277b	479a	402ab	581a	561a
cv. NewHy	181a	230a	173a	59b	263a	214a
cv. Oahe	512a	359b	483ab	544a	418ab	545a
---------- 28 lb N/A ----------						
cv. Hycrest	1383a	1321a	1326a	1481a	1253a	1702a
cv. Jose	1329a	727c	1830a	1440ab	1160bc	1364ab
cv. Luna	2110b	1337b	1640b	1876b	2160b	2939a
cv. Manskal	416ab	1019b	1822a	1862a	1889a	1586ab
cv. NewHy	465b	742a	474b	655ab	518b	495b
cv. Oahe	1763a	1643ab	1564ab	1510ab	1410b	1559ab

[1] In rows, means followed by the same common letter are not significantly different ($P<0.05$).

Picloram applied in an aqueous solution increased DM yield of crested wheatgrass cv. Hycrest by 64%, pubescent wheatgrass cv. Luna by 62%, and tall wheatgrass cv. Jose by 45%, but reduced DM yield of hybrid wheatgrass cv. NewHy by 67% (Table 6). Similar to 2,4-D, picloram mimics natural plant hormones, but it is translocated more rapidly in the plants and is active through both foliage and roots, thus being more toxic to some broad-leaf weeds. Picloram may also cause plant injury in some cool-season grasses to a greater extent than 2,4-D when applied at early stages of their development (Gesink et al., 1972; Canode, 1974). A combined application of picloram and UAN fertilizer had no significant effect on DM yield when compared to plants treated only with UAN fertilizer.

Dry matter was not significantly affected by dicamba herbicide, either applied in an aqueous solution or in the mixture with UAN fertilizer, except for crested wheatgrass cv. Hycrest, which responded to application of dicamba with 74% increase in DM yield when compared to untreated control (Table 6). Grasses are generally tolerant to dicamba herbicide because of its rapid metabolism (Ashton and Crafts, 1981) and herbicide-related plant injuries and herbage biomass reduction are not common (Berry and Buchanan, 1975; Hall, 1976).

The effects of metsulfuron applied in an aqueous solution on DM yield of wheatgrasses were similar to those of triasulfuron (Table 6). When compared to control, both of these sulfonylurea herbicides increased DM yield of tall wheatgrass cv. Jose by 58% and 56%, and crested wheatgrass cv. Hycrest by 43% and 74%, respectively. Also hybrid wheatgrass cv. NewHy responded to the treatment with metsulfuron by increasing yield DM by 45%. Cool-season grasses are tolerant to sulfonylurea herbicides (Biljon et al., 1988; West and Standell, 1989), especially at doses lower than 0.04 lb ai/A (Warner et al., 1986; McLain and Evans, 1988) and at high temperature and soil moisture after application (Gillespie et al., 1985; Ferreira et al., 1990). Application of sulfonylurea herbicides in mixtures with UAN fertilizer did not affect DM yield when compared with control plants with the exception of intermediate wheatgrass cv. Oahe, which responded to the combined treatment of metsulfuron and UAN fertilizer with 18% reduction in DM yield. A lack of significant herbage biomass reduction due to combined application of sulfonylurea herbicides and UAN fertilizer might be related to relatively high temperature and adequate soil moisture after treatment (Stahlman et al., 1997).

Herbage Biomass Production In The Second Growing Season

Residual effects of herbicide treatment and UAN fertilizer application on DM yield of wheatgrasses were not observed in the second growing season (Table 1). Below average precipitation during fall 1999 and spring 2000 together with higher than normal temperatures during that period (Fig. 1) resulted in significantly less herbage biomass production in the second growing season when compared to that during the year of establishment (Table 7). Plants of hybrid wheatgrass cv. NewHy did not survive to the second growing season. Tall wheatgrass cv. Jose produced more herbage DM than other wheatgrasses.

Table 7. Dry matter production (lb/A) of wheatgrasses in the second growing season, averaged over herbicide and UAN fertilizer treatments.

cv. Hycrest	cv. Jose	cv. Luna	cv. Manska	cv. NewHy	cv. Oahe
485 b[1]	1469 a	457 b	553 b	no data	565 b

[1] In rows, means followed by the same common letter are not significantly different ($P<0.05$).

CONCLUSIONS

Results indicate that application of UAN fertilizer in a mixture with herbicides did not affect DM yield of wheatgrasses. In fact, application of UAN fertilizer combined with herbicides improved establishment of wheatgrasses compared with herbicides applied in an aqueous solution. This improvement involved less leaf injuries (chlorosis, necrosis) and fewer stunted plants, which resulted in a better stand coverage and greater herbage biomass production. Wheatgrasses varied in their responses to aparticular herbicide but, in general, sulfonylurea herbicides triasulfuron and metsulfuron, and auxin-type herbicides picloram and dicamba increased or did not affect DM yield when compared to control plants. In contrast, application of the auxin-type herbicide 2,4-D reduced growth of most wheatgrasses when compared to control plants, both when 2,4-D was applied in an aqueous solution or in combination with UAN fertilizer. Yield DM was considered in this experiment as the ultimate response criterion for herbicide efficacy. When compared to untreated plants, application of auxin-like herbicides resulted in a higher incidence of temporary leaf and plant injuries than application of sulfonylurea herbicides. Those leaf and plant injuries, however, did not affect DM yield (picloram) or had more permanent effects and reduced wheatgrass productivity (2,4-D). Residual effects of herbicide applied with UAN fertilizer on herbage production were not observed in the second growing season, most probably due to growth limiting weather conditions.

Based on the results of this experiment, weed control with herbicides (except for 2,4-D) commonly used in pasture and grassland management may be applied for wheatgrass stand establishment in semi-arid environments of the Texas Rolling Plains. Other management practices, however, require further research to improve herbage productivity and stand persistence of wheatgrass pastures.

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An Economic Assessment of Red Imported Fire Ant Impacts on Texas Production Agriculture

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ABSTRACT

A survey of 3,612 Texas agricultural producers was conducted to estimate the economic damage Red Imported Fire Ants impose on agricultural producers. Statewide and regional damage estimates for crop losses, livestock losses, equipment repair and equipment replacement, medical expenses, veterinary cost, farmstead damages, and control costs are derived. Agricultural damages in Texas annually exceed $90 million and 37% of the damage is a consequence of lost crop yield. Average per farm loss, for farms reporting losses, range from a low of $26 for farms located in agricultural district 2-N in West Texas to a high of $9,438 for farms located in agricultural district 10-S located in Southeastern Texas.

KEYWORDS: RIFA, Economic Impacts, Damages

Red Imported Fire Ant (RIFA) infestations were first documented in Texas in 1953, and today over 56 million Texas acres are infested with RIFA (Barr and Drees, 1996). Beginning in 1958, the Texas Department of Agriculture initiated a county quarantine program to control the spread of RIFA by quarantining the state's six most eastern counties. The quarantine required producers to obtain a permit to move products (primarily agricultural), that are known to contribute to the spread of RIFA, from a quarantined county into or through a non-quarantined county. After 43 years of continuous quarantine, the quarantine program has proven ineffective as RIFA infestations steadily moved westward, and 160 Texas counties are now under quarantine. In 1997, in an effort designed to both control the spread of RIFA and to document the severity of the RIFA infestations, the Texas legislature funded a 6-year initiative, known as the Texas Fire Ant Initiative. The general objectives of the initiative are to document the economic and biological severity of RIFA, and to discover appropriate and cost-effective management programs that may alleviate continued damage from this pest in the future. One specific goal of the Texas Fire Ant Initiative is to determine the economic impacts of RIFA activity on production agriculture. Knowledge of the agricultural impacts are intended to serve as a benchmark for measuring the economic benefits and costs of implementing either statewide or regional management control programs.Prior research on the economic impact of RIFA to Texas agriculture has relied exclusively on using a combination of published secondary data, derived under narrowly controlled experimental conditions, and statistical techniques to estimate statewide agricultural damages. For example, in the first two year cycle of the Texas Fire Ant Initiative, Polk, Teal and Segarra (1999) applied statistical procedures to limited published data on RIFA induced yield losses for a variety of crops grown under diverse conditions throughout the southeastern United States to estimate annual RIFA crop losses to Texas at $45.5 million. In a complementary study, also funded by the Texas Fire Ant Initiative program, Teal et. al. (1998) again used limited published secondary data to estimate annual RIFA damage losses to the Texas Cattle industry at $255 million. Due to a poor statistical fit, their 95% confidence interval estimate was extremely large, having a lower bound of $27.8 million, and an upper bound of $572.9 million. Given the lack of precision and wide variation in existing damage estimates, there was a legitimate need for a primary agricultural producer level survey to collect spatially disaggregated producer data for purposes of estimating the agricultural costs and benefits (if any) associated with RIFA infestations. This study addresses this need by developing regional and statewide agricultural estimates for RIFA damages using survey data collected from 3,612 agricultural producers.

DATA COLLECTION METHODS

The data collection phase of the study was completed in the fall of 1999 and winter of 2000. The data reflected costs and benefits of RIFA activity for the 1999 calendar year. A structured questionnaire was developed in association with the Texas Agricultural Statistical Service (TASS). A multiple choice, discussion and fill-in-the-blank survey design was utilized to collect the necessary data and facilitate the respondent's ability to meaningfully respond to the survey. Moreover, the survey design permitted easy tabulation of the collected survey data using the SAS Statistical Analysis System.

The TASS area frame sampling procedure was utilized to assure the data were obtained from an appropriately stratified and representative sample of agricultural producers. The TASS area frame sampling procedure is commonly used to provide accurate regional and county level estimates on crop acreage, crop yields, numbers of agricultural producers, and input use. The TASS administered the personal interviews as an addendum to their 1999 Fall Area Survey. The sample design provided 3,612 useable surveys.

The data collected from each agricultural producer included information on (1) irrigated and non-irrigated acres of cropland in the operation, (2) crop losses related to RIFA, (3) livestock losses related to RIFA, (4) equipment repair costs due to RIFA, (5) equipment replacement cost due to RIFA, (6) RIFA damages to the farmstead, (7) RIFA related medical expenditures, (8) RIFA related veterinary expenditures, (9) cost of RIFA control materials, (10) special equipment purchased to apply RIFA control materials, and (11) the agricultural benefits of RIFA infestations. The complete text of the questionnaire is available from the authors upon request.

Secondary data were used to augment the survey data. Secondary data sources used consist of the 1997 United States Census of Agriculture, and other data annually compiled by the TASS. The TASS provided the sample design expansion factors (weights) necessary to aggregate the survey data into damage estimates for each of the fifteen Texas agricultural statistics districts, and the statewide totals. The 15 Texas agricultural statistics districts are identified in Figure 1.

RIFA DAMAGES TO PRODUCTION AGRICULTURE

Statewide Overview

Estimated RIFA damages annually exceed $90 million for Texas agricultural producers (Table 1). Crop yield losses due to RIFA activity are the largest damage category at $33.4 million and comprise 36.9% of all damages. Equipment repair cost is the second largest damage category at nearly $17 million and is closely followed by expenditures for control materials at $16 million. Thus, statewide, crop yield losses, equipment repairs, and control material expenditures account for 73.3% of all RIFA damages. Farmstead damages and equipment replacement cost account for $9.1 million and $7.4 million of RIFA damages, respectively, and livestock losses are a relatively small fraction of annual damages at $4.6 million. Somewhat surprisingly, the medical ($0.56 million) and veterinary ($0.86 million)

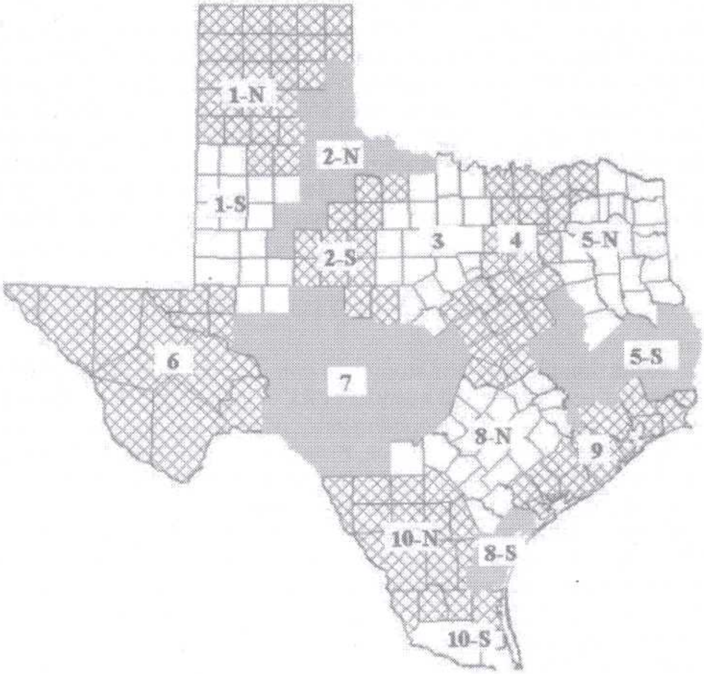

Figure 1. Texas Agricultural Districts.

Table 1. Statewide breakdown of all damages by loss and expenditure category.

Damage Category	Damage	%of Total Damage	# of Reporting Damage	%of FarmsReporting Damage
Crop Yield Loss	$33,441,777	36.92	259	7.17
Livestock Loss	$4,627,030	5.11	211	5.84
Repair Cost	$6,956,961	18.72	375	10.38
Replacement Cost	$7,390,836	8.16	135	3.74
Farmstead Cost	$9,056,496	10.00	240	6.64
Medical Cost	$561,356	0.62	87	2.41
Veterinary Cost	$860,856	0.95	40	1.11
Control Cost	$16,019,737	17.69	1,181	32.70
Equipment Cost	$1,656,983	1.83	113	3.13
State Total	$90,572,032	100.00	1,358	37.60

Note: The farm survey consisted of 3,612 observations.

[1]The value for the total number of farms reporting damages is not equal to the sum of the number of observations in each damage category. The state total value is the number of surveyed farms reporting at least one type of damage, but many farms reported more than one type of damage.

costs associated with RIFA each comprise less than 1% of total agricultural damages. Statewide totals, for the number of farms and percentage of farms reporting damages in each each specific damage category are tabulated in Table 1.

Despite an annual statewide RIFA damage estimate of $90 million, only 37.6% of the 3,612 surveyed farms reported damages in at least one RIFA related damage category, with the most common damage being expenditures for control materials (32.7%). Moreover, only 7.2% of the surveyed farms reported RIFA related crop losses even though yield losses account for nearly 37% of all damages. Hence, crop yield losses tend to be concentrated on a few farms in regions susceptible to RIFA activity or farms specializing in crops susceptible to RIFA.

In addition to damages not being uniformly distributed over damage categories, damages are not uniformly distributed over agricultural districts within the state. RIFA damages for the two Northeastern Texas Agricultural Statistical Districts (Districts 4 and 5-N) comprise more than 53% of all reported damages even though these two districts account for only 13% of the state's area. The high reported damages for these two districts may be explained by Adams et al. (1983) and Semevki et al. (1996) findings, which report that corn and soybean yields are sensitive to RIFA density levels. These two districts have a relatively high level of soybean and corn production and the RIFA density levels in these districts are the highest in the state (Thorvilson). A breakdown of total RIFA damage for each agricultural statistical district is reported in Table 2. Generally speaking, the eastern districts have the greatest percentage of farms reporting damages with nearly 73% of all farms in District 8-S reporting damages. A combination of warm temperature and high soil moisture create favorable RIFA habitat. In the hot relatively dry Texas High Plains Districts (1-N, 1-S, and 2-N) and arid District 6 of West Texas less than 1% (7 farms) of the surveyed 738 farms in these four districts reported RIFA damages. This finding is consistent with the fact that none of the 68 counties comprising these four districts are currently under a RIFA quarantine.

Table 2. Summary data on number of farms surveyed, number farms reporting damages, and total reported damages by district.

District	Total Damage	District Percent State Damages	Distric Farms Surveyed	Surveyed District Farms with Damage	Percent Farms Reporting Damages
1-N	$6,256	0.01	257	1	0.39
1-S	$66,640	0.07	262	3	1.15
2-N	$2,808	0.00	186	3	1.61
2-S	$70,556	0.08 7.73	243	6	2.47
3	$6,998,447	28.52	350	215	61.43
4	$25,826,786	24.50	506	252	49.80
5-N	$22,194,130	7.73 28.52	346	189	54.62
5-S	$7,002,361	24.50	285	126	44.21
6	$0	7.73	33	0	0.00
7	$4,590,655	0.00	325	185	56.92
8-N	$8,529,670	5.07	347	185	53.31
8-S	$6,847,868	9.42	33	24	72.73
9	$4,508,108	7.56 4.98	247	129	52.23
10-N	$2,568,191	2.84	137	37	27.01
10-S	$1,359,557	1.50	55	3	5.45
State Total	$90,572,032	100.00	3612	1358	37.60

[1]State total for percentage of farms reporting damages is a weighted statewide average value.

Statewide per Farm and per Acre Damages

Table 3 provides a statewide breakdown for the percentage of farms reporting each type of damage loss, and two average per farm damage measures by damage category. The first average per farm damage measure is limited to farms reporting a loss in each damage category, whereas the second average per farm damage measure calculates per farm damages by damage category for all surveyed farms. As expected, calculated average damages per farm, by damage category, is considerably higher for farms reporting a loss than the average for all surveyed farms. Crop yield loss is the the largest damage category under both measures at $2,145 per farm for farms reporting a crop yield loss (7.17% of surveyed farms), and $125 per farm for all surveyed farms. However, the relative ranking of the two damage measures do not always coincide. For example, livestock losses at $922 per farm is the second largest damage category for farms reporting a particular RIFA damage, but is the sixth highest ranked damage category among all surveyed farms at $22 per farm due to the fact that only 5.84% of surveyed farms reported livestock losses. Average total damage is $941 for farms reporting a damage in at least one damage category (37.6% of the surveyed farms), which is nearly three times greater than the average total damage value of $354 for all surveyed farms. Thus, using the average damage value for all farms, significantly understates the average damage to impacted farms.

Table 4 is similar to Table 3 except that damages are expressed on a per acre basis to control for differences in farm size. As before, the first damage measure calculates per acre damage by damage category for crop acreage of farms reporting damages in each damage category, whereas the second measure calculates per acre damage by damage category for all surveyed farms. Statewide, per acre yield damage is the largest damage category by both per acre measures. Moreover, on a per impacted acre basis, the ranking of the three highest damage categories is consistent with the damage ranking attained on a per

Table 3. Statewide breakdown of average farm damage by loss and expenditure category.

Damage Category	% Farms Reporting Damage by Category	Average Damage for Farms Reporting each Damage	Average per Farm Damage for all Surveyed Farms by Damage Category
Crop Yield Loss	7.17	$2,145	$125
Livestock Loss	5.84	$992	$22
Repair Cost	10.38	$664	$69
Replacement Cost	3.74	$816	$30
Farmstead Cost	6.64	$547	$36
Medical Cost	2.41	$212	$2
Veterinary Cost	1.11	$278	$4
Control Cost	32.70	$175	$57
Equipment Cost	3.13	$233	$7
Total	37.60	$941	$354

Note: The farm survey consisted of 3,612 observations.

[1] The sum of average per farm damage for each damage category does not sum to average total per farm damage for farms reporting damages. The average damage reported for each specific cost category for farms reporting damages is the average for farms reporting a specific damage. Not all farms reporting a damage have damages in all damage categories. Average total per farm damage for farms reporting damage is the average damage of all farms reporting a damage in at least one damage category.

Table 4. Statewide breakdown of per acre cropland damage by loss and expenditure category.

Category	% of Surveyed Acreage Impacted	Survey Acres Impacted	Average Damage per Acre for FarmsReporting each Damage	Average Damage per acre for all Surveyed Farms by Damage Category
Crop Yield Loss	3.26	67,627	$6.69	$0.22
Livestock Loss	1.52	31,501	$2.52	$0.04
Repair Cost	5.72	118,676	$2.10	$0.12
Replacement Cost	2.11	43,696	$2.52	$0.05
Farmstead Cost	3.00	62,228	$2.11	$0.06
Medical Cost	0.55	11,329	$0.75	$0.00
Veterinary Cost	0.79	16,282	$0.85	$0.01
Control Cost	10.87	225,272	$0.92	$0.10
Equipment Cost	1.43	29,620	$0.89	$0.01
Total	13.41	278,059	$4.60	$0.62

Note: Total crop acres for all surveyed farms is 2,073,010 acres.

[1]The sum of average per acre damage for each damage category does not sum to average total per acre damage for farms reporting damages. Average per acre cropland damage for each specific cost category is the average for the cropland acreage associated with farms reporting each specific damage. Not all farms reporting a damage had damages in all damage categories and thus impacted acres vary by damage category. Average total per acre damage for all cropland acreage is associated with farms reporting a damage in at least one damage category.

impacted farm basis, crop yield loss is highest, livestock losses are second highest, and machinery repair cost is the third highest loss category. As was the case on a per farm basis, per acre yield damage is greater for farms reporting a yield loss than for all farms ($6.69 per acre versus $0.22 per acre). Given that 7.17% of all surveyed farms had cropyield damages (Table 3) and that the acreage associated with those losses accounts for only 3.26% of all surveyed cropland (Table 4), the average farm reporting a yield loss had roughly one-half the crop acreage of all surveyed farms. As is discussed in subsequent sections, smaller farms tend to specialize in higher valued crops, such as soybean, corn, and citrus, which are more susceptible to RIFA yield losses.

District per Farm and per Acre Total Damages

Table 5 presents a statewide district level comparison for the percentage of surveyed farms reporting RIFA damage, and the two measures of per farm total damage. As before, the first measure is average total farm damage by district for farms reporting RIFA damages, and the second measure is average total farm damage by district for all surveyed farms. For farms reporting damage losses, District 10-S in South Texas has the highest noted that only 5.5% of the surveyed farms in this district reported RIFA damages. The great majority of farms in this district are not small citrus orchards and do not invest heavily in the specialized chemicals and application equipment used by citrus growers. This is borne out by the fact that the average total damage measure, per farm, for all farms surveyed in District 10-S is $515 which is only 45% higher than the corresponding statewide average per farm damage of $354. By both per farm damage measures, damages tend to be above the statewide average in the eastern districts and well below the statewide average in the western districts.

Table 6 complements Table 5 and presents the per acre total damage comparisons by district. As expected, average per acre damage for farms reporting damages is greatest in South Texas District 10-S. However, close inspection of Table 6 reveals that only 0.03% of the surveyed acres in this District are associated with farms reporting damages (exclusively citrus orchards), and per acre damage for all surveyed acreage in this District is below the state average ($0.45 versus $0.62).

Per acre damages for farms reporting damages are highest in District 5-N (northeastern Texas) at $13.25 per acre, and lowest in District 1-N (Texas panhandle) at $0.11 per acre. Over 75% of the acreage in District 5-N is associated with farms reporting RIFA damages, whereas only 0.3% of the crop acreage in District 1-N is associated with farms reporting RIFA damages. Excluding agricultural District 6, located in arid West Texas where no surveyed farm reported RIFA damage, all districts whose average farm size is less than the statewide average (Districts 3, 4, 5-N, 5-S, 6, 7, 8-N, and 9) have damages considerably above the statewide per acre average for all surveyed farms. The average per acre damage in these districts ranged from a low of $2.04 per acre to a high of $9.99 per acre in comparisions to the statewide average figure of $0.62 per acre. This result is the consequence of these districts having climatic conditions favorable to RIFA infestations and the tendency of smaller farms to specialize in higher value crops susceptible to RIFA yield losses.

