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16. Abstract: The recommendation that the mowing height should be 7 inches was confirmed by the research in most situations. This height of mowing provides the best opportunity for mid-seral grasses to be established in the rights-of-way. Mowing at 2 inches will remove stem bases and basal crowns in which carbohydrates are stored and reduce tiller recruitment and initiation of new growth. A 2-inch mowing height will eventually remove mid-seral grasses from the vegetative community. A mower speed of 4 mph and a setting of a 6-inch cut on the mower will result in a verdure of 7 inches. To minimize pop-ups or rooster tails, the speed of 4 mph is recommended for grasses other than thick stem grasses especially Johnsongrass. For a thick-stemmed grass or Johnsongrass, a mowing speed of 2 mph is recommended. For those areas of the State where snows frequently occur, a recommendation of 2 inch mowing height on the immediate shoulder is recommended to reduce the formation of a snow drift onto the driving lanes of the highway. This same recommendation can be made for those areas with drifting sand.

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RIGHT-OF-WAY MOWING HEIGHT RESEARCH

by

John Borrelli, Ph.D., P.E.
Richard E. Zartman, Ph.D.
Ronald E. Sosebee, Ph.D.
Cynthia B. McKenney, Ed.D.

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conducted for

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The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

Implementation Statement

This project reaffirmed that the current mowing height recommendation of 7 inches is best for maintaining most native grasses in the rights-of-way. Furthermore, if the mower height is set at 6 inches and the forward speed of the mower is 4 mph, a 7 inch cut height will result.

The project documented the affects of mowing height and timing for short, mid-seral, and tall grasses. For example, the dominant short-grasses such as blue grama and buffalograss are relatively non-affected by mowing height. Mid-seral and tall grasses are damaged and have reduced viability if mowed short during their reproductive stages. Observations from the plots noted severe damage to mid-seral grasses and tall grasses for the 2-inch mowing height.

The report provides useful information on minimizing fire danger for fires started in the rights-of-ways. Detailed information was also provided on the potential for snow and sand drifting on roadways as a function of the height of grasses in the rights-of-way.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
	AREA			
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
	VOLUME			
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
	MASS			
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
	ILLUMINATION			
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
	FORCE and PRESSURE or STRESS			
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate

(Revised September 1993)

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INTRODUCTION

Background

The focus of this project was to develop practical information and recommendations on the relationship between height and frequency of mowing. There are concerns that current mowing practices are not timed to maximize the viability of the mixture of plants, especially native grasses, found in highway right-of-ways. It is hoped that mowing frequency can be reduced in some locations to minimize right-of-way maintenance costs. This project was intended to determine the optimum mowing height with respect to maintaining a viable stand of acceptable vegetation, reseeding of annual plant materials especially native flowers, and the frequency of required mowing. The optimum height must also be considered with respect to the total cost of maintenance of right-of-way vegetation. To accomplish the above objectives, plots were established near Andrews, Brady, Lufkin, and Tahoka and responses measured to various treatments of mowing height, frequency of mowing, and root mass. From a separate set of plots, measurements were taken on plant population changes, morphological development, and carbohydrate reserves in plants. In a separate experiment, data were collected on the related issues of mowing height and mower speed versus rooster tails.

While severely limiting vegetation within right-of-ways appears to be a desirable consideration, several other factors needed to be addressed. Tourism represents a large industry in Texas during the height of the wildflower season. Protecting these plant materials and allowing them to reseed each year is important to the State's economy. Mowing too early or too frequently in the plant's life cycle will reduce the plant's ability to store carbohydrates needed to allow the plant to withstand periods of stress. In addition, seed head formation will not have time to occur inhibiting the production of seed for the following season. Mowing also creates an entry point for insects and diseases while increasing water loss through the damaged tissues. Of course, limiting the frequency of mowing reduces vegetation management costs allowing funds to be applied to other needs.

The existing vegetation on the roadside needs to be maintained in a healthy status to prevent soil erosion with the least amount of inputs. Excessive mowing limits carbohydrate storage damaging the overall plant status during periods of stress, and in time leads to population decline. Grass species produce a deeper root system in proportion to the amount of leaf area left to photosynthesis. Repeated close mowing generally results in a reduced root system, which is less able to explore the soil profile for available moisture. However, close mowing does increase grass density, which helps to minimize soil erosion.