Table 5. Summary data on number of farms surveyed, percentage of farms reporting damages, per farm damage for farms reporting damages, and per farm damage or all surveyed farm damages by district.

District	Number Surveyed Farms	% Surveyed Farms with Damage	Average Farm Damage for Reporting Farms	Average Farm Damage for all Surveyed Farms
1-N	257	0.39	$150.00	$0.58
1-S	262	1.15	$46.67	$0.53
2-N	186	1.61	$26.33	$0.42
2-S	243	2.47	$311.83	$7.70
3	350	61.43	$655.29	$402.53
4	506	49.80	$1,385.17	$689.85
5-N	346	54.62	$1,611.94	$880.51
5-S	285	44.21	$570.25	$252.11
6	33	0.00	$0.00	$0.00
7	325	56.92	$716.77	$408.01
8-N	347	53.31	$669.38	$356.88
8-S	33	72.73	$1,159.71	$843.42
9	247	52.23	$552.74	$288.68
10-N	137	27.01	$697.11	$188.27
10-S	55	5.45	$9,438.33	$514.82
State	3,612	37.60	$941.37	$353.93

Note: State averages are weighted averages.

Table 6. Summary data on cropland acres for farms surveyed, percentage of Cropland acres with damages, total per acre damage for cropland acres associated with farms reporting damages, and total per acre damage for all surveyed acreage by district.

District	Cropland Acreage all Survey Farms	% Surveyed Acreage of Farms Reporting at Least One Damage Category	Average Per Acre for Farms Reporting Damage	Average Per Acre Damage for All Surveyed Farms
1-N	451,528	0.29	$0.11	$0.00
1-S	271,114	0.80	$30.73	$0.00
2-N	176,646	0.65	$0.07	$0.00
2-S	300,971	2.62	$0.24	$0.01
3	63,954	40.07	$5.50	$2.20
4	164,337	56.75	$3.74	$2.12
5-N	30,508	75.39	$13.25	$9.99
5-S	22,209	77.25	$4.19	$3.24
6	5,876	0.00	$0.00	$0.00
7	58,020	40.42	$5.65	$2.29
8-N	55,611	33.13	$6.72	$2.23
8-S	131,443	29.19	$0.73	$0.21
9	35,026	52.91	$3.85	$2.04
10-N	242,182	4.08	$2.61	$0.11
10-S	63,585	0.03	$1,584.79	$0.45
State	2,073,010	13.41	$4.60	$0.62

[1] Per acre average damage for farms reporting damage is calculated as total district damage divided by total cropland acres for all surveyed district farms reporting at least one type of damage.
[2] Per acre average damage for all surveyed farms is calculated as total district damage divided by the total cropland acres for all surveyed district farms.

District Comparisions of Damage Categories

The percentage of surveyed farms reporting RIFA damages in each damage category varies considerably by district (Table 7). For example, farms reorting expenditures for control cost range from a low of 0% in District 6 to a high of 63.6% in District 8-S, with the overall state average being 32.7%. The percentage of farms reporting repair cost damages also varies considerably between districts, ranging from a low of 0% in Districts 1-N, 1-S, 2-N, and 6 to a maximum of 21.21% in District 8-S, with the state average being 10.38%. Moreover, within a district, if the percentage of farms reporting damages in a given damage category is above average, it is likely the other damage categories will have an above average percentage of farms reporting damages.

However, the relative percentage of farms reporting losses by damage category does not provide an accurate measure of the intensity of the economic damage to impacted farms. For example, 8.92% of the farms in District 7 report equipment replacement damage compared to only 2.89% in District 5-N. But for farms with equipment replacement cost damages, per farm replacement cost is nearly 14 times larger in district 5-N than in district 7 ($4,267 versus $310). In District 5-N, the high RIFA mound density levels cause frequent damage to combine cutting surfaces during harvest and the sickle must be frequently

Table 7. Percentage of surveyed farms reporting damages by district and damage category.

	Agricultural Districts							
Damage Category	1-N	1-S	2-S	2-N	3	4	5-N	5-S
Crop Yield Loss	0.00	0.00	0.00	0.00	7.14	11.07	13.29	7.37
Livestock Loss	0.00	0.00	0.00	0.00	1.43	4.74	2.89	1.40
Repair Cost	0.00	0.00	1.23	0.00	16.29	10.87	15.90	12.28
Replacement Cost	0.00	0.00	1.23	0.00	6.00	4.55	2.89	3.86
Farmstead Cost	0.00	0.00	0.00	0.00	8.86	14.03	13.87	7.72
Medical Cost	0.00	0.00	0.00	0.54	0.86	1.98	1.16	4.91
Veterinary Cost	0.00	0.00	0.00	0.00	3.14	2.17	1.45	2.46
Control Cost	0.39	1.15	1.23	1.61	59.43	41.50	47.69	37.54
Equipment Cost	0.00	0.00	0.41	0.54	1.71	4.15	10.40	3.86
Total	0.39	1.15	2.47	1.61	61.43	49.80	54.62	44.21
Sample Size	257	262	243	186	350	506	346	285

	Agricultural Districts: continued							
Damage Category	6	7	8-N	8-S	9	10-N	10-S	State
Crop Yield Loss	0.00	5.23	6.34	12.12	6.07	3.65	0.00	5.84
Livestock Loss	0.00	3.38	5.48	3.03	2.02	0.73	0.00	2.21
Repair Cost	0.00	16.31	16.71	21.21	10.93	17.52	1.82	10.38
Replacement Cost	0.00	8.92	6.92	9.09	3.24	1.46	1.82	3.74
Farmstead Cost	0.00	5.85	7.20	12.12	6.07	2.92	1.82	6.64
Medical Cost	0.00	0.31	0.58	0.00	2.02	0.00	0.00	1.11
Veterinary Cost	0.00	0.62	2.59	3.03	0.00	0.00	0.00	1.38
Control Cost	0.00	47.38	46.40	63.64	19.71	19.71	5.45	32.70
Equipment Cost	0.00	1.54	4.32	12.12	2.92	2.92	3.64	3.13
Total	0.00	56.92	53.31	72.73	27.01	27.01	5.45	37.60
Sample Size	33	325	347	33	247	137	55	3,612

Note: The total category represents surveyed farms which reported damages for at least one damage category.

replaced. Even though the incidence of farms reporting damages may be small, damages to those farms are often significant. Table 8 illustrates this point for district 5-N on a per farm and per acre basis for each specific damage category.

RIFA BENEFITS TO PRODUCTION AGRICULTURE

There is an ongoing debate concerning the existence and magnitude of potential agricultural benefits to RIFA infestations. Some researchers have found that RIFA preys on agricultural pests such as boll weevils and corn ear work (Semevski et al. 1996, Sterling 1987). If the economic magnitude of this benefit is sufficiently large, it potentially could offset RIFA damages on some crops or in some regions of the state. Table 9 reports our survey-based estimate of RIFA benefits. Probably the most interesting finding is that 3.74% (135 out of 3,612) of the surveyed farms reported RIFA benefits, but only 10 of the 135 farmers reporting a benefit could provide a dollar measure of the benefit value. As many as 10% of the farms in the heavy corn producing Districts 4,5-N, 8-N, 8-S, and 9 report benefits, but most were unable to numerically quantify the benefit value. Even though most farmers reporting benefits in these four districts were unable to quantify the benefit value they received from RIFA infestations, they generally responded that their primary benefit is due to the reduction in the corn ear work population. Other benefits mentioned less frequently were the control of ticks and the boll weevil populations. The $1.54 million statewide benefit estimate provided in Table 8 is derived only from those respondents stating there was a benefit value). Thus, it is likely that our survey results significantly understates the statewide agricultural benefit.

Table 8. District 5-N per farm and per acre damages by damage category.

	Per Farm			Per Acre		
	Percent Farms with Damage	Farms Reporting Damage	All Farms Surveyed	Percent Acreage w/ Damage	Farms Reporting Damage	All Farms Surveyed
Crop Yield Loss	13.29	2,524.65	335.65	48.01	7.93	3.81
Livestock Loss	2.89	865.00	25.00	9.95	2.85	0.28
Repair Cost	15.90	876.09	139.26	46.77	3.38	1.58
Replacement Cost	2.89	4,267.00	123.32	2.88	48.54	1.40
Farmstead Cost	13.87	1,119.90	155.36	42.19	4.18	1.76
Medical Cost	1.16	188.75	2.18	0.10	25.17	0.02
Veterinary Cost	1.45	185.00	2.67	10.80	0.28	0.03
Control Cost	47.69	165.69	79.01	61.17	1.47	0.90
Equipment Cost	10.40	173.42	18.04	35.13	0.58	0.20
Total	54.62	1,611.94	880.51	75.39	13.25	9.99

Note: Not all farms reported damages in all damage categories. Thus, the number of farms and their associated acres vary by damage category. Average total per farm and per acre damage for farms reporting damage is for those farms and associated acreage reporting damage in at least one damage category.

CONCLUSION

RIFA damages annually cost Texas agricultural producers $90 million. Reduced crop yields accounts for nearly 37% of these losses. Machinery repair costs and expenditures for chemical and mechanical controls account for another 36.4% of the agricultural damages. Medical and veterinary costs collectively comprise only 1.57% of the cost imposed on agricultural producers. Over 92% of surveyed farms reporting RIFA benefits were unable to quantify the benefit value. Only 10 out 135 farms reporting RIFA benefits were able to quantify the benefit value. Only 10 out of the 135 farms reporting RIFA benefits were able to quantify the benefit value. Thus, it is likely that the agricultural benefit is significantly understated.

Agricultural damage is not uniformly distributed over the state, as over 53% of statewide damages are concentrated in the northeastern corner of the state. Hight precipitation levels create favorable RIFA habitat, and those areasof the state generally have largest RIFA damages. Crop selection is also a factor in RIFA damage estimation. Citrus growers spend more than 10 times the state average on control measures and special application equipment for crop protection. Producers of lower value agricultural crops find it more cost-effective to accept RIFA-induced yield losses instead of attempting to control RIFA infestations. Statewide, crop yield loss damages are more than two times larger than control cost expenditures which suggests that existing control technologies are not cost

Table 9. Summary data on number of farms surveyed, percentage of surveyed farms reporting benefits, number of farms reporting benefits, and total benefits by district.

		Farms Reporting Benefits but Unable to Quantify Benefit Value		Farms Reporting Benefits and Able to Quantify Benefit Value		
District	Surveyed Farms	Percent	Number	Percent	Number	Estimated Benefit
1-N	257	0.00	0	0.00	0	$0
1-S	262	0.38	1	0.00	0	$0
2-N	186	0.00	0	0.00	0	$0
2-S	243	0.00	0	0.00	0	$0
3	350	1.43	5	0.57	2	$6,558
4	506	4.94	25	0.99	5	$1,500,204
5-N	346	6.65	23	0.87	3	$31,503
5-S	285	2.81	8	0.00	0	$0
6	33	0.00	0	0.00	0	$0
7	325	3.38	11	0.00	0	$0
8-N	347	10.37	36	0.00	0	$0
8-S	33	9.09	3	0.00	0	$0
9	247	8.10	20	0.00	0	$0
10-N	137	2.19	3	0.00	0	$0
10-S	55	0.00	0	0.00	0	$0
State	3,612	3.74	135	0.28	10	$1,538,264

Note: Estimated district benefit was calculated by applying the TASS expansion factors to the survey benefit data.

effective for agricultural producers producing lower value crops. Areas of the state specializing in corn, soybean, sorghum, peanut and rice production generally report higher per acre yield loss damages than other areas of the state. Additional research is needed on understanding crop yield response for these five crops to RIFA density levels, and the rate of RIFA spread. Knowledge of these bio-physical relationships will enhance the ability of agricultural economists to target areas of Texas where comprehensive RIFA control programs will be cost-effective.

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Grain Sorghum Desiccation with Sodium Chlorate and Paraquat in the Texas Rolling Plains

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ABSTRACT

Grain sorghum [*Sorghum bicolor* (L.) Moench] is frequently planted in late June and early July in many parts of the Rolling Plains. Late planting results in grain maturing under unfavorable environmental conditions, prolonging high grain moisture content. Field studies were conducted at the Chillicothe Research Station, Chillicothe, Texas to evaluate grain sorghum desiccants that could accelerate grain moisture loss. Desiccation treatments of sodium chlorate at 6.7 and 13.4 kg/ha or paraquat at 0.7 and 1.4 kg/ha were applied to a medium-late-maturing grain sorghum hybrid. In both years, desiccation treatments did not affect grain moisture loss during the 16 days after treatment. These results indicate that desiccants are generally ineffective in reducing grain moisture for late-planted sorghum in the Rolling Plains of Texas especially when grain moisture is < 24% at application and high relative humidity follows desiccant application.

KEYWORDS: chemical desiccants, grain moisture loss, *Sorghum bicolor*

INTRODUCTION

Grain sorghum production in Texas exceeds 1.2 million hectares most years. However, production in the Rolling Plains is less stable than other areas of the state due to dryland production and periodic droughts that greatly affect yield. From 1994 to 1998, planted hectares in Districts 2N and 1S (comprising most of the Rolling Plains) has varied from 42 to 93 thousand hectares. Harvested hectares as a percentage of planted hectares also varies greatly depending on environment: from a high of 91% in 1997 to a low of 36% in 1998. Generally, 75 to 90% of the planted hectares is harvested for yield[1]. Many of the hectares are planted in early spring.

Late grain sorghum planting (late June/early July) in the northern Rolling Plains normally results in higher yields (Clark, 1997), but maturity is delayed into fall when environmental conditions are not as favorable for grain moisture loss as when grain matures in the heat of summer. Ideally, grain sorghum should be harvested when seed moisture content is < 13%. Local grain handling facilities are not equipped to dry sorghum to a suitable level for storage. Therefore, a hard freeze is typically necessary to kill late-planted sorghum

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[1] Texas Agricultural Statistics, 1994 to 1998. Compiled by the Texas Agricultural Statistics Service, United States Department of Agriculture and Texas Department of Agriculture. P.O. Box 70, Austin, TX 78767.

plants and subsequently dry the grain to acceptable harvest moisture levels. Cool weather delays grain moisture loss and harvest. Delay in harvesting increases lodging and bird damage and reduces seed quality and yield (Clark 1997). Previous research with grain sorghum by Bovey and McCartey (1965) demonstrated that the chemical desiccants such as magnesium chlorate and diquat {6,7-dihydrodipyrido[1,2-%:2',1'-c]pyrazinediium ion} applied to the leaves and head will accelerate grain moisture loss when moisture contents were initially high; i.e. 38% or above. Desiccation treatments were less effective when initial seed moisture was 32% or less. Other chemicals such as paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) and cacodylic acid (dimethyl arsinic acid) applied to grain sorghum also enhanced leaf desiccation of mature stands (Bovey and Miller 1968). Regehr et al. (1996) observed significant decreases in grain moisture over a 3-wk period when grain sorghum was treated with either sodium chlorate or diquat at an initially high grain moisture content of 49%. Donnelly et al. (1977) documented accelerated grain moisture loss from a foliar nitrogen application until grain moisture content reached 20 to 25%. At this point, rainfall and high humidity negated any additional grain moisture loss. There is no information on the effects of desiccation treatments on grain moisture loss with late-planted grain sorghum in a semi-arid environment such as the Rolling Plains.

The objective of this paper is to determine if chemical desiccation treatments of sodium chlorate and paraquat are effective in accelerating harvest maturity following black layer formation (i.e. physiological maturity of the grain) in a medium-late-maturing grain sorghum hybrid planted late in the season in the Texas Rolling Plains.

MATERIALS AND METHODS

A medium-late-maturing hybrid (W625Y) was planted into an Abilene clay loam (fine, mixed, thermic, Pachic Arguistoll) at 11.5 and 13 seeds/m on 26 June 1998 and 8 July 1999, respectively, at the Texas Agricultural Experiment Station near Chillicothe, TX. The area was fertilized with 56 kg/ha N and 34 kg/ha P on 26 June 1998 and 7 July 1999. Propazine at 0.9 kg/ha was applied for early season weed control on 27 June 1998 and 9 July 1999, whereas pendimethalin at 0.84 kg/ha was applied and incorporated with a rolling cultivator on 7 August 1998 and 6 August 1999 for late season weed control. Plots consisted of four rows on 1-m centers and 4.9 m long. The site was pre-watered and received only one additional irrigation in each year. When about 50% of the sorghum kernels reached black layer or physiological maturity, sorghum was treated over the top with either sodium chlorate at 6.7 and 13.4 kg/ha or paraquat at 0.7 and 1.4 kg/ha. A non-ionic surfactant, Latron AG-98, was added with paraquat at 0.25% v/v. Treatments were applied on 19 October 1998 and 4 November 1999. Dessicants were applied at 140 L/ha using a CO_2-propellant sprayer equipped with four Turbo-Teejet 11002 nozzles[2] spaced 51 cm apart. Grain sorghum heads were harvested from the center 4-m section of a single row at 0, 4, 8, and 16 days after treatment (DAT), threshed with a plot combine, and grain moisture determined.

The experiments were arranged as a randomized complete block design with four replicates per treatment. Data were analyzed using analysis of variance, and means were separated with a Least Significant Difference (LSD) at 0.05. The interactions tested were the 4-way interaction of year by harvest interval by chemical treatment by application rate, and then all subsequent 3- and 2-way interactions were tested.

RESULTS AND DISCUSSION

Desiccation treatment combinations of chemical treatment by application rate had no affect on grain moisture loss. The only effect that was recorded was harvest interval

[2]Spraying Systems Co., North Ave. at Schmale Road, Wheaton, IL 60189.

within year. As expected, grain moisture decreased over time (Table 1). In both years, desiccants were applied to grain sorghum with moisture ranging between 19 and 25% (Table 2). The lower grain moisture content probably attributed to the desiccants ineffectiveness at drying down the grain. These results do not exhibit the same level of grain moisture loss observed by Regehr et al. (1996) and Bovey and McCartey (1965). In several of their treatments, grain sorghum was desiccated when initial grain moisture content exceeded 30%, resulting in significant moisture loss compared with non-treated grain. However, application of desiccants to grain with moisture content less than 30% was much less effective in reducing grain moisture content. Additionally, high relative humidity following desiccant application may have reduced the efficacy of the desiccants (Table 3). Donnelly et al. (1977) noted little benefit from urea-ammonium nitrate desiccation treatments when initial grain moisture content was lower than 20 to 25% and relative humidity was high.

Table 1. Grain moisture 4, 8, and 16 days after treatment. Grain moisutre data were combined across harvest dates and treatments.

Harvest interval	Grain moisture	
Days	1998	1999
0	24.4	19.3
4	25.1	16.9
8	20.5	15.5
16	18.1	13.0
LSD (0.05)	------------0.8------------	

Table 2. Grain sorghum moisture content for each chemical treatment by application rate and harvest interval combination in each year at 4, 8, and 16 days after treatment.

Year	Treatment	Rate kg ai/ha	Grain Moisture* 4	8	16
			------------%----------		
1998	Sodium Chlorate	6.7	24.7	21.7	18.5
		13.4	26.3	20.2	17.9
	Paraquat	0.7	24.7	20.2	17.7
		1.4	25.2	20.6	17.3
	No treatment		24.5	20.0	19.2
1999	Sodium Chlorate	6.7	16.5	16.2	13.3
		13.4	17.1	15.7	13.0
	Paraquat	0.7	17.4	15.6	12.9
		1.4	16.7	15.4	12.4
	No treatment		16.9	14.8	13.3
LSD (0.05)			NS	NS	NS

*Initial grain moisture content on date of treatment was 24.4% and 19.3% in 1998 and 1999, respectively.

Table 3. Maximum (max) and minimum (min) relative humidity (%) from the day of desiccant application to 16 days after treatment in 1998 and 1999.

DAT	1998		1999	
	max	min	max	min
1	100	32	92	89
2	96	20	93	89
3	98	80	94	42
4	98	30	97	38
5	100	30	91	38
6	100	32	81	42
7	100	20	93	37
8	100	34	-	-
9	98	68	88	30
10	98	50	-	-
11	98	30	-	-
12	98	16	82	29
13	100	54	92	26
14	100	100	82	22
15	100	80	84	22
16	100	60	76	27
	98	70	-	
Ave.	99	47	89	41

Although the desiccants were ineffective in this environment, desiccants may provide better grain dry down under more favorable environment conditions. However, the possibility of observing a small decrease in grain moisture may not justify the application cost of paraquat or sodium chlorate which ranges from $3.00 to $9.00/ha.

With current grain prices, dryland grain sorghum production in the Texas Rolling Plains is marginally profitable, even in years with favorable environments. Desiccating plants when the majority of the sorghum kernels have not reached physiological maturity and are still high in moisture content will most likely result in yield loss, further reducing profitability.

Results from our 2-yr study indicate that desiccant applications were generally ineffective (and most likely uneconomical) in reducing grain moisture in late-planted grain sorghum.

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Food Habits and Dietary Overlap of Elk and Mule Deer In Guadalupe Mountains National Park, Texas

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ABSTRACT

Botanical composition of elk *(Cervis elaphus nelsoni)* and mule deer *(Odeocoileus heminous crooki)* diets was determined using microhistological examination of fecal material from March, 1978 through February, 1979 in Guadalupe National Park, Texas. Annual diets of elk consisted of 48% browse, 32% grasses, and 20% forbs. Oaks *(Quercus spp.)*, desert ceanothus *(Ceanothus greggii)*, curlyleaf muhly *(Muhlenbergia setifolia)*, blue grama *(Bouteloua gracilis)*, and common horehound *(Marrubium vulgare)* were the major forages used by elk. Annual mule deer diets consisted of 77%browse, 21% forbs, and 2% grasses. Oaks, desert ceanothus, mountain mahogany *(Cercocarpus montanus)*, bladderpods *(Lesquerella spp.)* were the primary forages consumed by mule deer. Overall, annual dietary overlap was moderately high (58%). Overlap was greatest in the browse component and was highest during spring (91%) and summer (65%).

KEYWORDS: competition, elk, food habits, mule deer

Declines in elk (*Cervus elaphus nelsoni*) numbers over recent years in Guadalupe Mountains National Park, Texas (GMNP) has become a growing concern to GMNP resource managers and various wildlife groups. Elk inhabiting the southern Guadalupes in Texas and New Mexico are descendants of 45 animals released in McKittrick Canyon, Texas in 1929. After their introduction, elk dispersed throughout GMNP (Davis, 1940). Early information on elk population growth is limited. Wright and Thompson (1934) estimated that the herd of 45 had increased to 60 by 1934, while Davis (1940) estimated the population at 400 animals in 1938. Efforts to obtain information on elk population dynamics were initiated in 1954 when Texas Parks and Wildlife Department (TPWD) began annual censuses. The fist survey estimated 100-150 elk (Uzzell, 1954). Estimates during the early to mid-1960's indicated a peak population of 350 animals (TPWD, unpublished project reports). Beginning in 1966, TPWD censuses showed steady declines in elk numbers (TPWD, unpublished project reports). TPWD's last 3 censuses, conducted 1971 to 1973, each indicated a population of 225 elk (TPWS, unpublished project reports). Mammal surveys conducted in 1973 and 1975 by Genoways et al. (1977) estimated only 100-150 elk within GMNP. Censuses conducted during 1976 and 1978 put the elk population number at 104 and 111 animals, respectively (Moody, 1979).

Desert mule deer (*Odeocoileus heminous crooki*) are common in GMNP. A recently completed census estimated the population to be over 600 animals with little fluctuation in animal numbers observed over recent years (R. Reisch, pers. Comm.,1980). According to

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Mike Hibson (Texas Parks and Wildlife, unpublished data) he found 35 mule deer per 1,000 acres in 1978 and 47 mule deer 1,000 acres in 1979. From the time period of 1980 to 1990, there were an estimated 23 mule deer per 1,000 acres and only 14 mule deer per 1,000 acres from 1991 to 2001.

The objective of this study was to evaluate potential competitive interactions between elk and mule deer for available forage and determine if this is a possible explanation for declining numbers of elk in Guadalupe Mountains National Park, Texas.

MATERIALS AND METHODS

The study was conducted in Guadalupe Mountains National Park in Culberson and Husdpeth counties in the Trans-Pecos region of Texas. Eleven vegetation types occur in GMNP (Glass et al., 1974) and are further described by Bunting (1978) and Krysl (1979). Four major vegetation types accounted for 92% of the total study area. These include: (1) the creosotebush type, which is found on the very shallow, rocky soils of the fans and flats, (2) the mountain shrub vegetation type, which is the most abundant type within the study area, (3) the desert shrub type, which usually occurs on more xeric sites that those occupied by the mountain shrub vegetation type, and (4) the coniferous forest type, which is found predominantly at higher elevations and at low elevations in the heads of major drainage systems.

Approximately 30 mule deer and 30 elk fecal group samples (+/- 2 samples) were collected each month from March, 1978 through February, 1979. We attempted to collect monthly fecal samples from all vegetation types within GMNP; however, this was not always possible because of the seasonal inaccessibility of some areas. Each vegetation type was visited at least once during each season of the year.

Microscopic slides were prepared of reference and fecal material as described by Free et al. (1970). Microhistological examination of fecal material followed the procedures outlined by Sparks and Malechek (1968). Twenty microscope fields were examined at 100x magnification for each sample. Similarity of diets between elk and mule deer was calculated using Kulcyznski's formula (Oosing, 1956). The similarity index represents the percentage of the 2 diets that are identical. For seasonal analysis of food habits, 4 seasons were used to correspond to plant phenology in GMNP. The seasons were: Winter (December-February), Spring (March- May), Summer (June-August), and Fall (September-November).

RESULTS AND DISCUSSION

Elk Food Habits

Annual diets of elk consisted of 48% browse, 32% grasses, and 20% forbs. Oaks (*Quercus undulata, Quercus pungens, Quercus grisea*) were the dominant browse used during all seasons of the year (Table 1). Heavier use of oaks have been attributed o their high protein level throughout the year than found in other shrubs (Swank, 1958). Forbs were consumed predominantly during the fall and winter seasons, whereas grasses were used primarily during spring and summer (Table 1).

The high percentage of browse in annual diets of elk (48%) was considerably higher than reported elsewhere (DeNio, 1938; Morris and Schwarts, 1957; Mackie 1970; Anthony and Smith, 1974). Annual diets of elk usually are dominated by grass rather than browse as demonstrated for Roosevelt elk (63% grass) in California (Harper, 1963), southern Colorado elk (73% grass) (Hansen and Reid, 1974), and Pecos Basin elk (83% grass) in New Mexico (Burt and Gates, 1959). Kufeld (1973) combined various studies conducted in

Table 1. Vegetation (mean %) making up 3 % or more of a seasonal diet for elk in Guadalupe Mountains National Park, Texas.

Forage	Season of Year			
	Spring	Summer	Fall	Winter
Grasses:				
Curly leaf muhly	8	3	2	2
Blue grama	7	8	6	4
Littlelawn needlegrass	5	1	2	5
Threeawns	5	1	2	5
Western wheatgrass	4	t	t	1
Sideoats grama	3	t	t	t
New Mexico needlegrass	3	t	t	t
Wolftail	t	4	3	2
Indiangrass	t	3	3	1
Forbs:				
Bladderpods	5	t	-	-
Common horehound	3	3	12	19
Leatherweed croton	t	6	9	6
Narrowleaf globemallow	t	2	4	3
Browse:				
Oaks	27	29	35	31
Desert ceanothus	9	9	2	t
Forage:				
Mountain mahogany	4	2	t	t
Alligator juniper	t	-	-	5
Total:	81	72	80	83

t = <1.0%

Montana and determined the year-long elk diet consisted of 68% grasses, 25% forbs, and 7% browse. Forbs were predominantly used during the summer season in Montana, accounting for 64% of the total seasonal diet in that area. The preponderance of browse in elk diets in our study, coupled with a lack of season variation in browse consumption, suggests high use was related to an abundance of palatable browse, rather than a preference for woody species. Grasses were readily available.

Elk can consume high levels of browse in winter. Trout and Leege (1971) reported that elk during the winter in Idaho used 82% browse. Similarly, Lang (1958) found mountain mahogany (*Cercocarpus montanus*) and oak to be the primary plants eaten during winter, comprising 32% and 16% of the diet, respectively.

Mule Deer Food Habits

Annual diets of mule deer consisted of 77% browse, 21% forbs, and 2% grasses. Browse was the major forage type taken by mule deer in all seasons (Table 2). Forbs were consumed by mule deer, predominantly during the winter and spring seasons with cool season species forming the majority of the forb component (Fig. 2 and Table 2). Mule deer used grasses primarily during summer (Fig. 2). Littleawn needlegrass (*Stipa lobata*) and *Muhlenbergia* sp. were the primary grass species in the deer's annual diet.

Table 2. Vegetation (mean %) making up 3 % or more of a seasonal diet for mule deer in Guadalupe Mountains National Park, Texas.

Forage	Season of Year			
	Spring	Summer	Fall	Winter
Forbs:				
Bladder Pods	12	t	-	10
Grandleaf Midlwort	3	t	t	t
Flannel Mullein	-	-	3	1
Leatherweed croton	t	t	3	3
Browse:				
Oaks	20	38	38	31
Desert ceanothus	17	15	5	2
Mountain mahogany	16	8	17	10
Apache plume	6	4	3	3
Junipers	6	2	4	13
Skunkbush	t	6	3	t
Total:	81	84	76	74

t=<1.0%

Oaks, mountain mahogany, and desert ceanothus (*Ceanothus greggii*) were dominant browse plants consumed by deer in GMNP throughout the year, comprising 54% of the annual diet. Boeker et al. (1972) determined that oaks and mountain mahogany accounted for 56% of the annual diet in mule deer in southwestern New Mexico. Anderson et al. (1965) reported that wavyleaf oak (*Quercus undulata*), junipers (*Juniperus* spp.), hairy cercocarpus (*Cercocarpus montanus*) and yucca (*Yucca* spp.) species represented 54% of the annual diet. Stewart (1959) determined that oaks, junipers, mountain mahogany, and ceanothus comprised 43% of the annual diet for mule deer in the Capitan Mountains, New Mexico. He reported that oaks accounted for 27% of the annual diet and was the primary browse species consumed, which was similar to the results found in our study.

Dietary Overlap

The overall dietary similarity indices suggests that the overlap between elk and mule deer was moderate for all seasons combined (Table 3). However, there was a high degree of overlap in the browse component during all seasons except summer. Elk and mule deer relied heavily on browse throughout the year.

Table 3. Seasonal mean similarity indexes (%) generated between mule deer and elk in Guadalupe Mountains National Park, Texas.

	Season of Year				
Forage	Spring	Summer	Fall	Winter	Annual
Grasses	8	5	16	13	11
Forbes	24	59	25	35	36
Browse	91	65	75	75	77
Overall	60	55	57	60	58

Among the browse, oaks were predominant, and accounted for 31% of the annual diets for both elk and mule deer. Mountain mahogany, desert ceanothus, and junipers comprised the majority of the remaining dietary browse component for both ungulate species. Our data generated a browse similarity index of 77% on an annual basis (Table 3), with the highest seasonal overlap occurring in browse in the spring diet (91%). This was a response by both animal species to new browse growth in spring, prior to initial growth of grasses in GMNP. With growth and foliation of the grasses occurring in late spring and early simmer, the elk diet changed toward grasses, hence the observed drop in the summer browse similarity indices (Table 3).

Annual diet similarity indices for forbs and grasses were low, averaging 37% and 13% respectively. Forbs in the diets of elk and mule deer overlapped primarily in the summer and winter seasons, while the overlap for grasses was greatest during the fall and winter seasons (Table 3).

Hansen and Reid (1974) found the overall dietary overlap between mule deer and elk in southern Colorado ranged from 3% in winter to 48% in summer. Our results suggest a greater dietary overlap during winter than they reported, which suggests that in GMNP there may be a greater potential for competition between mule deer and elk during this particular season than that found in southern Colorado.

CONCLUSIONS

At the time of this study, elk populations were about 100% greater than they are today, while mule deer populations were about 300% greater. Although diets of elk and mule deer were moderately similar, there is no direct evidence that competition for food affected populations of either species because both species have declined at this time. Browse plants are used significantly, but browse species are also abundant. The downward trend in elk numbers from the 1930 to 1960 era suggest population estimates at the time of this study may simply be a phenomenon of elk reaching a stable equilibrium with the habitat. It is unknown how much predation, changing habitat, and environmental factors have negatively affected populations since the early 1980s.

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Response of Isozymes in *Allium* to Thermal and Aerobic Stress

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ABSTRACT

Screening for tolerance to stress can be an expensive and time consuming process, and can be difficult to accurately assess. If molecular markers could be identified that are linked to tolerance to a specific stress, selection would be more exact. We tested two species of onion using 18 enzyme systems to ascertain utility of the isozymes as markers for stress tolerance. Only alcohol dehydrogenase exhibited promise of differential expression under different stress conditions. Inducibility, however, was not consistent.

KEY WORDS: breeding selection, marker selection, onion

As plant breeders, we are interested in identifying molecular markers to assist in selection of onion plants tolerant to stress. Isozymes are preferred markers for us because we use isozymes routinely in our breeding program, and they have been used to detect changes in hardiness in other plant species (Faw and Jung, 1972, cited by Kang and Titus, 1987). Isozymes are easily extracted and electrophoresed, many plants can be assayed in a single day, relatively little plant material is required, and they usually demonstrate repeatable and consistent banding patterns. Among enzymes which have exhibited variant alleles in response to stress in other systems are alcohol dehydrogenase (Benfey and Chua, 1989), glucose-6-phosphate dehydrogenase (Sadakane and Hatano, 1982), glutathione reductase (Guy and Carter, 1984), and malate dehydrogenase (DeJong, 1973). Benfy and Chua (1989) report that changes in gene expression accompanying oxygen deprivation are similar to those of thermal stress and that ADH is an inducible enzyme. Thus, the conditions for our study were cold and oxygen deprivation. Our study was conducted to ascertain if enzyme systems could be identified in *Allium* in which novel isoforms would be exhibited consistently and with sufficient resolution when plants were exposed to stress conditions.

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MATERIALS AND METHODS

Leaf and root material of *Allium cepa* cv 'Temprana.' *A. fistulosum* var 'Heshiko,' and interspecific (Allium *fistulosum* x A. *cepa)* hybrids were extracted in either glutathion buffer [1.5% (w/v) glutathion in 0.1M Tris buffer pH 3.5 with a final pH 7.0-7.5] or dithiothreitol (DDT) buffer (10mM DTT in 75mM Tris-HCI pH 8.5). Extracts were electrophoresed on horizontal starch or polyacrylamide gel systems. Horizontal starch: 12% starch of Tris-Citrate and Histidine buffer systems (Vallejos, 1983), or 13% starch of F system for maize (Stuber et al, 1988). Polyacrylamide: protocol followed Hanson and Jacobsen (1984) with these modifications: 20% (w/v) sucrose was added to the running gel; gels were run with 0.12 M Tris-0.96 M glycine buffer (pH 8.5) in both electrode tanks (Laemmli, 1970) pulsed 3 h at 10 mamps and run 16 h at 15 mamps at 40°C.
Eighteen enzymes were studied. Those stained after Vallejos (1983) were: alcohol dehydrogenase (ADH; E.C.1.1.1.1), diaphorase (DIA; E.C.1.6.-.-), glucose phosphoisomerase (GPI; E.C.5.3.1.9), glutamate oxaloacetate transaminase (GOT; E.C.2.6.1.1), isocitrate dehydrogenase (IDH; E.C.1.1.1.42), lactate dehydrogenase (LDH; E.C.1.1.1.27), malate dehydrogenase (MDH; E.C.1.1.1.37), malic enzyme (ME; E.C.1.1.1.40), peroxidase (PRX; E.C.1.11.1.7), phosphoglucomutase (PGM; E.C.2.7.5.1), 6-phosphoglucanate dehydrogenase (6-PGDH; E.C.1.1.1.44), shikimate dehydrogenase (SKDH; E.C.1.1.1.25), superoxide dismutase (SOD; E.C.1.15.1.1), triosephosphate isomerase (TPI; E.C.5.3.1.1); and after Acquaah (1992): amylase (AMY; E.C.3.2.1.-), glutathion reductase (GR; E.C.2.7.5.1), succinate dehydrogenase (SUD; E.C.1.3.99.1), xanthine dehydrogenase (XDH; E.C. 1.2.1.37).

Plants of each genotype were grown at the TTU Greenhouse in 3" pots for 12 weeks under 25°C ambient conditions and then subjected to one of two stress treatments. Following stress treatments, plants were returned to the greenhouse. Plants either were held in a growth chamber at 5°C for seven days, tissue was electrophoresed on days 3 and 7 during treatment and on days 3 and 7 after treatment under greenhouse conditions; pots were held at ambient greenhouse conditions, 25°C, but immersed in water for seven days with samples electrophoresed on days 3 and 7 during treatment and days 3, 7, and 14 after plants were no longer flooded. Control plants were maintained under ambient greenhouse conditions in the greenhouse.

Cloned 'Heshiko' individuals were collected after plants multiplied as tillers. Individuals heterozygous for ADH-1, $Adh\text{-}1^3/Adh\text{-}1^6$, were selfed and genotypes $Adh\text{-}1^3/Adh\text{-}1^6$ and $Adh\text{-}1^6/Adh\text{-}1^6$ selected for further analyses and were also crossed with genotypes $Adh\text{-}1^4/Adh\text{-}1^4$ in order to recover $Adh\text{-}1^4/Adh\text{-}1^6$ individuals for comparison studies of expression of allele 6 (Mangum and Peffley, 1994). Treatments were conducted on clones of Heshiko that expressed $Adh\text{-}1^3/Adh\text{-}1^3$ (3/3), $Adh\text{-}1^3/Adh\text{-}1^4$ (3/4), $Adh\text{-}1^3/Adh\text{-}1^6$ (3/6), and $Adh\text{-}1^4/Adh\text{-}1^6$ (4/6). One individual was grown under ambient greenhouse conditions as an experimental control, while a sister clone was placed under one of each stresses. Tissue of control plant was extracted prior to stress and electrophoresed.

RESULTS AND DISCUSSION

Enzyme resolution appears in Table 1. Polymorphism between species was observed for ADH, DIA, GPI, IDH, LDH, MDH, ME, 6-PGDH, PGM, PRX, SKDH, and TPI. AMY and GR did not resolve on any of the gel systems used. ADH was the only enzyme exhibiting an altered banding pattern following either stress treatment; subsequent investigations focused on expression of ADH.

Table 1. List of enzymes exhibiting resolution.

LOCUS	polymorphism Ac	Af	Plant material	Gel system	LOCUS	polymorphism Ac	Af	Plant material	Gel system
Adh-1	f	s[1]	rts	TC,P	6-Pgdh-2f	s	rts,lvs	F	
Dia	f	s	rts,lvs	F	Prx	f	s	rts,lvs	TC
Got			rts,lvs	P	Pgm	f	s[1]	rts,lvs	TC,P
Gpi-1	f	s[1]	rts,lvs	His	Sod			rts	TCP
ldh-1	f	s[1]	rts	His	Skdh-1	f	s	rts,lvs	TC,F,P
Ldh	f	s	rts	His	Sud			rts,lvs	TC,F,P
Mdh	f	s	rts	TC,F,P	Tpi	f	s	rts,lvS	TC,F,P
ME	f	s	rts	TC	Xdh			rts	F,P
6-Pgdh-1	s	f[2]	rts,lvs	F					

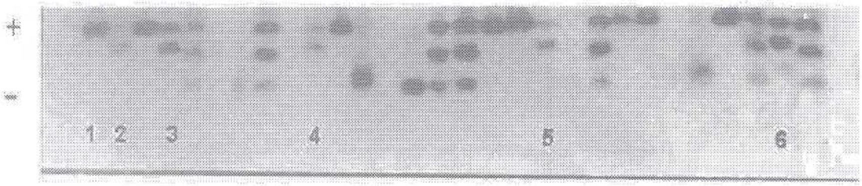
Ac = *Allium cepa;* Af = *A. fistulosum*
TC = Tris-Citrate, His = Histidine, F = F system for maize, P = Polyacrylamide
1 = described in Peffley et al., 1985.
2 = described in Mangum and Peffley, 1994.

Heshiko plants with *Adh-1*^{3}/*Adh-1*^{6} genotype when not stressed exhibited the expected banding pattern for a dimeric enzyme, i.e., with a faster migrating band *Adh-l*^{3}, a slower migrating band *Adh-1*^{6}, and a band of intermediate mobility, the heterodimer. Lanes exhibiting all three bands were scored as *Adh-1*^{3}/*Adh-1*^{6s}, the 's' designating the presence of a 6/6 homoallele (Fig. 1, lanes 3 and 6). Allele 6 always disappeared after *Adh-1*^{3}/*Adh-1*^{6s} plants were exposed to stress, but the heterodimer, 3/6, and the 3/3 bands remained, leaving a pattern with two bands (Fig. 1, lanes 2, 4, and 5). Throughout this study, any individual expressing only the two faster, cathodal bands was scored as *Adh-1*^{3}/*Adh-1*^{6}.

Adh-1^{3}/*Adh-1*^{6s} plants grown under ambient greenhouse conditions and expressing the 6/6 band were placed into the growth chamber at 5°C for seven days. The 6/6 homoallele disappeared in all plants after three days of cold treatrnent. After seven days of stress, plants were returned to greenhouse conditions and usually the 6/6 reappeared after three days. In many individuals, the 6/6 homoallele did not reappear even after seven days. *Adh-1*^{3}/*Adh-1*^{6s} plants exposed to anaerobic stress also lost activity of the slow band after three days, the slow allele returned in all plants only after the plants had been in greenhouse conditions for 14 days.

When the *Adh-1*^{6} protomers bind other allele 6 protomers, making a functional 6/6 enzyme, a slow band appears. Even when the slow band appears, however, it stains less intensely than the expected 1:2:1 ratio exhibited when all subunits reassociate in ratios expected for a dimeric enzyme. The allele 6 protomers apparently are still translated under stress conditions, else the heterodimer would not be present. However, the binding of 6/6 homoprotomers is either not functional, loosely-associated in its quanternary structure or the binding is very sensitive to stress conditions. An aberrance perhaps related to the fitness of plants with the 6/6 genotype has been observed in an independent study where controlled crosses yielded fewer than the expected number of 6/6 progeny (Mangum and Peffley, 1994).

We could induce the loss of the 6/6 band, but we could not always induce the reappearance of the 6/6 band. This pattern was observed over a two-year period after repeated runs of Heshiko material. The qualifications for a molecular marker are that they are predictable and reliable. After eight repeated tries with starch and polyacrylamide gels, we could resolve the 6/6 homoallele in only 19 of 109 plants, thus disqualifying its use as a marker for stress.



Photograph of *Allium* electrophoretic gel of ADH-1. Lane 1 *Adh-1*^{3}/*Adh-1*^{3}; lanes 2, 4, and 5 *Adh-1*^{3}/*Adh-1*^{6}; lanes 3 and 6 *Adh-1*^{3}/*Adh-1*^{6a}.

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Nutritional Evaluation of Low-Grade Corn for Ruminants

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ABSTRACT

Two experiments, involving in vitro evaluations and one metabolism study, were conducted to determine the digestibility and utilization of low grade corn (corn that suffered germ discoloration because of respiration damage). Seven samples of corn grain containing various percentages of total kernel damage (TKD) were obtained either from a grain exchange or a grain elevator in the Texas High Plains. Diets evaluated contained: 1) No. 1 grade, 2% TKD; 2) No. 2 grade, 4.8% TKD; 3) No. 5, 11.8% TKD; 4) sample grade (SG), 18.6% TKD; 5) SG, 20.1 % TKD; 6) SG, 41.6% TKD; and 7) SG, 55% TKD. In vitro DM and OM digestibilities and pepsin digestible protein (PDP) did not differ ($P > .05$) among the seven samples. Moreover, the samples were similar in ash, CP, ADF, and starch content and readily available starch. Ether extract values were less (1.5 to 2.2%) than commonly reported for corn and increased ($P < .05$) linearly as TKD increased. In a metabolism study with sheep, four treatments were evaluated: 1) 75% No. 1 grade corn; 2) 37.5% No. 1 and 37.5% SG; 3) 18.75% No. 1 and 56.25% SG; and 4) 75% SG corn. Digestibilities of dietary DM and OM, ADF, and nitrogen (N) as well as retention of dietary N in growing wethers did not differ ($P > .05$) when No. 1 corn was replaced with SG corn. Therefore, SG is a nutritionally viable alternative to No. 1 corn in ruminant diets.

KEY WORDS: Low Grade Corn, Ruminants, Digestibility, Starch Availability

Corn grain is a major source of dietary energy for livestock in the U. S., particularly in growing and finishing diets of beef cattle. Grain for cattle feeding is often purchased from external sources and grain quality is important. The USDA has a grain grading system for standardization and communication of the quality of a particular quantity of grain and in most instances these USDA grades (1978) are used to establish the price paid for a particular lot of grain. In the Texas High Plains, another scale (Southwest Scale of Grain Premiums and Discounts) is used in grain trading (Table 1). The content of total kernel damage (TKD) is one grading factor for which corn grain is discounted under the Southwest Scale. Total kernel damage is a very general category, and although the discount rate changes when the percentage of TKD exceeds 15%, this scale does not reflect the particular type(s) of damage (with the exception of heat damage) within a corn sample.

Germ damaged kernels (GDK), distinguished by a brown to black discoloration of the germ or embryo, are often encountered in improperly stored grain. Kernel damage of this type is frequently the result of excess moisture in stored grain, sufficient to

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promote microbial growth or spontaneous heating (Pomeranz, 1974). Kernels in which only the germs are discolored do not visually seem to be severelydeteriorated. Because this form of damage contributes to the TKD of a corn sample, it often results in the sample being severely discounted.

Table 1. Southwest Scale of Grain Discounts[1].