Mowing is a defoliation process in which portions of the stems and leaves are removed. Grass response to mowing height (and frequency) depends upon morphological development at the time of mowing and the frequency and intensity (stubble height) of mowing. Sod-forming and bunch grasses will respond differently to mowing, as well as elevation of flowering culm and elongation of internodes. Height and frequency of mowing will affect root growth and development, tiller recruitment, and carbohydrate reserves that ultimately affect the vigor of the grasses. (Everson, 1966)

The direct effects of mowing height are visually obvious while indirect influences are more subtle. For example, mowing the right-to-way may cause increased soil compaction when the soils are wet. Removing the vegetation will increase the solar radiation reaching the soil surface and causing increased soil temperatures. Soil density and soil temperature along with carbohydrate reserves directly control the species of vegetation that are found along the highway right-of-ways. From a maintenance standpoint, the height and frequency of mowing impacts the cost maintenance. In addition, the minimum height of mowing may be dictated by the amounts and size of debris found within the right-of-ways.

Scope

This project had three major phases. First, a comprehensive literature search was compiled on mowing height effects on plant density, rooting depth, and viability, on vegetative barriers for snow and soil collection, on nutrient need and carbohydrate reserve responses of grasses, and optimum speed of mowers. The results of the literature review were published in Borrelli et al. (1999).

Second, plots were established in 4 different geographical locations in the State. The purposes of the plots were to determine changes in specie composition caused by different mowing heights and frequency of mowing. The plots were established at the following locations:

Andrews—at Andrews, Texas the plots were in the right-of-way on US 385 and were located approximately 7.45 miles north of the intersection of US 385 and SH 158 or approximately 3.17 miles north of the Ector and Andrews County lines.

Brady—at Brady, Texas the plots were located on the south right-of-way of HY 190 approximately 3.9 miles northeast from the intersection of HY 377 and HY 190.

Lufkin—at Lufkin, Texas the plots were located approximately 1.5 miles from the junction of HY 2497 southwest on HY 94. The plots were located on the north right-of-way.

Tahoka—at Tahoka, Texas the plots were approximately 6.5 miles west of Tahoka on HY 380. The plots were located on the south right-of-way.

The third phase of the project was the detailed study on total non-structural carbohydrates in blue grama (*Bouteloua gracilis*), silver bluestem (*Bothriochloa saccharoides*), and Lehmann lovegrass (*Eragrostis lehmanniana*). Plots were established in Andrews, Crosby, and Lynn counties.

CARBOHYDRATE ANALYSES/STANDING CROP/TILLER DENSITY

Introduction

The total non-structural carbohydrates were evaluated monthly on selected grasses along highway rights-of-way at two locations from October 1998 through November 2000. The objectives of this portion of the Project were to evaluate the effect of mowing on the health and vigor of the dominant species growing at these locations and the impact of "long-term" mowing on their survivability. The species and locations selected were blue grama (*Bouteloua gracilis*) in Crosby County and silver bluestem (*Bothriochloa saccharoides*) in Lynn County. A third species and location [Lehmann lovegrass (*Eragrostis lehmanniana*) in Andrews County] were initially selected, but the research plots were destroyed by highway construction.

Blue grama and silver bluestem were selected for this portion of the Project on the basis of availability and abundance of grasses commonly growing along the highway rights-of-way. It is apparent as one travels throughout the State of Texas that most of the mid and tallgrass climax species have been eliminated from the highway rights-of-way that are subjected to repeated mowing year after year. The dominant species along many of the rights-of-way are Lehmann lovegrass in far west Texas (west of a line drawn north to south through Andrews and Odessa); silver bluestem in most of north and west Texas; K.R. bluestem (*B. ischaemum*) in central Texas; and bahaigrass (*Paspalum notatum*) in east Texas. All of the species in the above list are mid- to later-seral (but not climax) species. It is easy to draw a line along the rights-of-way in central Texas where little bluestem (*Schizachyrium scoparium*) has been eliminated by the mowing practices of that area. Climax species such as black grama (*B. eriopoda*) in far west Texas have also generally been eliminated from the roadsides. The only climax species in far west Texas not impacted by mowing (because of the difficulty in mowing deep sand rights-of-way) include big bluestem (*Andropogon gerardii*), little bluestem, and some Indiangrass (*Sorghastrum nutans*). Likewise, the tall grass climax eastern gamagrass (*Tripsacum dactyloides*) in east Texas occurs only in areas where roadsides are not regularly and frequently mowed.

Dominant shortgrasses such as blue grama and buffalograss (*Buchloe dactyloides*) that grow in the High and Rolling Plains of Texas are relatively non-affected by mowing, unless mowing results in very short stubble heights. The greatest impact of frequent and close mowing on blue grama is that mowing, like continuous, heavy grazing, causes a shift in growth habit from a bunchgrass to a sod-forming growth habit.

Selection of species to study was based upon shoot development and internode elongation and availability of the species. Grasses that have delayed internode elongation such as the shortgrasses (i.e., blue grama) are less subject to damage from defoliation (by mowing, grazing, etc.) than those plants that tend to elevate their "growing points" and elongate their internodes early such as the mid and tall grasses (i.e., big bluestem, Indiangrass, little bluestem, and eastern gamagrass). Silver bluestem is a "mid- to later-seral (hereafter referred to as mid-seral) species that is much more tolerant of defoliation than tall grasses because of it status along the ecological succession gradient. In general, proper (not severe) defoliation does not cause severe injury to grasses if they are in the vegetative (short-shoot) stage. However, if they have shifted from the vegetative stage to the reproductive (long-shoot) stage, they can easily be damaged, and ultimately killed, especially mid to tall grasses. For this reason, many, if not most of the tall grasses no longer occur along roadsides that are regularly and frequently mowed.

Likewise, the time of mowing forbs (wildflowers) is very critical. If wildflowers are mowed after they have elevated the flower stalk, they are very easily damaged or killed. Although wildflowers were not part of our research, if one's objective is to have wildflowers along roadsides, then timing of mowing is very critical. For maintenance of wildflowers, mowing should either be done very early (before the flower stalk is elongated) or very late (after the wildflowers have completed their annual reproductive cycle).

Materials and Methods

This research was conducted on two mid and short grasses in west Texas and in the Southern High Plains of Texas. The research areas were located along highway rights-of-way to closely resemble the Texas Department of Transportation's mowing practices as much as possible. The two locations included a site in Crosby County that represents both mid- and short-grass species; and a site in Lynn County that represents mid-grass species.

<u>Description of Study Area</u>

The Crosby County site is approximately 3 to 5 km north of U.S. Highway 62/82 on Farm Road 2591, approximately 4 km east of Crosbyton, Texas. The average annual temperature is 15°C and the average annual precipitation is 57 cm, 80% of which occurs May through September. The latitude and longitude of the study site are 33° 39' and 101° 14'W, respectively. The average elevation is approximately 917 m (National Oceanic and Atmospheric Administration, NOAA, 2001).

The dominant soil of the surrounding area is a Mansker-Potter complex. The Mansker soil (find-loamy, carbonatic, thermic calcidic paleustoll) comprises 55% of the complex and is predominantly a fine sand loam. The Potter soil (Loamy-skeletal, carbonatic, thermic petronodic Ustic haplocalcid) comprises approximately 20% of the complex and is predominantly a shallow, loam soil, and 10% escarpment. The remainder is made up of Likes loamy fine sand, Miles loamy fine sand, Miles fine sandy loam, Berthoud fine sandy loam, Berthoud loam, Vernon clay loam, and Spur fine sandy loam. The topography has an average of 4% slope. The complex typically has low fertility and moderate (Mansker) to low (Potter) water-holding capacity. The Complex is used primarily for rangeland. Controlled defoliation is needed to maintain cover of grass for the control of runoff and erosion. Decreasers are sideoats grama, and little bluestem and the climax vegetation. It also contains increasers such as blue grama, buffalograss, sand dropseed (*Sporobolus cryptandrus*), and black grama (*Boutelaua chondrosioides*) (Koos et al. 1966). The dominant grasses in the mowing treatments were predominantly blue grama and sideoats grama. The little bluestem population occurred in an infrequently mowed area that was selected for this study.

The Lynn County site is approximately 8 to 11 km west of Tahoka, Texas on U.S. Highway 380. The average annual temperature is 14°C and the average annual precipitation is 50 cm, most of which occurs May through September. The latitude and longitude are 33° 10'N and 101° 47'W, respectively. The average elevation is approximately 949 m (NOAA 2001). The dominant soil of the surrounding area is an Amarillo fine sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalf) that is moderately fertile with moderate water holding capacity. The slope averages 0 to 3%. This soil requires careful management to protect against wind erosion. The native vegetation of this site includes primarily blue grama, sideoats grama, Arizona cottontop, little bluestem, and silver (Mowery and McKee 1959). Currently, the dominant vegetation of the roadside is silver bluestem.