Item	Discount
Trading basis for No. 2 corn per hundredweight	
Moisture	Moisture reductions are by weight equal to 1.5 times percentage moisture above 15.5%. Deductions for moisture shall be taken from the net weight before other discounts are applied.
Test weight	$.01 for each lb. or fraction thereof from 53.9 to 50 lbs.; $.05 for each lb. or fraction thereof below 50 lbs.
Broken kernels & foreign material	$.02 for each 1% or fraction thereof from 5.1% to 10%; $.04 for each 1% or fraction thereof from 10.1 to 20%
Heat damage	$.01 for each 0.1% from 0.3 through 3%.
Total damage	$.02 for each 1% or fraction thereof from 5.1 to 15.0%; $.04 for each 1% or fraction thereof from 15.1 to 20%.
Heating	$.05
Musty*	$.10
Sour*	$.10
Weevily*	$.05

*When grain is musty, sour or weevily, the buyer has option of applying discounts or returning grain to seller at seller's expense.
[1]Premium = $.15 for No. 1

The actual value of GDK corn as an energy source for ruminants has not been well established. Therefore, these studies were conducted with the following objectives: 1) to determine the chemical composition of GDK low grade corn (LGC); 2) to measure the digestibilities of starch and protein of GDK corn; and 3) to determine the relative in vivo digestibilities of DM, OM, ADF, CP, and N retention by growing wethers fed different levels of sample grade corn (18.6% TDK) by replacement of No. 1 grade corn.

METHODS AND MATERIALS

Experiment 1

For the *in vitro* study, five, 200-g samples of yellow corn were furnished by a grain inspection service in Amarillo, TX. Germ damage (evidenced by germ discoloration) was the only type of damage present in the samples. Broken kernels and foreign material had previously been removed. Test weights were not furnished for each sample; however, the grain inspector stated that all the corn samples had a test weight of approximately 57 lb./bu. All five samples from Amarillo were grown in the Texas Panhandle. One sample of damaged corn (containing 18.6% TKD) was obtained from a grain elevator in Castro County, TX and a sample of No. 1 grade corn from the Texas Tech University Feed Mill also were included in the study. The type of kernel damage present in the two samples graded in Lubbock also was described as germ damage by heat (evidenced by germ discoloration). In addition, the sample from Castro County contained a slight amount of visible mold. The TKD amounts are shown in Table 2.

Table 2. Grade and total kernel damage content of corn grain used in the in vitro experiment[s].

Grain	Total kernel damage, %
No. 1 grade yellow corn	2.0
No. 2 grade yellow corn	4.8
No. 5 grade yellow corn	11.8
Sample grade yellow corn	18.6
Sample grade yellow corn	20.1
Sample grade yellow corn	41.6
Sample grade yellow corn	55.0

[a]Corn was graded according to the Official United States (USDA Standard for Grain, 1978).

Corn samples were ground through a Wiley Mill (Model 4, Arthur Thomas Co., Philadelphia, PA) to pass a 1-mm screen before laboratory analyses. Samples were stored in airtight containers and refrigerated to prevent deterioration. Treatments for in vitro evaluations were arranged in a completely random design and analyzed by analysis of variance. Bartlett's test was used to determine homogeneity of treatment variances (Steel and Torrie, 1980). The effect of increased amounts of TKD on chemical composition and digestibility of corn were determined using orthogonal polynomials (linear and deviations from linearity) according to Steel and Torrie (1980).

Dry matter content of the corn samples was determined by drying samples in a forced-air oven for 48 h at 101°C. Ash, CP (Kjeldahl), pepsin digestible protein (PDP), and ether extract (EE) were determined by official AOAC (1990) methods. A commercial laboratory determined total starch content (SC) and readily available starch (RAS). Acid detergent fiber was determined by the method of Goering and Van Soest (1970).

In vitro dry matter digestibility (IVDMD) and *in vitro* organic matter digestibility (IVOMD) were evaluated in triplicate by the Moore modification of the two-stage Tilley and Terry procedure described by Harris (1970), which was further modified by using 2-g samples and 100-mL buffer:ruminal fluid solution (70:30) in 250-mL centrifuge tubes (Summers and Sherrod, 1976). Ruminal fluid was collected (6 h after feeding) from a steer fitted with a ruminal cannula receiving a cracked corn and cottonseed hull-based diet. Residue contents of each centrifuge tube were filtered through a sintered glass crucible following the pepsin stage of digestion. Residues in crucibles were ashed, and IVOMD was calculated after drying.

Experiment 2

Diets used in a sheep metabolism study contained approximately 75% ground corn, 15% cottonseed hulls, and 10% protein, mineral, and vitamin supplement. Corn in the diets was supplied by different levels of SG corn and No. 1 grade corn as described in Table 3. Composition of the diets and supplements are presented in Tables 4 and 5, respectively.

Eight crossbred wether lambs (initial weight 77 lb.) were paired randomly by weight and allotted to a replicated 4 x 4 Latin square design. Initial pairs were maintained for the duration of the experiment. Lambs were housed in individual crates designed for total fecal and urine collection. The four diets were offered to the lambs during a 14-d adjustment period before collection of feces and urine. Urine, feces, and orts were collected daily over a 7-d period. Ten percent of the urine volume was measured and composited daily. Total daily fecal excretion and orts were collected and stored for subsequent analyses and samples of each diet were taken for further analyses. Before sub-sampling, feces were homogenized in a mixer with distilled water.

Table 3. Grades of corn used in the metabolism study, Experiment 2[a].

U.S. Grade	Test weight (lb./bushel)	Moisture, %	Damaged kernels, (total), %	Broken corn and foreign material, %
No. 1 yellow corn	57	13.3	2.0	1.6
Sample grade yellow corn (musty)	57	10.3	18.6	3.9

[a]Corn was graded according to the Official United States USDA Standard for Grain, 1978.

Table 4. Composition of diets used in the metabolism study, Experiment 2.

	Treatments			
Item	1	2	3	4
Ingredient[a]	%			
Sample grade corn	0	37.34	56.01	74.68
No. 1 grade cor	74.68	37.34	18.67	0
Cottonseed hulls	15.02	15.02	15.02	15.02
Supplement	10.30	10.30	10.30	10.30
Chemical composition	%			
DM	89.52	89.77	89.94	89.87
Ash	3.99	4.08	4.10	4.22
ADF	13.37	12.91	13.55	14.25
CP	13.34	13.38	13.18	13.15

[a] As fed basis.

[b] Percentage of DM, determined

Table 5. Composition of supplement used in the metabolism study, Experiment 2.

Ingredient[a]	%
Cottonseed meal	69.03
Urea (47% N)	7.08
Ammonium sulfate	3.85
Sodium chloride	2.02
Potassium chloride	7.08
Molasses	1.53
Calcium carbonate	9.11
Trace mineral	.20
Vitamin A, D, and E Premix[b]	.10

[a]Dry matter basis.
[b]Premix contained vitamin A 60,000 IU/g, vitamin D 400,000 IU/g, and vitamin E 275 IU/g.

Fecal DM was determined by drying the feces for 72 h at 65°C. Dry matter content of the diets and orts was determined by drying at 101°C for 48 h. Ash and Kjeldahl N were determined according to AOAC (1975) methods. Acid detergent fiber determinations were conducted using the procedure described by Goering and Van Soest (1970). Results for a replicated Latin square were analyzed using analysis of variance and orthogonal polynomials (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Chemical composition of the corn samples is shown in Table 6. Ash values of the seven corn samples (1.2 to 1.47%) are slightly less than the ash content (1.5%) of ground corn reported by the NRC (1982). Ash content of corn samples did not vary ($P > .10$) with increasing levels of TKD.

Table 6. *In vitro* and chemical analyses.

	Treatment[a]							
Item, %[a]	1	2	3	4	5	6	7	SEM
Total damage	2.0	4.8	11.8	18.6	20.1	4.06	55.0	
Dry matter	86.93	86.03	86.59	88.52	87.15	86.41	85.60	
Ash[b]	1.26	1.44	1.28	1.27	1.47	1.23	1.20	.02
Crude protein[b]	8.62	9.59	8.11	8.66	9.39	8.82	8.54	.17
Acid detergent fiber[b]	3.55	3.69	4.09	3.51	3.23	3.21	3.42	.05
Ether extract[b,c]	1.58	1.97	1.64	1.62	1.67	2.21	2.20	.21
Total starch[b]	71.26	69.97	74.77	70.72	69.30	73.72	70.27	.81
Readily available starch[b]	25.70	26.55	22.96	24.02	22.79	24.13	26.37	2.00
Pepsin degradable protein[d]	38.03	39.16	33.07	37.81	35.40	37.70	42.15	.96

[a]1=No. 1 grade corn; 2=No. 2 grade corn; 3=No. 5 grade corn; 4, 5, 6, and 7=sample grade corn with different levels of total damage.
[b]Percentage of dry matter.
[c]Linear effect ($P < .05$).
[d]Percent of total crude protein.

Crude protein values were transformed using an angular transformation before statistical analysis because of heterogeneity of variance (Steel and Torrie, 1980). The untransformed CP values of corn samples are listed in Table 6. The CP content of the samples ranged from 8.11 to 9.59% which was less than the figure of 10% given by NRC (1982). Crude protein did not vary (P > .10) with the level of TKD in corn samples. The PDP (as a percentage of CP) of the corn samples also failed to demonstrate a response (P > .10) due to kernel damage.

Acid detergent fiber content of corn samples did not vary (P > .10) with increasing TKD content. The ADF content of the corn samples used in this study (3.21 to 4.09%) was similar to the ADF value (3.0%) for ground corn reported by the NRC (1982).The EE content increased (P < .05) in a linear fashion as the level of TKD increased. The EE values observed in this study (1.58 to 2.21%) were somewhat lower than the value of 4.3% reported by NRC (1982), and similar to that of Summers and Sherrod (1976), who reported an EE content of 2.4% for SG corn (59% TKD), and Quakenbush et al. (1963), whose results showed a total oil content of corn breeds ranging from 1.2 to 5.7% when extracted with a hexane:acetone mixture.

Total SC of corn samples used in this study (69.3 to 74.77%) was similar to the value of 72% reported by Inglet (1970) and was not affected (P > .10) by TKD content (Table 6).

Table 7 shows the untransformed IVDMD and IVODMD digestibilities of the corn samples. Heterogeneity of variance was detected, and the data were transformed using angular transformation before statistical analyses were conducted (Steel and Torrie, 1980). Neither IVDMD nor IVOMD exhibited a response (P > .10) to TKD content.

Table 7. *In vitro* dry matter (IVDMD) and organic matter (IVOMD) digestibility.

	Treatment[a]						
Item, %	1	2	3	4	5	6	SEM
Total damage	2.0	4.8	11.8	18.6	20.1	41.6	
IVDMD	96.63	98.14	95.19	94.13	96.07	95.00	1.26
IVOMD	97.07	98.00	95.71	94.75	96.47	95.42	1.05

[a]1=No. 1 grade corn; 2=No. 2 grade corn; 3=No. 5 grade corn; 4, 5, 6, and 7=sample grade corn with different levels of total damage.

In vivo digestibility and N retention of the corn diets are shown in Table 8. In vivo DM, OM, ADF, N digestibility and N retention (as a percentage of N intake) did not differ (P > .10) among treatments. However, DM and OM digestibilities tended (P > .10) to vary in a cubic fashion as percentage of TKD increased in the diet. Acid detergent fiber responded to dietary LGC levels in a cubic manner (P = .05). Bolsen et al. (1981) reported that *in vivo* DM and protein digestibility of a diet containing insect-damaged sorghum was not significantly higher than a diet containing either a control (not subjected insect or fungal damage) sorghum or a fungal-damaged sorghum, but was significantly higher than a diet containing 50% control sorghum and 50% fungal damaged sorghum. Furthermore, the digestibility values of the DM and CP in the diets containing either the control or the fungal-damaged sorghum were higher (though not reported as significant) than the diet containing 50% control and 50% fungal-damaged sorghum. Although the increase or decrease of certain digestibilities reported in the present study might not conform to a more logical expected result (linear increase or decrease in response to damage) they do not appear to be unique to this study.

Table 8. *In vivo* digestibles and nitrogen retention of corn diets by lambs in Experiment 2.

Item, %	Treatments[a]				SEM
	1	2	3	4	
Dry matter digestibility[b]	79.5	77.8	79.5	77.2	.73
Organic matter digestibility[b]	80.2	7.6	80.2	77.9	.74
Acid detergent fiber digestibility[c]	32.1	29.4	37.1	32.7	2.09
Nitrogen digestibility	68.5	67.6	68.9	67.1	.99
Nitrogen retention, g/d	23.0	26.2	25.3	25.0	2.52

[a]1=74.68% No. 1 corn; 2=37.34% sample grade corn and 37.34% No. 1 grade corn; 3=56.01% sample grade corn and 18.67% No. 1 grade corn; 4=74.68% sample grade corn
[b]Cubic trend ($P < .10$).
[c]Cubic effect ($P = .05$).

In this study, neither ash, CP, ADF, nor total SC exhibited a consistent increase or decrease as a reflection of TDK (when damage was in the form of germ discoloration). These findings are partially supported by the data of Lichtenwalner et al. (1979) in which no significant difference was found between weathered or unweathered sorghum grainsin terms of EE, CP, crude fiber, and N-free extract. Values for ash, CP, cell walls and estimated soluble carbohydrate as determined by Summers and Sherrod (1976), did not consistently increase or decrease among corn samples containing various levels of TKD. However, a tendency for EE to decrease as TKD increased was observed. The positive linear relationship between EE and TKD observed in these studies might have been the result of varietal differences in the corn samples examined. The TKD content of the corn samples did not seem to affect IVDMD, IVOMD, SC, or availability of CP in a manner that would suggest this grading factor (when a result of the form of kernel damage present in the corn samples examined) can be used to predict these properties of grain. Corn samples used in this study were likely of different varieties, agronomic background, cultivation, and storage history. The history of corn grain is not always available to the grain purchaser when corn is traded on the basis of grade. The amount of information obtained concerning the background and treatment history of corn used in this study was representative of that commonly furnished when grain is purchased for livestock feed.

Corn samples, in both the in vitro and in vivo studies, with greater levels of TKD, did not necessarily have lower nutritional value than corn samples with less damage. The TKD content did not seem to reflect the in vivo digestibilities nor N utilization of diets containing various levels of damaged corn. This observation, along with results of in vitro digestibilities and chemical composition determinations, suggest that the general grading factor of "TKD" is not a reliable indicator of the nutritional value of corn grain for ruminants. The grading factor of TDK encompasses several different forms of kernel damage, of which only one form was examined in this study.

IMPLICATIONS

The applicability of the results from these in vitro and in vivo studies, using corn grain with germ discoloration and a very small amount of mold, to the nutritional value of corn grain containing other forms of kernel damage is not known. Discounting grain on the basis of TKD, without considering the type(s) of kernel damage present, is unwarranted in terms of nutritional value for ruminants. However, processing qualities coupled with storability are important considerations in determining the relative value of LGC in commercial livestock enterprises. The effect of kernel damage on these grain qualities was not examined in this study.

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Plant Stand Density and Row Configuration Effect on Production of Texas Pinkeye Hull Cowpea

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ABSTRACT

In the Texas Rolling Plains (northwest Texas), cowpea [*Vigna unguiculata* (L.) Walp.] is often considered a replacement crop following early-season cotton (*Gossypium hirsutum* L.) failure. A 3-yr field experiment using a 6x2 factorial in a randomized complete block design was conducted to determine the optimum row spacing and planting density for maximum production of Texas Pinkeye Purple Hull Cowpea. Factor A consisted of six plant stand densities: 0.5, 0.6, 0.8, 1.1, 1.5 and 1.8 plants/sq ft whereas, factor B consisted of 1 or 2 rows (spaced 40 inches or 12 inches apart, respectively) on beds formed 40 inches apart. Seed yield was higher with 2 rows per bed than one row per bed and was highest (754 lbs/ac) at 1.5 plants/sq ft. This was significantly higher than at 1.1 plants / sq ft or lower densities. Seed yield was closely related to pods/sq ft. Pods per plant were higher with 2 rows per bed than with 1 row per bed and decreased with increasing plant stand density. Seeds per pod were not affected by either row spacing or plant stand density. Pea weight was only slightly affected by plant stand density. This study found that a yield of about 900 pounds per acre may be achieved with 70,000 plants per acre, planted in 2 rows per bed and an average within row spacing of 5 inches. Pod density or pods/sq ft was an important regulator of seed yield, whereas seeds per pod and seed weigtremained relatively constant.

KEY WORDS: seed yield, pods per sq ft, row spacing, and plant population

Cowpea has been shown to produce more acceptable yields than many other leguminous crops under many diverse climatic conditions, soils, and cultural practices (Fery, 1981). Cowpea breeding is well documented in the literature for such factors as disease resistance (Hare and Thompson, 1989; Fery, 1985; Kuhn, 1989; Patel, 1985; Pathak, 1988), heat tolerance (Hall and Patel, 1989), nitrogen fixation (Miller, 1989), and mineral nutrition (Marsh, 1989). Limited precise information is available for the southern U.S. and in the Rolling Plains of Texas on the effect of in-row or between-row spacing and plant stand density on cowpea yield. Conflicting results exist for cowpea response to various spatial arrangements. Ezedinma (1974) and Nangju et al. (1975) found no relationship between within-row and between-row spacings, whereas Haizel (1972) found that bunch type cowpea yield increased when a square planting arrangement was practiced rather with a rectangular planting arrangement. Nangju (1979) reported a seed yield decline for leafy cowpea cultivars at high plant densities. He postulated that the yield decline was due to more vegetative than reproductive growth because of excess leaf area resulting from plentiful rainfall and good soil fertility. Smittle (1989) reported that erect, early, and determinate cultivars are more suited to high density planting while semi-erect or vining, indeterminate, and high branching cultivars are more suited to low density planting. Grantz and Hull (1982) reported that widely spaced plants accumulated greater proportions of shoot dry matter in reproductive parts at mid-season than did closely spaced plants. A stronger association between yield and planting density was seen for determinate bean types (ACanyon and ABlue Lake 274) than for indeterminate types because the latter has more yield component compensation for the increased area/plant at lower planting densities (Crothers and Westerman, 1976). Chambliss and Turner (1972) reported increased seed yield of southern peas with increasing plant stand density. However, increasing the plant population from 20,000 to 30,000 plants per acre offered only a slight yield response. Herbert and Baggerman (1983) reported decreased cowpea seed yield with increased row spacing. They attributed this to the interaction of row width and plant stand density to available water.

In the Rolling Plains of northwest Texas cowpeas are grown as a catch crop either after wheat (*Triticum aestivum* L.) harvest or after loss of a primary crop, such as cotton. In general, a catch crop is a quick and fast growing crop grown between harvest or planting of two main crops, or as a substitute crop after a crop failure. Recently, producers have considered cowpea as an alternate crop in an attempt to diversify their farming operations. Sustaining soil productivity and fertility presents a serious challenge in the warmer southern U.S.A. (Doran and Smith, 1987) because of low soil organic matter, fragile soils, high evapotranspiration, low plant available water, and crust formation (Clark et al., 1993). The objective of this research was to determine the optimum plant stand density and row spacing for maximum cowpea yield. Treatment effects were evaluated on seed yields, pods per plant, seeds per pod, pods per sq ft, and pea weights.

MATERIALS AND METHODS

This experiment was conducted on a Miles fine sandy loam (fine loamy, mixed, thermic Typic Paleustalfs) in 1992, 1995, and 1996 at the Texas A&M University Experimental Farm near Munday, TX (33°27' N, 99°38' W, and ground elevation of 1460 ft). A 6x2 factorial experiment was conducted using a randomized complete block design with four replicates (Gomez and Gomez, 1984). Factor A consisted of six levels of successive desired plant stand densities: 0.5, 0.6, 0.9, 1.2, 1.8, and 2.4 plants / sq ft. Factor B consisted of 1 row (40 inches apart) and 2 rows (12 inches apart) per bed on raised beds formed 40 inches apart (Fig. 1). Because of yearly weather fluctuations (Table 1) actual plant stand densities differed from year to year. The 3-yr average plant stand densities were 0.5, 0.6, 0.8, 1.1, 1.5, and 1.8 plants / sq ft (Table 3). Texas Pinkeye Purple Hull was used as the experimental cultivar. This determinate, pinkeye, purple hull cultivar has an erect bush growth habit,

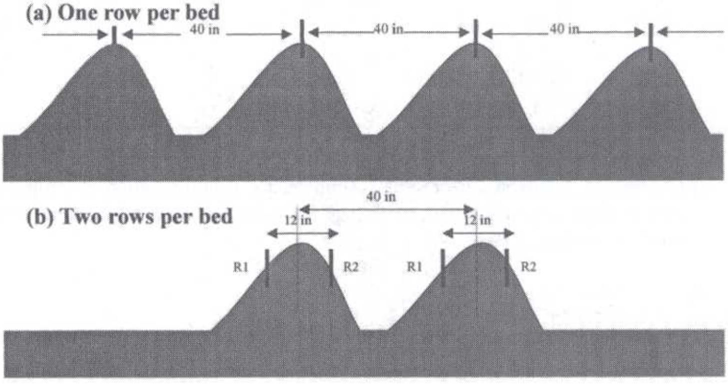

Figure 1. Planting pattern: (a) one row per bed, between row spacing 40 inches; (b) two rows per bed, between row spacing 12 inches, R1 is row 1 and R2 is row 2, dotted lines (....) indicate center of the bed 40 inches apart.

and concentrated pod set at or above the foliage level (Miller and Scheuring, 1994). The plot size was 4 rows by 20 ft long. Planting was done with a hand planter (Precision Garden Seeder, Model 1001B, Earthway Products Inc., Bristol, IN). Plants in the single row per bed treatment were established in the center of each bed, whereas plants in the two rows per bed treatment were established 6 inches to each side of the bed center (12 inches apart). Plots were over seeded and thinned immediately after emergence to obtain the desired plant stand density.

A post-plant application of 2 lbs / ac metolachlor [(2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide)] was used for weed control. Plots received no fertilizer and were irrigated as needed to maintain adequate soil moisture in the root zone. Malathion [(0,0-dimethylphosphorodithioate of diethyl mercaptosuccinate) and diazinon (0,0-diethyl 0-(6-methyl-2-(1-methylethyl)-4-pyrididyl) phosphorothioate)] were applied twice during bloom to control aphid infestations. In 1992, 1995, and 1996 cowpeas were planted on 7 July, 11 July, and 18 June, respectively, and were harvested approximately 90 days after planting on 2 October, 13 October, and 15 September, respectively.

Plant count was taken approximately 7-d before harvesting from 5 ft of row length. Seed yields were determined by harvesting a 30 sq ft area. Seeds per pod and pods per plant were determined at harvest. Average pea or seed weight was based on 100 seeds.

Data were analyzed using the SAS computer program (SAS Institute Inc., 1989). Combined analyses of variance were run on 3 years data. Mean separation was done using orthogonal contrasts.

Table 1. Seasonal rainfall and daily maximum mean temperature data at the Munday, TX test site.

Month	Rainfall				Daily max. mean temperature			
	1992	1995	1996	30-yr Avg.[a]	1992	1995	1996	30-yr Avg.[a]
	inches				°F			
June	7.83	3.46	1.42	2.99	88	93	86	93
July	3.98	2.99	3.58	2.32	96	102	90	98
August	1.65	6.02	4.77	2.05	92	100	84	98
September	2.36	5.08	4.45	2.87	91	88	76	90
October	0.00	0.55	1.06	2.52	85	84	67	80
Season total	15.83[b]	18.11[c]	15.28[d]	12.76	-	-	-	-

[a]Source: Climatography of the United States No. 20-41, Climatological Summary, U. S. Department of Commerce, National Oceanic and Atmospheric Administration in cooperation with Cotton Economic Research and Bureau of Business Research of the University of Texas at Austin, December 1970.

[b] - From July 7 to October 2.
[c] - From July 11 to October 13.
[d] - From June 18 to September 15.

Table 2. Analysis of variance of seed yield and other plant paramenters.

Source of variation	df	Seed yield	Pods per plant	Seeds per pod	Pea weight
		----------------------------Probability (*P*)---------------------------			
Year	2	0.0001	0.0001	0.0023	0.0001
Reps within year	9				
Treatment	11				
Plant stand density	(5)	0.0001	0.0001	0.7188	0.0079
Row spacing	(1)	0.0001	0.0012	0.7460	0.2324
Plant stand density x row spacing	(5)	0.3392	0.0304	0.5560	0.2906
Year x Treatment	22				
Plant stand density x year	(10)	0.2863	0.0001	0.2544	0.8134
Row spacing x year	(2)	0.0015	0.0001	0.3338	0.0950
Plant stand density x row spacing x year	(10)	0.2479	0.1455	0.0416	0.7754
Error	99				
Total	143				
Contrast		Single degree of freedom contrasts (Pr>F)			
Plant stand density					
0.5 vx 0.6 plants / sq ft		0.1915	0.0001	0.1320	
0.6 vs 0.8 plants / sq ft		0.8592	0.0006	0.3612	
0.8 vs 1.1 plants / sq ft		0.1256	0.0001	0.1719	
1.1 vs 1.5 plants / sq ft		0.0243	0.0155	0.0137	
1.5 vs 1.8 plants / sq ft		0.0726	0.0421	0.4430	

Table 3. Effect of plant stand density and row spacing on seed yield at Munday, TX.

	Plant density			Within row spacing		Seed yield		
	1R/B	2R/B	Avg	1R/B	2R/B	1R/B	2R/B	Avg
	----------Plants/sq ft----------			------inches-----		-------------lbs/ac-----------		
	0.4	0.5	0.5	8	15	504	677	591
	0.6	0.6	0.6	6	12	552	716	634
	0.8	0.9	0.8	5	8	597	660	628
	1.1	1.1	1.1	4	7	646	712	679
	1.4	1.6	1.5	2	5	689	820	754
	1.7	1.9	1.8	2	4	655	735	695
Avg	1.0	1.1	1.1	-	-	607	720	664
SED	0.1	0.1	0.1	-	-	47	47	34

SED = Standard Error of Difference between means.
1RB = one row per bed, between row spacing 40 inches.
2RB = two rows per bed, between row spacing 12 inches.

RESULTS AND DISCUSSION

Seed yield varied from year to year depending upon environmental conditions (Table 1 and Table 2). Pea yield was highest in 1992 (1054 lbs/ac) followed by 1996 (744 lbs/ac) and 1995 (196 lbs/ac) (data not shown). The low seed yield in 1995 was due to lower plant stand density (0.8 in 1995 vs 1.3 and 1.1 plants/sq ft in 1992 and 1996, respectively), lower number of pods per plant (4.1 in 1995 vs 9.1 and 9.2 pods per plant in 1992 and 1996, respectively), and lower number of seeds per pod (4.4 in 1995 vs 6.9 and 6 seeds per pod in 1992 and 1996, respectively). However, pea weight was slightly higher in 1995 (0.60 oz per 100 seed) than in 1992 (0.59 oz per 100 seed) and 1996 (0.55 oz per 100 seed). High temperatures in July 1995 resulted in poor emergence and high rainfall in August and September (Table 1) possibly resulted in poor stand and lower seed set in that year.

Overall, seed yield was higher with 2 rows per bed than 1 row per bed but it was higher only two out of three years (1992, $P < 0.0002$; 1996, $P < 0.0001$). This may have been due to less evaporation from the soil surface with two rows per bed (more soil shading). Bowers et al. (1976), Bradley and Baker (1974), and Stewart (1965) all concluded that yield increases could be expected with closer row spacings if more determinate varieties were used.

Although seed yield varied from year to year, the average seed yields were 591, 634, 628, 679, 754, and 695, lbs/ac at 0.5, 0.6, 0.8, 1.1, 1.5, and 1.8 plants/sq ft, respectively (Table 3). The seed yield was higher ($P < 0.0243$) only at 1.5 plants/sq ft compared with all other planting densities except at 1.8 plants/sq ft. Year x plant stand density interac was about 1.5 plants/sq ft. At plant populations below this the inputs probably were not tion did not affect seed yield. From our study we found that the optimum plant population efficiently was about 1.5 plants/sq ft. At a plant population above this probably resulted in crowding and severe competition for inputs. At a plant population of 1.8 plants/sq ft, yield was slightly decreased and seed cost was higher. Working on dry bean, Grafton et al. (1988) reported similar results with determinant varieties. Pods sq ft were calculated by multiplying number of plants / sq ft by the average number of pods per plant. Pods/sq ft seems to be an important parameter determining seed yield per unit area. In general pods /sq ft increased with plant population up to 1.5 plants / sq ft and then remained the same at 1.8 plants/sq ft. Pods / sq ft were 5.6, 5.9, 6.8, 6.6, 7.3, and 7.3 at 0.5, 0.6, 0.8, 1.1, 1.5, and 1.8 plants/sq ft, respectively (Fig. 2). Pods/sq ft followed a pattern similar to that of yield (Fig .2). Although pods/sq ft were similar on 1.5 and 1.8 plants/sq ft, seeds per pod was lower at 1.8 than at 1.5 plants/sq ft (Table 4). The lower seeds per pod may have resulted in slightly lower yields at 1.8 plants/sq ft than at 1.5 plants/sq ft. Similarly, pods/sq ft were higher for 2 rows per bed than 1 row per bed (8.6 vs 7.1 pods/sq ft). These findings were similar to the ones reported by Nangju (1979) and Herbert and Baggerman (1983).

Pods per plant were higher with two rows per bed than one row per bed (Table 2 and Table 4) and decreased with increasing plant stand density. Similar findings were reported by Grafton et al. (1988), Nangju (1979), Grantz and Hall (1982), and Herbert and Baggerman (1983). For determinate and indeterminate cowpea, Haizel (1972) found increasing number of pods per plant with decreasing plant stand density. Bennett et al. (1977) suggested that high seed yield could be achieved in high plant density conditions by the development and utilization of cultivars with few erect branches and a high number of nodes per branch. Pods per plant were affected by plant stand density x row spacing, plant stand density x year, and row spacing x year interactions (Table 2).

Seeds per pod were not affected by either row spacing or plant stand densities (Table 2 and Table 4). Working on a determinate dry bean cultivar, Grafton et al. (1988) reported that seeds per pod were not affected by stand density. A similar finding for a determinate cowpea cultivar was reported by Haizel (1972).

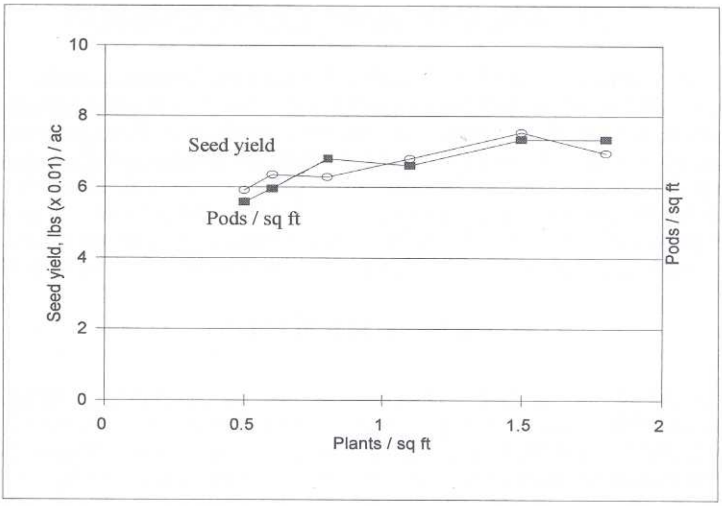

Figure 2. Seed yield (lbs x 10^{-2}/ac) and pod density (pods / sq ft) as affected by plant stand density (plants/sq ft).

Table 4. Effect of plant stand density and row spacking on pods per plant, seeds per pod, and pea weight at Munday, TX.

	Plant density			Pods per plant			Seeds per pod			Pea weight		
	1 R/B	2R/B	Avg	1 R/B	2R/B	Avg	1 R/B	2R/B	Avg	1 R/B	2R/B	Avg
	---Plants / sq ft--			------------------Number----------------------						--oz / 100 seed--		
	0.4	0.5	0.5	11.0	12.9	12.0	6.2	5.7	6.0	0.60	0.59	0.59
	0.6	0.6	0.6	8.4	10.9	9.7	5.5	6.2	5.9	0.58	0.58	0.58
	0.8	0.9	0.8	8.0	8.1	8.1	5.5	5.3	5.4	0.57	0.57	0.57
	1.1	1.1	1.1	5.9	6.1	6.0	5.5	5.8	5.7	0.57	0.60	0.58
	1.4	1.6	1.5	4.6	5.2	4.9	6.2	5.7	6.0	0.57	0.56	0.57
	1.7	1.9	1.8	4.0	4.0	4.0	6.0	5.6	5.8	0.57	0.58	0.57
Avg	1.0	1.1	1.0	7.0	7.9	7.4	5.8	5.7	5.8	0.58	0.58	0.58
SED	0.1	0.1	0.1	0.7	0.7	0.5	0.6	0.6	0.4	0.00	0.00	0.00

SED = Standard Error of Difference between means

1 RB = one row per bed, betrween row spacing 40 inches

2 RB = two rows per bed, between row spacing 12 inches

Overall, pea weight was not affected by plant stand density but it was significantly lower only at 1.5 plants/sq ft when compared with 1.1 plants/sq ft (Table 2 and Table 4). Grafton et al. (1988) did not find any differences in seed weight with increasing plant stand density either for determinate or indeterminate dry bean.

In this study the highest seed yield was obtained with the combination of a 12 inches between row spacing and 5 inches within row spacing that resulted in 1.6 plants/sq ft. Pod density or pods/sq ft (plant stand density x pods per plant) was the important regulator of seed yield, whereas seeds per pod and seed weight remained reasonably constant.

SUMMARY AND CONCLUSION

Seed yield for Texas Pinkeye Purple Hull Cowpea planted on raised beds 40 inches apart was greater with 2 rows per bed than 1 row per bed. Seed yield was greatest (754 lbs/ac) at 1.5 plants/sq ft. Seed yield was closely related to pods/sq ft. Pods per plant was higher with 2 rows per bed than 1 row per bed and decreased with increasing plant stand density. Seeds per pod were not affected by either row spacing or plant density. Pea weight was only slightly affected by plant stand density. Of the components of seed yield, pod density or pods/sq ft (plant stand density x pods per plant) was an important regulator of seed yield, whereas seeds per pod and pea weight remained somewhat constant.

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Redberry Juniper Response to Picloram and Top Removal in the Texas Rolling Plains

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ABSTRACT

Redberry juniper (*Juniperus pinchotii* Sudw.) mortality was evaluated following top removal, picloram application (1, 10, 20%, and 4 cc/3 ft of plant height), and cut-stump treatment with picloram (1, 10, and 20%) on clay flat and shallow redland range sites in the Texas Rolling Plains. The objectives were to determine mortality of redberry juniper following different treatment regimes, and develop sound recommendations for redberry juniper management. Fifty trees were randomly assigned to each treatment. Trees mechanically treated were cut to approximately a 4-inch stump height with a chain saw. Chemically treated trees were sprayed with a basal application of picloram. Trees that received a mechanical and chemical treatment were cut to a stump height of 4 inches and immediately treated with picloram. On the clay flat site, treatments of cut and spray 10 and 20% resulted in 100% mortality, whereas the cut only treatment had the lowest mortality at 7%. Trees in the cut only treatment had the highest number of resprouts, and the cut and spray 1% treatment was the only mechanical and chemical treatment combination that resprouted. The shallow redland site had similar results, with the cut and spray treatments having the highest mortality. Since labor is a major expense in individual plant treatments, spray only treatments are the least expensive treatments when evaluating cost per killed tree. Our results indicate that on both sites, the spray only 10% treatment optimized redberry juniper mortality while minimizing treatment cost. Based on these results, we recommend a basal application of a 10% picloram solution for managing redberry juniper in the Texas Rolling Plains. However, if the management objectives include removing the trees, then we recommend cutting the trees and immediately treating the stumps with a 10% picloram solution.

KEYWORDS: cedar, IPT, *Juniperus*, precision application

Redberry juniper is a native multi-stemmed evergreen that naturally occupied rocky, shallow sites in limestone or gypsum soils (Correll and Johnston 1979). Overgrazing, fire suppression, and adaptability of the species have been implicated as the causes for redberry juniper invasion onto grasslands (Steuter and Britton 1983; McPherson and Wright 1990). Redberry juniper ranges from central and west Texas to western Oklahoma, northern New Mexico, central Arizona, and northern Mexico (Correll and Johnston 1979; Ueckert et al. 1994). The 1992 Natural Resource Inventory estimated that redberry juniper occupies about 9 million acres in Texas (Natural Resources Conservation Service 1997).

The ability of redberry juniper to resprout makes control difficult. Redberry juniper is considered an invader on most range sites and has little economic value. However, redberry juniper is desirable on some steep and rocky range sites because it stabilizes the soil and provides wildlife cover (Scifres 1980).

Mechanical, chemical, and pyric control methods have been used to manage redberry juniper (Scifres 1972; Schuster and George 1976; Steuter and Wright 1983; Ueckert and Whisenant 1982). The mortality of seedlings and juvenile trees following treatment is high compared to adult junipers due to the location of the bud zone above the soil surface (Smith et al. 1975). Although redberry juniper is relatively easy and inexpensive to control as seedlings and juvenile trees, action is not usually taken until trees mature and there is an obvious decrease in herbage production.

Redberry juniper has been noted for its ability to resprout after top removal (Correll and Johnston 1979). This characteristic makes redberry juniper more difficult to control than non-sprouting juniper species such as ashe juniper (*Juniperus ashei* Buchh.) and eastern redcedar (*Juniperus virginiana* L.). Redberry juniper regrowth after cutting was lowest for trees cut in June and highest for trees cut in December, with the amount of regrowth increasing with tree size (Schuster and George 1976). However, McPherson and Wright (1989) reported top removal of redberry juniper resulted in an average mortality of 33% on the High Plains and 19% on the Rolling Plains, but was not impacted by harvest date. Ueckert and Whisenant (1982) reported 100% mortality of redberry juniper seedlings that were hand grubbed 2 to 6 inches deep or cut at the soil surface, regardless of treatment date. Sixteen to 25 months after treatment, none of the seedlings had resprouted.

Picloram (4-amino-3,5,6-trichloro-2-picolinic acid) has proven successful in the management of redberry juniper (Scifres 1972; Schuster 1976; Ueckert and Whisenant 1982). Schuster (1976) reported that individual plant treatments with picloram or picloram plus 2,4,5-T (1:1) effectively controlled redberry juniper when applied as wetting sprays to foliage from April through September. Foliar sprays reduced the canopy by at least 95%, except when sprayed during August and October (Schuster 1976). Schuster (1976) reported that redberry juniper is most susceptible to foliar application of picloram in late spring and in early autumn. Applying 2 lb/acre yielded a 94% canopy reduction and 76% plant kill. Ueckert and Whisenant (1982) reported that pelleted picloram applied in the fall at 2 and 4 lb/acre killed 43 and 44% of the juniper seedlings, respectively. Spring applications of picloram killed 42 and 61%, respectively. Label recommendations for juniper spot treatment is 3 to 4 cc of picloram per 3 ft of plant height. Using a combination treatment, McGinty et al. (2001) reported very high control by treating the cut surface with 4% picloram in water immediately following cutting.

Redberry juniper competes with other vegetation for soil moisture, nutrients, and space, and has little economic and forage value (Taylor et al. 1997). Dense stands inhibit livestock handling and as the canopy cover increases forage production dramatically declines. The objectives of this study were to determine redberry juniper mortality following top removal, picloram application (1, 10, 20%, and 4 cc/3 ft of plant height), and cut-stump treatment with picloram (1, 10, and 20%), and develop practical and sound recommendations for managing redberry juniper with individual plant treatments.

MATERIALS AND METHODS

This study was conducted in 1996 and 1997 at the Texas Tech Experimental Ranch in Garza County near Justiceburg, Texas on clay flat and shallow redland range sites. The soils on these sites are Dalby clay (fine, mixed, thermic Typic Torrert) and Vernon clay loam (fine, mixed, thermic Typic Ustochrept), respectively (Richardson et al. 1965). Dominant vegetation includes tobosagrass (*Hilaria mutica* [Buckl.] Benth.), alkali sacaton (*Sporobolus airoides* [Torr.] Torr.), blue grama (*Bouteloua gracilis* [H.B.K.] Griffiths), pricklypear (*Opuntia* spp. Mill.), honey mesquite (*Prosopis glandulosa* Torr.) and redberry juniper.

The climate of Garza County is warm, temperate, and subtropical with dry winters and long summers. Average annual precipitation is 20 inches, with maximum precipitation usually occurring in May and June (NOAA 1911 to 1983). The average daily minimum temperature in January is approximately 27° F, and the average daily maximum temperature in July is about 95° F.

This experiment was designed as a completely randomized design with nine treatments on the clay flat site (control, top removal by chain saw, basal application of picloram [1, 10, 20%, and 4 cc/3 ft of plant height], and top removal plus slump treatment with picloram [1, 10, and

20%]) and six treatments on the shallow redland site (control, removal by chain saw, basal application of picloram [10 and 20%], and top removal plus stump treatment with picloram [10 and 20%]). Height of treated trees ranged from 3 to 9 ft, with trees less than 3 ft excluded from sampling. Fewer treatments were applied on the shallow redland site due to an insufficient number of trees in the desired height range. Redberry juniper trees on each site were marked and 50 trees randomly assigned to each treatment. The trees mechanically treated were cut to approximately a 4 inch stump height with a chain saw. Chemically treated trees were sprayed with a basal application of picloram following the technique described by Williamson and Parker (1995). Additionally, trees on the clay flat site were treated with 4 cc of picloram/3 ft of plant height following the label recommendation for ashe juniper. Trees mechanically and chemically treated were cut to approximately a 4 inch stump height. Following top removal stumps were immediately treated with picloram using the techniques described by Williamson and Parker (1995). Trees were considered dead if resprouting or green leaf material was absent 15 months post treatment.

All treatments were applied in July 1996 and treatment response was evaluated in mid October 1997. Chi-square analysis was used to assess mortality response to treatments at a=0.05 (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Clay flat site

Chi-square analysis on redberry juniper mortality indicated a difference between treatments (P<0.05). Two by two contrasts were calculated for all treatment comparisons. The only treatment that was not different from the control was the cut only treatment (P=0.2754). The other contrasts with the control were significant (P<0.05). A majority of the live trees sustained considerable top-kill 15 months after treatment. The cut only treatment had the lowest mortality at 7%, whereas the cut and spray 10 and 20% had 100% mortality (Table 1). Mortality was greater for the cut and spray treatments than for the spray only treatments. The direct application of picloram to the cut stump likely increased herbicide movement into the roots compared to the basal applications.

The label recommendation of 4 cc/3 ft of plant height had 68% mortality with a 58% canopy reduction of the live stems. Although mortality was not as high as other treatments, the amount of canopy available for photosynthesis was drastically reduced, resulting in trees with a reduced capacity for carbohydrate production. The full impact of this treatment may not occur for several years. A higher mortality would be expected with the label recommendation, but a reduced amount of liquid applied may have contributed to a lower mortality. The other herbicide treatments contained either 80, 90, or 99% water in the solution. A larger amount of liquid applied to the stem bases may have provided a more complete coverage of the base and penetration of the herbicide, and may have reduced the efficacy of the 4 cc/3 ft treatment.

Trees that were mechanically removed in the cut only treatment or a combination of cut and spray responded with resprouts. In the cut only treatment, 93% of the trees resprouted and averaged 109 resprouts per tree. It becomes evident that effective redberry juniper management requires a combination of treatments if the trees are to be mechanically removed above the soil surface. Application of a reduced rate of 1% immediately following top removal resulted in 77% mortality, and only 23% of the trees resprouted (Table 1). the lowest mortality was cut only at 6%, whereas cut and spray 10% and 20% both had mortalities of 100% (Table 1).Increasing the concentration of the spray solutionto 10 to 20 % applied immediately after cutting resulted in 100% mortality

Shallow redland site

Chi-square analysis indicated a difference between treatments (P<0.05). As on the clay flat site, the only treatment that was not different from the contraol was the cut only treatment (P=0.0783). The other contrasts with the control were significant (P<0.05).

Table 1. Redberry juniper mortality and frequency of resprouts on two range sites in the Texas Rolling Plains following mechanical and/or chemical treatments

Range Site	Treatment	Mortality	Resprout Frequency (%)
Clay Flat			
	Control	2a	1
	Cut Only	7a	93
	Spray Only 1%	60b	0
	Spray Only 10%	84bc	0
	Spray Only 20%	98c	0
	Cut & Spray 1%	77b	23
	Cut & Spray 10%	100c	0
	Cut & Spray 20%	100c	0
	4cc/3 ft	68b	0
Shallow redland			
	Control	0a	1
	Cut Only	6a	94
	Spray Only 10%	88b	0
	Spray Only 20%	88b	0
	Cut & Spray 10%	100b	0
	Cut & Spray 20%	100b	0

1Means within a site followed by the same letter are not significantly different.

There was no difference between spray only 10% and spray only 20% (P=0.9653), or cut and spray 10% 10 % and cut and spray 20% (P=1.0). The treatment with the lowest mortality was cut only at 6%, whereas cut and spray 10% and 20% both had mortalities of 100% (Table 1). The cut only treatment was the only treatment that responded with resprouts, with an average of 94 per tree. The resprout frequency for the cut only treatment was 88%, 1% for control trees, and all other treatments were zero. The two cut and spray treatments had 100% mortality compared to the two spray only treatments at 88%.

Schuster and George (1976) cut redberry juniper trees each month for one year. They found that one year following all treatments 17% of trees had not resprouted. The increased mortality may have resulted from cutting trees at different phenological stages. However, they found that resprouting was least for trees cut in May through August and greatest for trees cut in December. Resprout production of redberry juniper has been reported to increase as tree size increases (Schuster and George 1976). This same pattern was observed on both sites in the current study on cut only trees. Although resprout yield was not quantitatively measured, trees with small stem diameters and one or few stems had considerably fewer resprouts than trees with larger stem diameters and several stems.

MANAGEMENT IMPLICATIONS

It is economically and environmentally reasonable to use a lower concentration of picloram to manage redberry juniper than the label recommends for ashe juniper. Costs were reduced and mortality increased with spray only treatments on both sites. All of the herbicide-treated trees that did not die had decreased canopy densities, which allows for more light and water to penetrate the canopy and creates an environment more conducive for herbaceous vegetation. The combination of cutting and treating with 10 or 20% picloram was better than the cut only treatment, and was arithmetically higher than the spray only treatments. However, the trade-off for higher mortality in the cut and spray treatments is increased labor costs. Our results indicate that the spray only 10% treatment optimized redberry juniper mortality while minimizing treatment cost. Based on these results, we recommend a basal application of a 10% picloram solution for managing redberry juniper in the Texas Rolling Plains. However, if the management objectives include removing the trees, then we recommend cutting the trees and immediately treating the stumps with a 10% picloram solution.

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Root and Shoot Biomass of Plants Seeded in Crude Oil Contaminated Soil

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ABSTRACT

Using plants to enhance remediation of soil contaminated with crude oil is a viable remediation strategy. Rapid vegetative growth forms a plant canopy that acts to contain the contaminated soil by reducing surface runoff and erosion. Root growth in these soils stimulates microbial activity in the rhizosphere, which may accelerate bioremediation. The object of this study was to identify plants with the potential of enhancing bioremediation by measuring root and shoot biomass. In a greenhouse experiment, seeds were sown into a Windthorst sandy clay loam soil contaminated with 0 (control), 0.5, 5, or 10% unweathered north central Texas Crude oil. Experimental units consisted of seed flats with dimensions of 55 x 28 x 3.2 cm (L x W x H) with 20 individual rows. Seeds were sown in separate rows at the rate of ten seeds per row. Soil moisture was maintained near –30 kPa pressure by using subsurface irrigation. Treatments were conducted in triplicate in a completely randomized design. Plants were grown for 28 days after seeding. On day 28, root and shoot biomass was measured and the presence of nodules was noted. Averaged across all nineteenspecies, soil crude oil concentration of 0.5, 5, and 10% decreased shoot biomass by 75.8, 96.7, and 99.3% and root biomass decreased by 72.1, 96.1, and 99.5% relative to the control treatments. Lablab (Lablab purpureus) had the greatest shoot and root biomass production in the treatment with 0.5% crude oil. In the treatment with 5% crude oil Kenaf#2 (Hisbiscus cannabinus var. tainvng #2) had the greatest shoot and root production and in the 10% crude oil treatment Kenaf #3 (Hisbiscus cannabinus var. sf 459) had the greatest shoot and root production. The presence of unweathered crude oil inhibited nodule formation on all legumes. Results indicate that the species with the greatest potential to enhance phytoremediation are Lablab for soil with approximately 0.5% crude oil, Kenaf # 2 for soil contaminated with approximately 5% crude oil and Kenaf #3 for soils contaminated with 10% crude oil. Due to the drastic reduction in shoot and root biomass in crude oil contaminated soil, over-seeding, transplanting healthy plants, and delaying seeding to allow time for volatile phytotoxic-compounds to volatilize may decrease the time for a plant canopy establishment, encourage greater root biomass, and enhance phytoremediation.

KEYWORDS: Root biomass, Shoot biomass, Bioremediation
Phytoremediation, Remediation, Petroleum hydrocarbons

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INTRODUCTION

Oil contaminated soils are a concern because they are unsuitable for agricultural, industrial, or recreational uses and are potential sources for surface and ground water contamination that can endanger humans and wildlife. Phytoremediation, the use of plants to enhance remediation of soil *in situ* is an economic alternative to traditional methods of excavation and landfilling or incineration (Schnoor, 1997). With *in situ* remediation techniques it is vital to contain the contaminant to prevent its spread. A plant canopy established during phytoremediation can reduce contaminant spread by reducing surface runoff and erosion.

Using phytoremediation to enhance degradation of contaminants relies upon an extensive root system. Roots enhance remediation via several mechanisms including sequestering contaminants (Cunningham et al., 1995), improving soil aeration (Nye and Tinker, 1977; Schnoor, 1993) and reducing movement of contaminants in soil (Topp et al., 1986; Nair et al., 1993; Vlamis et al., 1985; Schnoor, 1993). Perhaps the greatest contribution of roots during phytoremediation of soil contaminated with crude oil is increasing the activity of soil microorganisms. Root growth stimulates microbial activity in the rhizosphere by 10-100 times that of non-rhizosphere soil (Pierzynski, et al., 2000). The increased microbial activity in the rhizosphere may increase the rate of biodegradation of crude oil into less toxic products such as CO_2, H_2O, cell biomass, and energy (Aprill and Sims, 1990; Nair, et al., 1993; McFarlane et al., 1990; and Sims and Overcash, 1983).

The object of this study was to identify plants with the potential of enhancing bioremediation by measuring root and shoot biomass.

MATERIALS AND METHODS

A Windthorst sandy clay loam soil (Fine, mixed, thermic Udic Paleustalfs) with no known history of contamination from petroleum hydrocarbons was selected for this study (Table 1). This soil was collected from the Tarleton State University Hunewell Ranch located near Stephenville, TX. The soil was air dried and passed through a 2-mm sieve. Soil organic matter content was determined by the Walkley-Black method (Nelson and Sommers, 1982). Soil pH was measured using a glass electrode and pH meter from a 1:1 soil to water solution (McLean, 1982). Particle size distribution was measured by the hydrometer method (Gee and Bauder, 1986).

Table 1. Physicochemical properties of a Windthorst sandy clay loam soil.

Sand[1]	Silt[1]	Clay[1]	OC[2]	pH[3]
50%	20%	30%	2.63%	7.2%

[1] Hydrometer method

[2] Organic carbon

[3] pH meter using 1:1 soil:distilled H_2O

Experiments were conducted in a greenhouse. Experimental units consisted of 20-row seed flats (55 x 28 x 3.2 cm) filled with soil in every other row. Soil was contaminated with 0 (control), 0.5, 5, or 10% unweathered north central Texas Crude oil that was 80.7% total petroleum hydrocarbons by weight. Nineteen plant species that thrive in north central Texas were selected for this study (Table 2). Seeds were obtained from Turner Seeds of Breckenridge, TX and from the Texas A&M University Stephenville Research and Extension Center. Plants were seeded at a rate of 10 seeds per row at a depth appropriate for the size of the seed. One species was seeded per row. Soils were kept near field capacity (-30 kPa pressure) by subsurface irrigation. Treatments were completely randomized and conducted in triplicate. On day 28, living plant biomass was removed from seed trays. Soil was rinsed from roots under a gentle stream of water. Roots and shoots were separated at the crown. Roots of legumes were examined for the presence of nodules. Biomass was oven-dried at 60 °C for at least 48 hours and final biomass of shoots and roots was recorded on a dry weight basis. Means of shoot and root biomass were separated using Duncan's multiple range test with means considered significantly different at $\alpha = 0.05$.

Table 2. Species screened to identify vegetative and root biomass production in soil contaminated with 0.5, 5, and 10% unweathered crude oil.

Common Name	Scientific Name
Armadillo burr medic	*Medicago polymorpha*
Buffalograss	*Buchloe dactyloides* var. *texoka*
Hairy vetch	*Vicia villosa*
Hubam sweet clover	*Melilotus albus*
Illinois bundle flower	*Desmanthus illinoensis*
Johnsongrass	*Sorghum halepense*
Kenaf #2	*Hisbiscus cannabinus* var. *tainvng #2*
Kenaf #3	*Hisbiscus cannabinus* var. *sf 459*
Lablab	*Lablab purpureus*
Laredo soybean	*Glycine max* var. *laredo*
Madrid yellow clover	*Melilotus* sp.
Morning glory	*Ipomoea* sp.
Rose Clover	*Trifolium hirtum*
Sorghum triumph	*Sorghum bicolor* var. *triumph*
Sunflower macro	*Helianthus annuus* var. *macrocarpus*
Sunflower mammoth	*Helianthus annuus* var. *mammoth*
Sunflower maximillian	*Helianthus maximiliani*
Tall Jose wheatgrass	*Agropyron elongatum*
Ragweed	*Ambrosia psilostachya*

RESULTS

Production of shoot biomass was reduced as soil crude oil content increased from 0% (control) to 10% (Table 3). Averaging across all nineteen plant species and comparing to the controls, shoot biomass decreased by 75.8, 96.7 and 99.3% in soil contaminated with 0.5, 5, and 10% crude oil respectively. Of the all species tested, a majority was severely affected by the presence of crude oil in soil. The addition of 0.5% unweathered crude oil prevented growth of 10 of the 19 species. As the amount of unweathered crude oil increased to 5 and 10%, the number of species surviving after 28 days was reduce to 6 and 2 respectively.

Table 3. Influence of crude oil on shoot biomass production (dry weight basis) 28 days after seeding and the calculated slope and correlation coefficient from linear regression analysis correlating crude oil content vs. biomass.

Plant Species	Crude Oil (%)				Regression[a]		
	0	0.5	5	10	$ß_0$	$ß_1$	r^2
	Biomass (mg)[b]						
Kenaf #3	131.4 ef	136.8c	45.0b	21.1a	130.6	-12.1	0.91
Kenaf #2	173.1 e	273.7b	106.2a	17.0a	224.0	-21.0	0.82
Sunflower macro	429.1 d	44.6d	17.7c	0.0b	229.5	-27.5	0.39
Sorghum triumph	668.6 c	0.0d	11.1c	0.0b	323.2	-39.6	0.31
Rose Clover	7.3 f	00.d	1.0c	0.0b	3.69	-0.42	0.31
Johnsongrass	17.8 ef	2.2d	0.5c	0.0b	9.63	-1.16	0.41
Lablab	1233.1 a	548.9a	0.0c	0.0b	839.7	-101.7	0.66
Sunflower mammoth	955.5 b	160.0c	0.0c	0.0b	531.1	-65.1	0.44
Laredo soybean	930.8 b	156.4c	0.0c	0.0b	517.6	-63.4	0.44
Tall Jose wheatgrass	70.4 ef	6.3d	0.0c	0.0b	36.7	-4.51	0.38
Morning glory	616.2 c	0.0d	0.0c	0.0b	296.0	-36.6	0.31
Buffalograss	5.2 f	2.1d	0.0c	0.0b	3.44	-0.42	0.63
Illinois bundle flower	108.6 ef	0.0d	0.0c	0.0b	52.2	-6.46	0.31
Madrid yellow clover	39.5 ef	0.0d	0.0c	0.0b	19.0	-2.35	0.31
Hairy vetch	38.7 ef	0.0d	0.0c	0.0b	18.6	-2.30	0.31
Armadillo burr medic	23.3 ef	0.0d	0.0c	0.0b	11.2	-1.39	0.31
Hubam sweet clover	22.5 ef	0.0d	0.0c	0.0b	10.8	-1.34	0.31
Sunflower max	13.7 ef	0.0d	0.0c	0.0b	6.58	-0.81	0.31
Ragweed	4.6 f	0.0d	0.0c	0.0b	2.21	-0.27	0.31
Average	288.9	70.0	9.6	2.0	171.8	-20.4	0.50
Average decrease in height relative to control		75.8	96.7	99.3			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

Among the soil treatments with 0.5% crude oil, Lablab produced the most shoot biomass followed by Kenaf #2 and the two were significantly different. Sunflower mammoth, Laredo soybean, and Kenaf #3 had the next greatest amount of shoot biomass production, but were not significantly different from each other.

In the soils treated with 5% crude oil, Lablab emerged and grew well through 14 days. However, it was not able to survive at this level of crude oil content and died by day 21 of the experiment. Thus, after 28 days, shoot biomass was greatest from Kenaf #2 followed by Kenaf #3 and the two were significantly different. Measurable shoot biomass was also recorded from Sunflower macro, Sorghum triumph, Rose clover, and Johnsongrass.The remaining 13 species did not emerge.

In the soils treated with 10% crude oil, shoot biomass was produced only from Kenaf #3 and Kenaf #2, which were not statistically different. The remaining 17 plant species did notemerge.

Table 4. Influence of crude oil on root biomass production (dry weight basis) 28 days after seeding and the calculated slope and correlation coefficient from linear regression analysis correlating crude oil content vs. biomass.

Plant Species	Crude Oil (%)				Regression[a]		
	0	0.5	5	10	$ß_0$	$ß_1$	r^2
	Biomass (mg)[b]						
Kenaf #3	35.1 d	45.6 cd	24.4 b	8.2 a	40.9	-3.25	0.90
Kenaf#2	62.4 d	134.7 b	38.5 a	3.8 b	97.3	-9.66	0.66
Sorghum triumph	655.0 a	0.0 d	13.1 c	0.0 c	317.0	-38.71	0.31
Sunflower macro	191.1 c	31.7 cd	12.0 c	0.0 c	108.3	-12.79	0.45
Johnsongrass	8.7 d	1.3 d	1.3 d	0.0 c	5.00	-0.56	0.43
Rose clover	0.9 d	0.0 d	0.9 d	0.0 c	-0.60	-0.04	0.13
Lablab	243.5 bc	232.5 a	0.0 d	0.0 c	221.7	-26.51	0.81
Sunflower mammoth	345.8 b	137.8 b	0.0 d	0.0 c	228.2	-27.69	0.62
Laredo soybean	331.6 b	57.8 c	0.0 d	0.0 c	185.3	-22.70	0.45
Tall Jose wheatgrass	27.5 bc	6.4 d	0.0 d	0.0 c	16.1	-1.97	0.49
Morning glory	286.5 d	0.0 d	0.0 d	0.0 c	137.6	-17.03	0.31
Buffalograss	19.3 d	4.4 d	0.0 d	0.0 c	11.3	-1.38	0.49
Madrid yellow clover	44.0 d	0.0 d	0.0 d	0.0 c	21.1	-2.62	0.31
Hairy vetch	38.6 d	0.0 d	0.0 d	0.0 c	18.5	-2.29	0.31
Hubam sweet clover	19.7 d	0.0 d	0.0 d	0.0 c	9.46	-1.17	0.31
Illinois bundle flower	18.0 d	0.0 d	0.0 d	0.0 c	8.64	-1.07	0.31
Armadillo burr medic	8.8 d	0.0 d	0.0 d	0.0 c	4.22	-0.52	0.31
Sunflower max	2.0 d	0.0 d	0.0 d	0.0 c	0.96	-0.12	0.31
Ragweed	1.0 d	0.0 d	0.0 d	0.0c	0.83	-0.10	0.31
Average	123.1	34.3	4.7	0.6	75.4	-8.96	0.54
Average decrease in height relative to control		72.1	96.1	99.5			

[a]Constant ($ß_0$), slope ($ß_1$), and correlation coefficient (r^2) of fitted first-order linear regression curves

[b]Means within a column with the same letter are not statistically different from each other (Duncan's test, $p < 0.05$)

A fitted regression analysis, plotting crude oil content vs. shoot biomass, showed good correlation for Kenaf #3 ($r^2 = 0.91$) and Kenaf #2 ($r^2 = 0.82$), but showed a poor correlation for most other plant species (Table 3). For example, many of the species with little or not vegetative biomass had a correlation coefficient of 0.31.

Root biomass was significantly reduced in soil with increasing crude oil content (Table 4). Averaging across all nineteen plant species and comparing to the controls, root biomass decreased by 72.1, 96.1 and 99.5% % in soil contaminated with 0.5, 5, and 10%

crude oil respectively. In addition to decreased root biomass, nodules were not observed on legumes grown in soil containing unweathered crude oil.

In the treatment with 0.5% crude oil, the greatest amount of root biomass was produced by Lablab followed by Kenaf #2 and their differences were significant. Laredo soybean, Kenaf #3 and Sunflower macro had the next greatest amount of root biomass production, but were not significantly different from each other.

In soil treated with 5% crude oil, root biomass was produced by six species. Kenaf #2 produced the most root biomass followed by Kenaf #3, which was significantly lower. Crude oil contamination decreased the amount of root biomass by 38% for Kenaf #2 and 30% for Kenaf #3 when compared to controls. Sorghum triumph and Sunflower macro had the next greatest amount of root biomass production. Root biomass was also observed in Johnsongrass and Rose clover.

Root biomass production in soils treated with 10% crude oil was statistically greatest for Kenaf #3 followed by Kenaf #2. Root biomass production was drastically reduced compared to the controls for these two Kenaf varieties. Relative to the root biomass in the control soil, there was a 77 and 99% reduction in root biomass for Kenaf #3 and Kenaf #2 respectively. None of the remaining 17 plant species emerged in soil with 10% unweathered crude oil.

Fitted linear regression correlating crude oil content vs. root biomass was 0.54 for the average of all 19 species (Table 4). The correlation coefficients were higher for the species with the greatest amount of root biomass production in contaminated soils. For example, the correlation coefficient's for Kenaf #3, Kenaf #2, and Lablab were 0.90, 0.66, and 0.81 respectively.

DISCUSSION

Increasing vegetative biomass may act to contain contaminated soil and prevent the spread of crude oil into surface and subsurface water. Closing the plant canopy reduces the impact of raindrops and decreases the possibility of detachment and transport of contaminated soils. Although Kenaf #2 and Kenaf #3 were grown in soil with 10% crude oil, shoot biomass was reduced by 90% for Kenaf #2 and 84% for Kenaf #3 relative to shoot production in uncontaminated soil. Thus, higher soil contamination increases the time required to develop an effective canopy, which will likely increase the risk of surface runoff and erosion.

Plants identified in this study with the greatest root biomass production are recommended for further study to determine their impact on enhancing bioremediation of crude oil contaminated soils. Increasing root biomass may increase phytoremediation in several ways. The carbonaceous exudates from plant roots are readily metabolized by microorganisms in the soil, which increases total microbial populations in the rhizosphere. Increased populations leads to an increase in activity in the rhizosphere, which may increase metabolic and cometabolic transformations of contaminants to less toxic products (Aprill and Sims, 1990; Nair, 1993; McFarlane et al., 1990; and Sims and Overcash, 1983). Crude oil degrades most rapidly in aerobic environments (Atlas, 1981; Bossert and Bartha, 1984; Leahy and Colwell, 1990). Roots improve soil aeration by directly giving off oxygen to the root zone and allow improved entry of oxygen into the soil by diffusion along old root channels (Nye and Tinker, 1977; Schnoor, 1993). Plants may sequester, absorb, and translocate crude oil to plant tissues, thereby removing these hydrocarbons from the soil environment (Cunningham et al., 1995). Additionally, roots can reduce downward movement of contaminants through the soil profile by extracting excess water during transpiration, thus reversing the vertical hydraulic gradient (Topp et al., 1986; Nair et al., 1993; Vlamis et al., 1985; Schnoor, 1993).

Because legumes did not form nodules when growing in soil containing unweathered crude oil, N -fixation will not occur and these plants will likely require nitrogen fertilizer to optimize their growth.

Because both shoot and root biomass production were drastically reduced in contaminated soil, further research is needed to find ways to increase biomass production in these soils. Increasing the seeding rate beyond that typically recommended or transplanting actively growing plants into contaminated soil could enhance bioremediation and reduce the time required to form a plant canopy.

Allowing time for volatilization prior to seeding may reduce the number of toxic compounds in soil and thus increase shoot and root biomass. Volatile compounds associated with unweathered crude oil, like the type used in this study, are usually phytotoxic and may cause seed damage, reduce germination, and decrease plant biomass production. Because the majority of volatile compounds volatilize from soil within 24-48 hours (Rhykerd 1998), delaying seeding following spills may increase production of shoot and root biomass and enhance the potential for phytoremediation.

CONCLUSIONS

Of the plants examined, Lablab produced the most biomass in soils contaminated with 0.5% crude oil while, Kenaf #2, and Kenaf #3 produced the most biomass in soils contaminated with 5 and 10% crude oil. These species show the greatest promise to enhance remediation of oil contaminated soils.

Possible strategies to enhance shoot and root biomass production include increasing the seeding rate above that recommended, transplanting actively growing plants into the contaminated soil, and delay seeding immediately following a spill to allow volatilization may remove phytotoxic compounds from the soil.

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Using Strongarm for Weed Control in Texas Peanut

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ABSTRACT

Field experiments were conducted in 1995 through 1997 in south and west Texas to evaluate Strongarm (diclosulam) for weed control in peanut. Strongarm applied preplant incorporated (PPI) at 0.15 oz product/A in combination with Sonalan at 1.1 qt/A controlled ≥ 95% Texas panicum, Palmer amaranth, morningglory species, and golden crownbeard and 91% devil's-claw. When Strongarm rates were increased to 0.44 oz/A, yellow and purple nutsedge were controlled at least 89% and 72%, respectively.

KEYWORDS: *Arachis hypogaea* L., broadleaf weeds, groundnut, purple nutsedge, preplant incorporated, yellow nutsedge.

Peanuts (*Arachis hypogaea L.*) in Texas are infested with several problem weeds, including Palmer amaranth (*Amaranthus palmeri* S. Wats.), Texas panicum (*Panicum texanum* Buckl.), golden crownbeard [*Verbesina enceliodes* (Cav.) Benth. & Hook. f. ex. A. Gray], yellow nutsedge (*Cyperus esculentus* L.), and purple nutsedge (*C. rotundus* L.) (Dowler, 1997). With increasing peanut acreage in west Texas, weeds such as devil's claw [*Proboscidea louisianica* (Mill.)Thellung], lanceleaf sage (*Salvia reflexa* Hornem.), prairie sunflower (*Helianthus petiolaris* Nutt.), woollyleaf bursage [*Ambrosia grayi* (A. Nels.) Shinners], Texas blueweed (*Helianthus ciliaris* DC.), and silverleaf nightshade (*Solanum elaeagnifolium* Cav.) may soon become problematic weeds in peanut.

The imidazolinone herbicides, Pursuit (imazethapyr) and Cadre (imazapic), partially control many of these weeds (Wilcut et al., 1991b; Webster et al., 1997; Grichar et al., 1992). However, Pursuit does not consistently control yellow nutsedge (Grichar et al., 1992; Wilcut et al., 1991a). Cadre controlled purple and yellow nutsedge as well or better than Pursuit at all application timings (Dotray and Keeling, 1997; Grichar and Nester, 1997) and provided better control of purple and yellow nutsedge in field experiments than other currently registered herbicides in peanut (Colvin and Brecke, 1993; Gooden and Wixson, 1992; Grichar and Nester, 1993; Wilcut et al., 1994a). Cadre also has a longer period of residual weed control when applied postemergence (POST) than Pursuit.

The 18 mo crop rotation restriction following imidazolinone herbicide use on peanut with cotton (*Gossypium hirsutum*) planting limits the use of the imidazoline herbicides, especially in west Texas (Richburg et. al., 1994; Wilcut et al., 1993). Common crop rotation

Table 1. Annual weed species and density at each location.

Location	Year	Weed Species	Density No./m^2	Applic. timing
LDS Farm	1995	Texas pancium	8-10	PPI
	1996	Palmer amaranth	12-14	PPI
		Texas pancium	10-12	PPI
		Yellow nutsedge	16-20	PPI
	1997	Palmer amaranth	16-18	PPI
		Texas panicum	10-12	PPI
		Golden crownbeard	6-8	PPI
Lubbock	1997	Palmer amaranth	25-30	PPI
		Devil's claw	4-6	PPI
		Yellow nutsedge	2-4	PPI
Mann	1996	Texas panicum	10-12	PPI
		Palmer amaranth	6-8	PPI
		Purple nutsedge	4-6	PPI
	1997	Yellow nutsedge	14-16	POST
		Palmer amaranth	4-6	PPI
		Texas panicum	6-8	PPI
O'Donnell	1996	Palmer amaranth	2-6	PPI
Seminole	1995	Purple nutsedge	3-4	PPI
Wier	1995	Yellow nutsedge	12-14	PPI
		Golden crownbeard	16-18	PPI
Yoakum	1995	Texas panicum	6	PPI
		Yellow nutsedge		PPI
	1996	Yellow nutsedge	15-20	POST
	1996	Texas panicum	8-10	POST
		Yellow nutsedge	30-40	POST

with peanut in west Texas is cotton-peanut-cotton. In south and central Texas, the common rotation is usually corn (*Zea mays* L.) or grain sorghum [*Sorghum bicolor* (L.) Moench] followed by peanut. The third year may be a grain crop or another year of peanut before the rotation back to a grain crop. In some areas of south and central Texas, watermelon (*Citrullus lanatus* L.) or other vegetable crops may be included in a rotation with peanut.

Cadre and Pursuit crop rotation restrictions after applying either in peanut include 9 mo for corn, 18 mo for cotton and grain sorghum, and 26 mo for most other crops excluding potatoes (*Solanum tuberosum* L.) which has a 40 mo rotation restriction (Anonymous, 1999). Rotation restrictions following Strongarm use in peanut include 18 mo for corn and grain sorghum, and 30 mo for all other crops (R. Lassiter, personal communication).

Strongarm is a recently registered triazolopyrimidine sulfonanilide herbicide for use in peanut. A petition for registration of Strongarm for use in soybean [*Glycine max* (L.) Merr.](Gander et al., 1997; Sheppard et al.,1997; Stafford et al., 1997) has been submitted and is pending at the U.S. EPA. As a preplant incorporated (PPI) or preemergence (PRE) treatment, Strongarm controlled many weeds found in soybean and peanut, including common cocklebur (*Xanthium strumarium* L.), morningglory species (*Ipomoea* spp.), common ragweed (*Ambrosia Artemisiifolia* L.), pigweed species (*Amaranthus* spp.), common lambsquarter (*Chenopodium album* L.), prickly sida (*Sida spinosa L.),* Florida beggarweed [*Desmodium tortuosum* (Sw.) DC.], bristly starbur (*Acanthospermum hispidum* DC.) and yellow nutsedge (Sheppard et al., 1997; Richburg et al., 1997; Braxton et al., 1997; Langston et al. 1997).

However, several studies have reported that Strongarm applied PPI or PRE did not control sicklepod *[Senna obtusifolia* (L.) Irwin Barneby] (Wilcut et al., 1997; Braxton et al., 1997). Strongarm applied POST also did not control prickly sida or common lambsquarters (Wilcut et al., 1997).

Field experiments were conducted in the Texas peanut growing regions with the following objectives: a) to evaluate Strongarm applied PPI or POST for weed control in peanut, b) to determine peanut tolerance to Strongarm, and c) to compare weed control and peanut yield with Strongarm to a commercial standard herbicide system.

MATERIALS AND METHODS

Field studies were conducted at twelve south and west Texas locations during the 1995 through 1997 growing seasons. In south Texas, studies were conducted at the following locations: Texas Agricultural Experiment Station near Yoakum in 1995 and1996, James Mann Farm near Pearsall in 1996 and 1997, Church of Latter Day Saints (LDS) Farm near Pearsall in 1995, 1996, and 1997, and the Joe Wier Farm near Charlotte in 1995. Soil type at the Yoakum location was a Tremona loamy fine sand (thermic Aquic Arenic Palenstalf) with less than 1% organic matter and pH of 6.8 to 7.2. At the James Mann Farm, the soil type was a Duval loamy fine sand (fine-loamy, mixed, hyperthermic Aridic Haplustalfs) with less than 1% organic matter and a pH of 7.0 to 7.2. Soil type at the LDS Farm was a Duval fine sandy loam (fine loamy, mixed, hyperthermic Aridic Haplustalfs) with less than 1% organic matter and a pH of 7.2 . At the Joe Wier Farm, the soil type was a Neuces loamy fine sand (loamy, mixed, hyperthermic Aquic Arinic Palenstalfs) with less than 1% organic matter and a pH of 7.2. In west Texas, studies were conducted near Seminole in 1995, near O'Donnell in 1996, and near Lubbock in 1997. Soil type near Seminole and O=Donnell was an Amarillo fine sandy loam (fine-loamy, mixed, thermic Aridic Palenstalf) with less than 1% organic matter and a pH of 7.8. Soil type near Lubbock was an Amarillo sandy clay loam (fine-loamy, mixed, thermic Aridic Palenstalf) with less than 1% organic matter and a pH of 7.8. These experimental sites are representative of the major peanut produing areas in south and west Texas.

GK-7peanut was used at all south Texas locations except the LDS farm in 1997 where the cultivar AT-108 was used. Peanut seed at 112 lb/A was planted approximately 2 in. deep immediately after the PPI herbicide applications. In west Texas, Tamrun 88 was planted 2 in. deep at 112 lb/A in a well-prepared seedbed using conventional equipment within one week of herbicide application. PPI treatments in south Texas were incorporated immediately after application with a power-driven tiller operated at a 2 in.depth. In west Texas, PPI treatments were incorporated with a rolling cultivator to a depth of 1 to 2 in. POST treatments were applied 3-4 wk after crop emergence.

The experimental design for all studies was a randomized complete block design with 3 to 4 replications. Plots were two rows wide, spaced 36 in apart and 25 ft long in south Texas and four rows wide, spaced 40 in apart and 30 ft long in west Texas. Naturally occurring weed species composition and densities are identified in Table 1.

In south Texas, herbicides were applied with a compressed-air bicycle sprayer using Teejet 11002[3] flat fan nozzles that delivered a spray volume of 20 gal/A at 28 psi. In west Texas, herbicides were applied using a tractor-mounted compressed-air sprayer using Teejet 8002[3] flat fan nozzles delivering 15 gal/A at 35 psi. POST applications of Cadre included an organosilicone-based surfactant[4] at 0.25% by vol. in south Texas and a crop oil concentrate[5] at 1.25% by vol. in west Texas. Weed control ratings were taken throughout the growing season; however, only late season ratings are presented. Visual estimates of weed control were based on a scale of 0% (no control or peanut injury) to 100% (complete control or death of the peanut) relative to the non-treated check. Peanut injury was estimated visually starting 2 wk after PPI treatments or 1 week after POST treatments and were recorded throughout the growing season. Peanut stunting was the parameter used in making the visual injury estimates.

Herbicide treatments were Sonalan applied PPI at 1.1 qt/A alone or in combination with Strongarm at 0.15, 0.30, 0.44 oz product/A, and Sonalan at 1.1 qt/A applied PPI followed by Cadre applied early postemergence (EPOST) at 1.44 oz product/A. A nontreated check was included at each location.

Data collected included visual estimates of crop injury and weed control (on a scale of 0% to 100% relative to the nontreated check) and peanut yield. Weed control and peanut injury were visually estimated early, mid-, and late-season during each year. Late weed ratings taken approximately 3 weeks prior to harvest are presented.

Peanut yields were obtained at four locations in south Texas. Yields were obtained by digging each plot separately, air-drying in the field for 5 to 8 days, and harvesting peanut pods with a combine. Weights were recorded after soil and foreign material were removed from the plot samples. Visible weed control data were subjected to arcsine transformation prior to analysis of variance, and significant differences among means for weed control and peanut yield were determined using Fisher's Protected LSD Test at the 5% level.

Since a treatment by year interaction occurred in soil-applied studies that examined peanut injury, yellow nutsedge control and in peanut yield, data are presented by year. Since there were no year by treatment interactions for devil=s claw, Texas panicum, Palmer amaranth, golden crownbeard, or morningglory species control, data were pooled over years.

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[3]Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189.

[4]Kinetic HV, proprietary blend of polyalkyleneoxide modified polydimethylsiloxone and non-ionic surfactant (99.5%). Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

[5]Agri-Dex, an 83% paraffin based petroleum oil with 17% polyoxyethlylated polyol fatty acid ester and polyol fatty acid ester. Helena Chemical Co., 5100 Poplar Avenue, Memphis, TN 38137.

RESULTS AND DISCUSSION

Peanut injury. Slight early season peanut injury (stunting) was observed in all three years following Strongarm PPI applications (Table 2). In 1995, Strongarm at 0.44 oz/A caused 3% stunting at Yoakum when rated 40 days after treatment (DAT) whileStrongarm caused no stunting 17 DAT at Wier. In 1996, Strongarm at 0.3 and 0.44 oz/A injured peanut 3% and 5%, respectively, when rated 44 DAT. In 1997, at the Mann Farm, Strongarm caused ≤ 8% peanut stunt while Cadre at 1.44 oz/A caused 3% stunting at the Lubbock location. No peanut stunting was observed at harvest in any of the three years.

Table 2. Peanut stunting following application of Strongarm PPI.

			1995		1996	1997	
Treatment	Rate product/A	Appl. timing	Yoakum 40 DAT[a]	Wier 17 DAT	Yoakum 44 DAT	Mann 21 DAT	Lubbock 26 DAT
			---------------	---------------	%	---------------	---------------
Check	-	-	0	0	0	0	0
Strongarm	0.15oz	PPI	1	0	0	0	0
Strongarm	0.3 oz	PPI	1	0	3	3	0
Strongarm	0.44 oz	PPI	3	0	5	8	0
Cadre	1.44 oz	POST	0	-	-	0	3
LSD (0.05)			2	NS	4	2	3

[a]DAT = days after PPI treatment

Texas panicum control. Strongarm and Cadre improved Texas panicum control over Sonalan alone (Table 3). Dinitroaniline herbicides, such as Sonalan, usually control large seeded annual grasses including Texas panicum (Wilcut et al., 1994b, 1995). Cadre applied POST controls small Texas panicum escaping earlier control efforts (Wilcut et al., 1993).

Table 3. Texas panicum and broadleaf weed control using soil applied Strongarm, 1995-97.

			Weed species				
Treatment	Rate	Appl. timing	Texas panicum	Palmer amaranth	Golden crownbeard	Pitted morningglory	Devil's claw
			----------	----------	%	----------	----------
	product/A						
Check	-	-	-	0	0	0	0
Strongarm	0.15 oz	PPI	97	95	100	99	91
Strongarm	0.3 oz	PPI	97	98	100	98	95
Strongarm	0.44 oz	PPI	99	99	100	99	96
Cadre	1.44 oz	POST	97	99	99	100	100
Sonalan	1.1 qt	PPI	87	77	-	-	38

Palmer amaranth control. All rates of Strongarm controlled Palmer amaranth ≥95% in south and west Texas which is comparable to control from Cadre (Table 3). Cadre provided 99% Palmer amaranth control. In contrast, Sonalan alone controlled Palmer amaranth 77%. In earlier work, Grichar (1997) reported Cadre controlled Palmer amaranth 95 to 100% and spiny amaranth (*Amaranthus spinosus* L.) 72 to 91% (Grichar, 1994).

Golden crownbeard control. Strongarm provided 100% golden crownbeard control regardless of rate, while Cadre controlled golden crownbeard 99% (Table 3). Cadre has provided inconsistent golden crownbeard control (personal observation) especially in low rainfall or irrigation areas. It has been speculated that lower rainfall or irrigation amounts may have resulted in less Cadre root absorption. Richburg et al. (1995) reported less Cadre was absorbed by yellow nutsedge under lower rainfall conditions.

Pitted morningglory control. All herbicide treatments controlled pitted morningglory at least 98% (Table 2). Richburg et al. (1997) reported that Strongarm controlled pitted morningglory in soybeans equal to or greater than Scepter (imazaquin). No differential response in control of *Ipomoea* morningglory species with Cadre has been reported (Richburg, et al., 1995; Wilcut et al., 1994a, 1995). In the southeast, morningglory control with Cadre has been greater than 80% in most instances (Richburg et al., 1995; Webster et al., 1997).

Devil's claw control. Cadre and all rates of Strongarm effectively controlled devil's-claw. Strongarm at 0.15 oz/A controlled devil's claw 91% at 132 DAT while Strongarm at ≥ 0.3 oz/A controlled devil's claw ≥ 95%. Similarly, Cadre provided 100% devil's-claw control (Table 3).

Yellow nutsedge control. In 1995, Strongarm at 0.15 oz/A provided poor yellow nutsedge control (25%) at Yoakum and moderate control (81%) at the Wier location (Table 4). Strongarm at 0.3 oz/A or greater controlled yellow nutsedge at least 94% at both locations, which was equal to control with Cadre.

At the Yoakum location in 1996, Strongarm at 0.15 oz/A provided < 60% yellow nutsedge control while other Strongarm rates provided control similar to Cadre (Table 4). At the LDS Farm location, all herbicide treatments controlled yellow nutsedge at least 88%. Yellow nutsedge control with Cadre was 94%. In 1997 at Lubbock, all Strongarm rates controlled yellow nutsedge at least 91% while Cadre completely controlled yellow nutsedge.

Table 4. Yellow and purple nutsedge control with soil applied Strongarm in 1995-97.

			Yellow nutsedge					Purple nutsedge	
			1995		1996		1997	1995	1996
Treatment	Rate product/A	Appl. timing	Yoakum	Wier	Yoakum	LDS	Lubbock	Seminole	Mann
			%						
Check	-	-	0	0	0	0	0	0	0
Strongarm	0.15oz	PPI	25	81	56	88	91	70	53
Strongarm	0.30 oz	PPI	96	95	94	96	98	77	75
Strongarm	0.44 oz	PPI	95	97	89	90	99	72	80
Cadre	0.07 oz	POST	99	99	89	94	100	92	93
LSD (0.05)			22	22	11	12	11	9	13

Yellow nutsedge has generally been controlled 80% or more with Strongarm applied PPI or PRE at rates ≥ 0.44 oz/A (Wilcut et al., 1997; Braxton et al., 1997). Cadre has generally provided more consistent control of yellow nutsedge than Pursuit (Grichar et al., 1992; Richburg et al., 1995; Dotray and Keeling, 1997). In greenhouse experiments, Cadre exhibited foliar and soil activity on purple and yellow nutsedge (Richburg, et al., 1994).

Purple nutsedge control. In 1995, Strongarm controlled purple nutsedge 70-77% regardless of rate (Table 4). Cadre controlled purple nutsedge 92%. In 1996, Cadre controlled purple nutsedge 93% while Strongarm at 0.3 oz/A or greater controlled purple nutsedge 75 to 80% (Table 4). Strongarm at 0.15 oz/A failed to adequately control purple nutsedge (53%).

Peanut yield. All herbicide treatments increased peanut yield over the non-treated check at Yoakum in 1995 and the LDS Farm in 1996 while no yield differences were noted at the Wier location (Table 5). Strongarm at 0.3 and 0.44 oz/A and Cadre increased peanut yield over the nontreated check at the LDS Farm in 1997 (Table 5).

These experiments indicated that Strongarm provides a broad spectrum of weed control similar to Cadre. While Cadre controls a broad spectrum of troublesome weeds, the major limitation for Cadre in southwest peanut production is the follow crop restrictions (Batts et al., 1995; York and Wilcut, 1995). Major crops rotated with peanut in Texas include corn, cotton, grain sorghum, and various vegetable crops. Label restrictions with Strongarm may limit its use in south and central Texas where corn or grain sorghum may be grown in rotation with peanut. However, Strongarm may be used in west Texas where most rotations are peanut followed by cotton.

Table 5. Influence of Strongarm on peanut yield.

Treatment	Rate	1995 Yoakum	1995 Weir	1996 LDS	1997 LDS
	product/A	%			
Check	-	1508	2353	1033	2544
Strongarm	0.15	2141	2649	2020	3342
Strongarm	0.3	2456	1959	2287	3511
Strongarm	0.44	2364	2324	-	3564
Cadre	1.44	2259	2331	2482	3467

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Estimating the Potential to Reduce Agricultural Irrigation Water Demand in West Central Texas

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ABSTRACT

The purpose of this paper is to assess future agricultural irrigation demand and estimate the potential for water savings from advanced irrigation technology adoption in Region F, an area encompassing 32 West Central Texas counties. This involved calculating irrigation water demand based on existing cropping activities, irrigation technologies and typical irrigation application rates and assessing the potential water savings resulting from adoption of the most feasible irrigation technology. Results suggest that certain counties within Region F (Borden, Glasscock, Loving, Midland, Reagan, Reeves, and Tom Green) will be unable to meet irrigation demands even with utilization of the most efficient technology. It can be anticipated that in those counties, some portion of the irrigated acres will shift to non-irrigated crop production or to other uses.

KEYWORDS: irrigation demand, furrow irrigation, surge flow, MESA, LESA, LEPA

As a result of the passage of Senate Bill 1 (SB1) in 1997, water planning in Texas became the domain of regional planning groups rather than the Texas Water Development Board. SB1 allows individuals representing numerous interest groups to serve as members of Regional Water Planning Groups (RWPG) to prepare regional water plans for their respective areas. These plans map out how to conserve water supplies, meet future water demand needs, and respond to future droughts in the planning areas. The purpose of this paper is to assess future agricultural irrigation demand and estimate the potential for water savings from advanced irrigation technology adoption in West Central Texas or Region F as the Texas Water Development Board designates it.

Crop production in Region F is diverse across the region due to differing climatic conditions, soil types, water sources (groundwater and surface), water quality and cropping mixes. To facilitate the investigation of feasible irrigation technologies, sub-regions within the region were identified which grouped counties with similar crop production characteristics. These sub-regions as shown in Figure 1 are: Western – Reeves

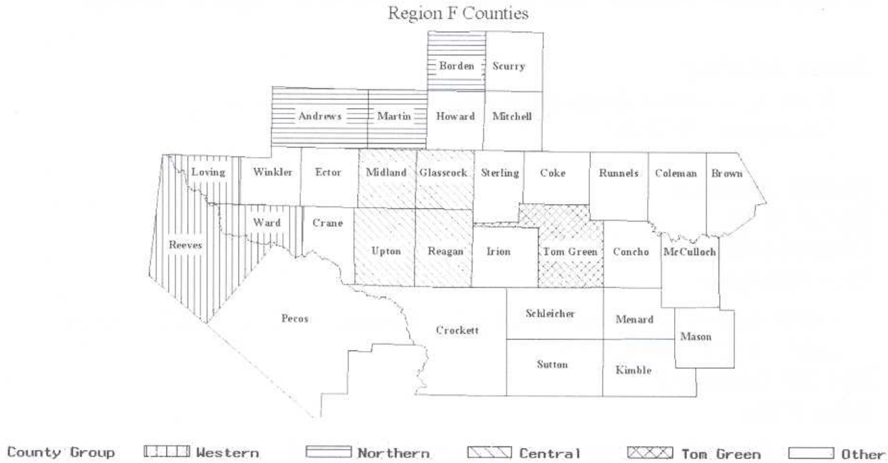

Figure 1. Region F Counties and Sub-Regions Examined for Senate Bill 1

and Loving counties; Central – Glasscock, Midland, Upton, and Reagan counties; Northern – Andrews, Borden, and Martin counties; and Tom Green County.

Water supplies within Region F come from groundwater and surface water sources. In 1997, groundwater sources accounted for 74 percent of total water use in the region. Groundwater sources include several major and minor aquifers across the region. Estimates of groundwater supplies for the period 2000 – 2050 were based on several assumptions relating to recharge and annual depletion of water held in storage. Surface water supplies are significant sources of irrigation water for several counties within the region. Seventeen major water supply reservoirs are located in Region F. However, only Red Bluff, Twin Buttes, Nasworthy and Brownwood provide significant irrigation supplies. Other surface water supplies come from run-of-the-river water rights.

The Region F Water Planning Group adopted revisions to the consensus-based projections used in the 1997 state water plan. These revisions were presented in a report titled "Revisions to Population and Water Demand Projections for Region F" dated June 1999 and prepared by Freese and Nichols, Inc. Water demand for agriculture and in particular irrigated agriculture dominates the projected regional water demand projections. Irrigation water demand is projected to account for between 69 and 74 percent of total water use in the region over the period 2000 to 2050.

The revised irrigation water demand projections were detailed in a report titled "Revisions to Irrigation Water Demand Projections for Region F" dated September 1999 and prepared by Alan Plummer Associates, Inc. The revised irrigation demand projections were based on the maximum irrigation volume for the region during the period of 1990 – 1997. Each county's maximum volume for any one year during the period was used, with the sum of each individual county's maximum demand giving the regional total. The rationale of this approach was to approximate a "dry-year" condition and also take into account the effect of increased irrigated acreage in some counties following the 1996 farm legislation.

The initial irrigation supply and demand projections for three time periods (2000, 2010, and 2020) for each county are presented in Table 1. As shown, a supply/demand imbalance is projected for 11 of the 32 Region F counties in 2000 and 10 of the 32 counties from 2010 through 2020. Several counties show extreme deficits in supply versus projected

Table 1. Initial irrigation water supply and demand projections (acre-feet of water) for Region F for 2000, 2010, and 2020.

	2000			2010			2020		
County	Supply	Demand	Difference	Supply	Demand	Difference	Supply	Demand	Difference
Andrews	17,780	18,931	-1,151	18,800	18,773	27	18,800	18,616	184
Borden	953	9,662	-8,709	957	9,649	-8,692	963	9,636	-8,673
Brown	13,250	10,526	2,724	13,250	10,491	2,759	13,250	10,455	2,795
Coke	809	667	142	809	666	143	809	666	143
Coleman	2,310	1,376	934	2,310	1,364	946	2,310	1,353	957
Concho	7,082	7,082	0	7,054	7,054	0	7,026	7,026	0
Crane	337	337	0	337	337	0	337	337	0
Crockett	500	439	61	500	432	68	500	424	76
Ector	9,095	8,602	493	9,102	8,500	602	9,104	8,399	705
Glasscock	20,668	68,521	-47,853	20,663	67,979	-47,316	20,664	67,437	-46,773
Howard	4,724	4,724	0	4,671	4,671	0	4,620	4,618	2
Irion	3,331	3,296	35	3,331	3,227	104	3,331	3,157	174
Kimble	2,276	1,128	1,148	2,276	1,089	1,187	2,276	1,049	1,227
Loving	324	582	-258	324	580	-256	324	578	-254
McCulloch	3,406	2,964	442	3,406	2,928	478	3,406	2,891	515
Martin	13,501	14,221	-720	13,450	13,976	-526	13,407	13,731	-324
Mason	18,000	17,501	499	18,000	17,255	745	18,000	17,009	991
Menard	6,080	6,080	0	6,061	6,061	0	6,041	6,041	0
Midland	31,934	66,574	-34,640	33,690	66,061	-32,371	35,143	65,548	-30,405
Mitchell	2,435	2,238	197	2435	2,226	209	2,435	2,215	220
Pecos	82,464	382,458	6	81,196	81,190	6	79,927	79,921	6
Reagan	28,064	46,697	-18,633	28,060	465,937	-17,877	28,059	45,177	-17,118
Reeves	66,667	105,831	-39,164	66,667	104,942	-38,275	66,667	104,053	37,386
Runnels	9,193	7,250	1,943	9,193	7,221	1,972	9,193	7,191	2,002
Schleicher	2,000	1,807	193	2,000	1,772	228	2,000	1,737	263
Scurry	3,742	3,325	417	3,742	3,219	523	3,742	3,113	626
Sterling	980	886	94	982	851	131	983	817	166
Sutton	2,461	2,248	213	2,461	2,206	255	2,461	2,164	297
Tom Green	82,239	120,102	-37,863	82,192	119,808	-37,616	82,145	119,515	-37,370
Upton	14,681	19,824	-5,143	14,681	19,547	-4,866	14,681	19,270	-4,589
Ward	5,843	11,273	-5,430	5,849	11,136	5,287	5,933	10,999	-5,066
Winkler	1,500	1,500	0	1,500	1,500	0	1,500	1,500	0
Total	458,629	648,652	-190,023	459,949	642,648	182,699	460,037	636,643	-176,606

Table 2. Irrigated acres by crop and by county in Region F in 1997 (Texas Water Development Board).

County/Crop_	Cotton	Grain Sorghum	Wheat	Alfalfa	Forage Crops	Hay Pasture	Vegetables	Peanuts	Pecans	Vineyards	Other	County Total
Andrews	8,200	—	—	—	—	80	—	3,500	120	—	—	11,900
Borden	5,000	—	—	—	—	—	—	—	40	—	—	5,040
Brown	—	—	—	—	885	2,161	—	500	3,600	—	—	7,146
Coke	200	—	22	—	—	53	—	—	40	—	—	315
Coleman	—	—	—	—	—	871	—	—	—	—	—	871
Concho	300	1,000	900	100	230	490	—	—	—	10	—	3,030
Crane	—	—	260	—	—	—	—	—	2	2	—	264
Crockett	—	—	217	—	—	78	—	—	—	—	—	295
Ector	625	500	1,100	244	120	488	54	—	690	31	30	3,882
Glasscock	50,700	1,900	400	58	21	—	95	—	209	—	18	53,401
Howard	2,800	—	—	408	—	153	—	—	144	—	—	3,505
Irion	—	595	272	61	593	436	8	—	57	22	56	2,100
Kimble	—	—	—	—	295	787	—	—	311	—	59	1,452
Loving	—	—	—	140	—	—	—	—	—	—	—	140
McCulloch	—	—	406	—	500	454	8	216	—	—	420	2,004
Martin	6,000	—	1,112	278	—	260	—	1,800	44	—	304	9,798
Mason	310	425	1,300	—	—	490	175	2,600	8	—	595	5,903
Menard	—	—	49	300	520	1,687	—	—	138	35	820	3,549
Midland	10,300	—	948	440	4,050	12,000	160	60	500	—	40	28,498
Mitchell	1,100	—	—	217	—	—	—	—	17	—	—	1,334
Pecos	9,700	1,200	278	4,469	3,750	2,500	2,259	—	3,060	1,031	674	28,921
Reagan	27,500	680	218	50	—	—	—	—	80	—	—	28,528
Reeves	8,500	269	800	5,032	4,805	100	7,067	—	233	—	1,927	28,733
Runnels	2,800	1,043	300	—	498	352	—	—	260	180	300	5,733
Schleicher	—	—	49	—	688	—	—	—	201	—	125	1,063
Scurry	300	—	150	145	51	55	35	—	21	—	7	764
Sterling	—	—	42	—	539	—	—	—	41	—	—	622
Sutton	—	—	900	—	252	58	—	—	152	—	—	1,362
Tom Green	26,600	7,600	6,800	1,600	3,900	1,400	—	—	1,600	300	5,471	55,271
Upton	8,500	87	1,099	—	140	315	—	—	340	—	956	11,437
Ward	300	—	—	600	140	62	—	—	44	5	—	1,151
Winkler	—	—	—	—	—	—	—	—	—	—	—	0
Crop Totals	169,735	15,299	17,622	14,142	21 977	25,330	9,861	8,676	11,952	1,616	11,802	308,012

irrigation demands. These include Glasscock, Midland, Reagan, Reeves, and Tom Green counties. For example, the projected supply of irrigation water in Glasscock County was the most significant irrigated crop with 55 percent of the acres followed by hay-pasture and forage crops at 8 percent and 7 percent, respectively. Six counties (Glasscock, Midland, Pecos, Reagan, Reeves, and Tom Green) account for 72 percent of the regions irrigated acres.

METHODS

Six alternative irrigation systems were evaluated in this analysis. Irrigation systems were selected on the basis of current use in the Region or having the potential to improve water use efficiency. The alternative irrigation systems analyzed included furrow flood (FF), surge flow (SF), mid-elevation sprinkler application (MESA), low elevation spray application (LESA), low energy precision application (LEPA) and subsurface drip irrigation (DRIP). It was assumed an irrigation system was installed on a "square" quarter section of land (160 acres). Terrain and soil types were assumed to not limit the feasibility of adopting an irrigation system. Further, application efficiencies for the various irrigation technologies were taken from those identified in the water management strategy report for Region A (Almas, et al., 2000).

The adoption of advanced irrigation technologies varies significantly across counties. To establish a baseline for water demand by crop and technology, a survey was taken to determine estimates of water use by crop using furrow irrigation methods, prevalence of existing irrigation technologies by crop, and limiting factors with regard to adoption of irrigation technologies in each of the Region F counties. This information was critical in establishing a basis for identifying potential water savings from accelerated adoption of more efficient technologies. In addition, the water use data and current state of irrigation technologies allowed for the calculation of irrigation demands based on 1997 irrigated crop acres for each county. These estimated water demand levels are hereafter referred to as calculated demand. This information was provided by Texas Agricultural Extension Service specialists: Dr. Billy Warrick, Extension Agronomist, San Angelo, Dr. Bryan Unruh, Extension Agronomist, Ft. Stockton, and Dr. Juan Enciso, Extension Irrigation Specialist, Ft. Stockton.

The current adoption of irrigation technologies is shown in Table 3. Conventional furrow irrigation practices were estimated to cover 56.3 percent of the region. When combined with surge, 66.9 percent of irrigated acres are under furrow or flood irrigation. Sprinkler systems are used on 21.6 percent of irrigated acres. Drip systems have been installed on 11.5 percent of irrigated acres. A more detailed description of the Region F acres and their utilization of various irrigation technologies by crop and county for furrow, surge flow, MESA, LESA, LEPA, and drip can be found in Johnson et al. (2000).

Water management strategies to reduce irrigation demand within Region F are limited. The most feasible strategy that was considered in this analysis involved the accelerated adoption of advanced irrigation technologies, with higher water application efficiencies. The adoption of more efficient irrigation technologies such as surge flow, mid elevation sprinkler application (MESA), low elevation sprinkler application (LESA), low energy precision application (LEPA), and surface and subsurface drip would allow the application of less irrigation water, thus reducing irrigation demands. The assumed application efficiencies for furrow, surge flow, LESA, LEPA, and drip are 60 percent, 75 percent, 78 percent, 88 percent, 95 percent, and 97 percent, respectively (New, 1999).

The selection of the most feasible advanced irrigation technology for each crop within a county was based on several assumptions and constraints relating to crop type, water source, and water quality considerations. The following guidelines were used:

1. Furrow and surge acres were moved to drip or sprinkler whenever feasible.

Table 3. Estimates of irrigated acres by county using specific irrigation systems in Region F in 2000 (Warrick and Enciso).

County/System	Irrigated Area	Furrow	Surge	MESA	LESA	LEPA	Drip	% Furrow & Surge	% Sprinkler	% Drip
Andrews	11,900	5,144	0	0	5,000	1,750	36	43.0	56.7	0.3
Borden	5,040	1,040	0	2,000	2,000	0	0	20.6	79.4	0
Brown	7,146	5,528	0	1,121	497	0	0	77.4	22.6	0
Coke	315	140	0	161	14	0	0	44.4	55.6	0
Coleman	871	87	0	740	44	0	0	10.0	90.0	0
Concho	3,030	2,400	0	460	160	0	10	79.2	20.5	0.3
Crane	264	262	0	0	0	0	2	99.2	0	0.8
Crockett	295	11	0	102	182	0	0	3.7	96.3	0
Ector	3,882	2,731	0	0	602	0	549	70.4	15.5	14.1
Glasscock	53,401	33,021	0	0	0	2,535	17,845	61.8	4.7	33.5
Howard	3,505	1,655	0	0	281	1,400	169	47.2	48.0	4.8
Irion	2,100	1,649	0	429	0	0	22	78.5	20.4	1.0
Kimble	1,452	985	0	54	413	0	0	67.8	32.2	0
Loving	140	140	0	0	0	0	0	100.0	0	0
McCulloch	2,004	594	0	1,336	74	0	0	29.6	70.4	0
Martin	9,798	2,881	0	1,731	1,877	3,000	309	29.4	67.4	3.2
Mason	5,903	550	0	4,967	386	0	0	9..3	90.7	0
Menard	3,549	2,867	0	647	0	0	35	81.3	17.7	1.0
Midland	28,498	8,969	0	6,230	12,374	0	925	31.5	65.3	3.2
Mitchell	1,334	995	55	163	121	0	0	78.7	21.3	0
Pecos	28,921	9,141	14277	0	2,367	97	3,039	81.0	8.5	10.5
Reagan	28,528	24,953	0	0	0	275	3,300	87.5	1.0	11.6
Reeves	28,733	5,544	14478	0	2,750	85	5,876	69.7	9.9	20.5
runnels	5,733	5,031	232	0	290	0	180	91.8	5.1	3.1
Schleicher	1,063	977	0	86	0	0	0	91.9	8.1	0
Scurry	764	562	15	30	157	0	0	75.5	24.5	0
Sterling	622	157	0	465	0	0	0	25.2	74.8	0
Sutton	1,362	1,255	0	15	92	0	0	92.1	1.9	0
Tom Green	55,271	44,109	3,275	349	6,671	0	867	85.7	12.7	1.6
Upton	11,437	9,142	0	0	0	0	2,295	79.9	0	20.1
Ward	1,151	856	220	0	70	0	5	93.5	6.1	0.4
Winkler	0	0	0	0	0	0	0	0	0	0
Total	308,012	173,346	32552	21,086	36,422	9,142	35,464	66.9	21.6	11.5

2. Existing sprinkler acres were moved to the most efficient sprinkler technology when ever feasible.

3. Surface water supplies were assumed to remain as furrow or flood due to problems associated with the use of sprinkler or drip technologies with surface supplies. While there may be ways to make more efficient use of surface water supplies, this would involve a county-by-county assessment, which was beyond the scope of this analysis.

4. The shift of furrow to drip was considered feasible for cotton and grain sorghum.

5. Other crops such as wheat, alfalfa, peanuts, forage crops, hay-pasture, etc were shifted from furrow to the most feasible sprinkler technology.

6. Orchard and vineyard crops currently under flood irrigation were not changed to alternative technologies.

7. The application efficiency of drip and LEPA in Reeves, Ward, Loving, and Pecos counties was reduced to 93 percent and 91 percent, respectively, to allow for a flood irrigation at least once every 3 years to leach any buildup of salts in the upper soil profile.

8. No additional sprinkler acreage was included in Glasscock, Midland, Upton, and Reagan counties due to the low well yields in those counties. This would involve using multiple wells per system and was deemed unlikely.

The methodology for calculating water savings in acre-feet was to shiftacreages of furrow irrigated crops to surge flow, MESA, LESA, LEPA, or drip when an advanced technology was considered feasible. The gross irrigation application rate per acre for each crop in a given county using a furrow system with an assumed application efficiency of 60 percent was used to calculate the effective per acre water application rate. The effective application rate was then used to calculate the required equivalent irrigation application rate with an advanced irrigation technology. For example, suppose the total per acre applied irrigation water for cotton using a furrow system was 16 acre-inches. Using the 60 percent application efficiency for furrow gave an effective application rate of 9.6 acre-inches. If a drip system were used with an application efficiency of 97 percent, the resulting application rate would be 9.9 acre-inches. Therefore, the potential water savings for a shift from furrow to drip would be 6.1 acre-inches per acre.

Accelerated adoption of advanced irrigation technologies, and in particular, adoption of the most feasible advanced technologies could potentially reduce irrigation demands while maintaining the highest level of irrigated production possible. In order to examine the impact of an aggressive rate of technology adoption, it was assumed that one half of the necessary adoption of advanced irrigation technologies would take place by the year 2010, with 100 percent adoption resulting by the year 2020. Admittedly, this involves a rather ambitious level of urgency, but the primary emphasis and interest was the potential water savings available solely through efficient technologies, not the rate of adoption.

RESULTS AND DISCUSSION

Table 4 depicts the cumulative acreages and irrigation technology for Region F by decade. Initially, estimates of prevailing irrigation technology utilization in 2000 revealed 56.3 percent of the acres irrigating by furrow. After implementation of the most feasible irrigation technologies, the percentage of acres under furrow declined to only 13.3 percent and sprinkler and drip irrigated technologies increased to 31.0 and 49.4 percent, respectively.

As previously described, 1997 crop production levels were paired with prescribed irrigation water application rates necessary for typical yields to estimate the calculated irrigation demand levels for each of the Region F counties. Table 5 presents the irrigation water supply and calculated demand by decade for Region F resulting from the implementation of accelerated adoption of advanced irrigation technologies. Differences between the initial irrigation water supply and demand projections and those with calculated demand can be explained by the different assumptions underlying their derivation. The initial water demand projections were based on the highest actual water demand during

Table 4. Acres and (percent of total acreage) under various irrigation technologies for 2000, 2010, and 2020 in Region F of Texas.

Year	Furrow (%)	Surge (%)	MESA (%)	LESA (%)	LEPA (%)	Drip (%)	Total (%)
2000	173,346	32,552	21,086	36,422	9,142	35,464	308,012
	(56.3)	(10.6)	(6.8)	(11.8)	(3.0)	(11.5)	(100.0)
2010	107,226	25,957	10,549	48,842	21,613	93,825	308,012
	(34.8)	(8.4)	(3.4)	(15.9)	(7.0)	(30.5)	(100.0)
2020	41,106	19,361	0	61,272	34,086	152,186	308,012
	(13.3)	(6.3)	(0.0)	(19.9)	(11.1)	(49.4)	(100.0)

1/Irrigation technologies included: Furrow - furrow flood irrigation; Surge - surge flow irrigation; MESA - mid elevation sprinkler application; LESA - low energy precision application; and Drip - subsurface drip irrigation.

the period 1990-1997. The calculated water demand projections were based on typical irrigation applications and adjusted for the prevailing irrigation technologies existing in the county. Irrigation water supply projections were identical for both scenarios and represented the levels adopted by the Region F Water Planning Group.

A negative difference between the supply and calculated demand identifies counties with unmet irrigation demands or irrigation water deficits. Ten counties (Borden, Crane, Glasscock, Howard, Loving, Midland, Pecos, Reagan, Reeves, Tom Green) showed unmet irrigation demand in 2000. By 2020 following full adoption of the most feasible irrigation technology, five counties (Borden, Glasscock, Loving, Midland, and Reeves) continue to be faced with unmet irrigation demand. This implies that the supply-demand relationship for irrigation water in these counties cannot be balanced solely from the adoption of more efficient irrigation technologies.

Table 6 presents the estimates of water savings (acre-feet) by decade from accelerated adoption technology as well as the remaining level of unmet demand (or irrigation water deficit) for each county in Region F. With partial adoption (50%) completed by 2010, the annual water savings for the calculated demand amounted to 45,629 acre-feet. Following full adoption in 2020, these annual water savings increased to 91,250 acre-feet. Looking at counties with unmet irrigation demand, for the calculated demand scenario, 36.7 percent of the initial deficit was recovered by 2010 and 62.6 percent recovered by 2020.

To this point, this analysis has focused on the irrigation demands by counties in Region F assuming no change in acreage. Table 6 also addresses this issue as it relates to those counties within Region F with unmet irrigation demand. In addition to listing the levels of water savings and unmet demand by decade, an estimate of irrigated acres lost as a result of insufficient irrigation water availability is provided. This estimate was calculated by dividing the county's unmet irrigation demand by the average annual irrigation application rate across all crops within a county.

SUMMARY AND CONCLUSIONS

This analysis examined the potential for accelerated adoption of irrigation technologies to address irrigation water supply and demand projection imbalances in West Central Texas. This analysis provides only a preliminary estimate of lost irrigated acres because it does not allow for the possibility of shifting to crop mixes that required less irrigation. Allowing for crop mix to change would require the specification of an objective function and the use of an optimization model, which was not feasible for this analysis.

Table 5. Irrigation water supply and calculated demand (acre-feet of water) for Region F of Texas with accelerated adoption of advanced irrigation technologies, for 2000, 2010, and 2020.

County	2000			2010			2020		
	Supply	Demand	Difference	Supply	Demand	Difference	Supply	Demand	Difference
Andrews	17,780	16,303	1,477	14,534	4,266	18,800	18,800	12,766	6,034
Borden	953	5,933	-4,980	5,566	-4,609	957	963	5,198	-4,235
Brown	13,250	9,794	3,456	9,723	3,527	13,250	13,250	9,652	3,598
Coke	8 09	469	340	423	386	809	809	376	433
Coleman	2,310	1,029	1,281	981	1,329	2,310	2,310	932	1,378
Concho	7,082	3,349	3,733	3,055	3,999	7,054	7,026	2,761	4,265
Crane	337	362	-25	307	30	337	337	251	86
Crockett	500	267	233	259	241	500	500	251	249
Ector	9,095	8,167	928	7,449	1,653	9,102	9,104	6,731	2,373
Glasscock	20,668	60,735	-40,067	52,616	-31,953	20,663	20,664	44,498	-23,834
Howard	4,724	5,512	-788	5,010	-339	4,671	4,620	4,507	113
Irion	3,331	2,826	505	2,723	608	3,331	3,331	2,619	712
Kimble	2,276	1,586	690	1,583	693	2,276	2,276	1,581	695
Loving	324	583	-259	583	-259	324	324	583	-259
McCulloch	3,406	2,017	1,389	1,865	1,541	3,406	3,406	1,713	1,693
Martin	13,501	12,157	1,344	11,198	2,252	13,450	13,407	10,240	3,167
Mason	18,000	7,390	10,610	6,877	11,123	18,000	18,000	6,364	11,636
Menard	6,080	4,280	1,800	4,227	1,834	6,061	6,041	4,175	1,866
Midland	31,934	40,921	-8,987	38,541	-4,851	33,690	35,143	36,161	-1,018
Mitchell	2,435	1,923	512	1,619	816	2,435	2,435	1,316	1,119
Pecos	82,464	86,228	-3,764	81,240	-44	81,196	79,927	76,251	3,676
Reagan	28,064	36,171	-8,107	29,907	-1,847	28,060	28,059	23,643	4,416
Reeves	66,667	83,402	-16,735	79,493	-12,826	66,667	66,667	75,584	-8,917
Runnels	9,193	7,657	1,536	7,038	2,155	9,193	9,193	6,419	2,774
Schleicher	2,000	1,675	325	1,521	479	2,000	2,000	1,367	633
Scurry	3,742	1,028	2,714	893	2,849	3,742	3,742	758	2,984
Sterling	980	784	196	727	255	982	983	669	314
Sutton	2,461	2,120	341	1,878	583	2,461	2,461	1,635	826
Tom Green	82,239	100,888	-18,649	90,204	-8,012	82,192	82,145	79,521	2,624
Upton	14,681	14,453	228	12,400	2,281	14,681	14,681	10,346	4,335
Ward	5,843	4,727	1,116	4,673	1,176	5,849	5,933	4,620	1,313
Winkler	1,500	0	1,500	0	1,500	1,500	1,500	0	1,500
Total	458,629	524,736	-66,107	479,113	-19,164	459,949	460,037	433,488	26,549

Table 6. Estimates of water savings (acre-feet) from accelerated adoption of technology, Water Deficit (acre-feet), and Acres Lost in Region F of Texas for 2000, 2010 and 2020.

	2000			2010			2020		
County	Water Savings	Water Deficit	Acres Lost	Water Savings	Water Deficit	Acres Lost	Water Savings	Water Deficit	Acres Lost
Andrews	0	0	1,769	0	0	0	3,537	0	0
Borden	0	4,980	368	4,220	4,190	4,609	735	4,235	4,111
Brown	0	0	71	0	0	0	142	0	0
Coke	0	0	47	0	0	0	94	0	0
Coleman	0	0	49	0	0	0	97	0	0
Concho	0	0	294	0	0	0	588	0	0
Crane	0	25	55	18	0	0	110	0	0
Crockett	0	0	8	0	0	0	15	0	0
Ector	0	0	718	0	0	0	1,436	0	0
Glasscock	0	40,067	8,118	35,146	32,275	31,953	16,237	23,834	28,716
Howard	0	788	503	502	237	339	1,005	0	0
Irion	0	0	104	0	0	0	207	0	0
Kimble	0	0	2	0	0	0	4	0	0
Loving	0	259	0	62	62	259	0	259	62
McCulloch	0	0	152	0	0	0	305	0	0
Martin	0	0	959	0	0	0	1,917	0	0
Mason	0	0	513	0	0	0	1,026	0	0
Menard	0	0	53	0	0	0	105	0	0
Midland	0	8,987	2,380	6,241	3,593	4,851	4,760	1,018	802
Mitchell	0	0	304	0	0	0	607	0	0
Pecos	0	3,764	4,989	1,263	17	44	9,977	0	0
Reagan	0	8,107	6,264	6,383	1,759	1,847	12,529	0	0
Reeves	0	16,735	3,909	5,771	4,630	12,826	7,818	8,917	3,390
Runnels	0	0	619	0	0	0	1,239	0	0
Schleicher	0	0	154	0	0	0	309	0	0
Scurry	0	0	135	0	0	0	270	0	0
Sterling	0	0	58	0	0	0	115	0	0
Sutton	0	0	243	0	0	0	485	0	0
Tom Green	0	18,649	10,684	10,191	4,915	8,012	21,367	0	0
Upton	0	0	2,054	0	0	0	4,107	0	0
Ward	0	0	53	0	0	0	107	0	0
Winkler	0	0	0	0	0	0	0	0	0
Total	0	102,361	45,629	71,797	51,678	64,740	91,250	38,263	37,081

Some counties (Crane, Howard, Pecos, Reagan, and Tom Green) exhibited unmet demand initially in 2000, but accelerated adoption of advanced irrigation technologies appeared to offer the potential to resolve their supply/demand imbalances. These counties were likely to lose (or shift) acreage to less water intensive activities until advanced irrigation technologies could enable them to be used for more profitable enterprises. Those counties which have unmet irrigation demand throughout the study period (Borden, Glasscock, Loving, Midland, and Reeves) appear to be faced with a higher probability of losses in irrigated acreage even with adoption of advanced irrigation technologies. Even full adoption of the most efficient feasible irrigation technology was unable to resolve the irrigation water supply/demand imbalances present in these counties. Additional irrigation water supplies beyond the scope of this study would be necessary to prevent shifts or loss of acreages over time.

If the response to unmet irrigation demand results in the loss of irrigated acres, those acres will either shift to a non-irrigated alternative crop or be removed from crop production altogether. While it is difficult to predict what crops will likely go out of production, this decision will most likely be guided by the relative value of water between available cropping alternatives. In order to assess this measure for the possible alternatives, the gross marginal value of water to selected irrigated crops was calculated for the sub-regions exhibiting unmet irrigation demand. This addition to income from irrigation (gross marginal value of water can be compared to the investment and pumping costs to determine economic feasibility. In general, we would expect those crops with lower gross marginal values of water to exit first.

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