Experimental plots at each study site were established as a line layout along the highway rights-of-way. Plots were chosen based on species homogeneity of the stand to minimize variability. Each plot was 25 m long by 3 m wide [five plants (3 for TNC, 2 for tiller development) were collected monthly October 1998 through mid April 1999]. The mowing treatments were imposed mid May through mid October for 1999 and 2000.

Rain gauges were placed at each study site to measure the amount of rainfall during the period of the study, but unfortunately they were stolen. Therefore, rainfall data were obtained from the official NOAA recording weather station closest to the study site within each county.

Mowing Height and Frequency Treatments

The primary objective of this research was to test the impact of height and frequency of mowing on grasses along the highway rights-of-way. Therefore, 33 plots were permanently identified along roadsides of the three highways described above. The mowing regimes included the following treatments along each of the described highway right-of-ways: (1) control (no mowing), (2) mow one time per year at the beginning of the growing season, (3) now one time per year at the end of the growing season, (4) repeated mowing monthly throughout the growing season, (5) repeated mowing bimonthly throughout the growing season, and (6) repeated mowing tri-monthly throughout the growing season. No mowing was done during winter. Mowing heights in the plots scheduled for mowing included 5 and 10 cm. Originally, a 15-cm mowing height in the plots was scheduled, but because small mowers can not elevate to 15 cm, this height was excluded from the experiment. Plots were mowed mid May through mid October of 1999 and 2000. Plots were mowed with a two wheel, height adjustable lawn mower pulled by a three-wheel All Terrain Vehicle (ATV).

The experimental design consisted of 5 mowing frequencies, 2 mowing heights, a control (no mowing), and 3 replications. The parameters studied to address the effect of height and frequency of mowing on selected grasses along the designated highway rights-of-way included: (1) TNC concentrations; (2) internode elongation; (3) tiller recruitment and tiller number/m^2; (4) number of plants/m^2; (5) aboveground biomass; (6) plant height; and (7) fuel moisture. Experimental procedures used to measure each of these parameters are described below.

TNC Analysis

Total nonstructural carbohydrate (TNC) concentrations were measured in two plants per plot collected on a monthly basis from May, 1999 through November 2000. Two plants from the control plots were also collected monthly from October 1998 through April 1999. Experimental design for TNC analysis consisted of 5 mowing frequencies, 2 mowing heights, a control (no mowing), 3 replications/treatments, and 2 plants (sub-samples/replications) per plot. A total of 66 plants were collected for each species studied (blue grama and silver bluestem). A total 132 plants were collected every month for TNC analysis. Additionally, 5 little bluestem plants were collected monthly for TNC analysis similar to the other two grasses.

The plant samples included shoots and roots. The samples were collected and immediately placed on ice in the field and transported to the lab for chemical analysis. Upon return to the lab, plant samples were dried in a forced air-oven at 60°C for 3 days. Subsequent to drying, soil was removed from the samples and the roots were dissected from the basal crown and stem bases of the grass plants. The stem base, including the lower 2 to 2.5 cm of the stem, and the basal crown were dissected from the rest of the shoot and root material, ground in a Wiley mill to pass through a 0.5 mm screen and stored in amber vials until TNC concentrations could be analyzed.

Carbohydrate concentrations were analyzed from 0.5 g tissue samples by acid hydrolysis as described by Murphy (1958). The half-gram samples were boiled for 2 hours in 60 ml of 0.2N HCL and then filtered through No. 2 Whatman filter paper into volumetric flashes. Distilled water was added to bring the volume of the filtrate up to 100 ml. An aliquot (1 ml) of the filtrate was extracted and mixed with 4 ml of distilled water. A 1 ml aliquot was then pipetted into a test tube into which 10 ml of anthrone reagent was added. After heating for 15 to 20 minutes at 97°C, the TNC concentration was measured spectrophotometrically at 612 nm.

All samples were referenced with glucose standard (100 ppm). Carbohydrate concentrations were estimated by comparing each sample to the glucose standards at a known concentration. Aliquots from duplicate samples were analyzed for each sampling date. The TNC concentration percentage for each plant sample was calculated as follows:

$$\text{TNC (\%)} = [\text{Absorbance}/0.27] \times 100$$

The data were report as percent TNC across time.

Internode Elongation

Every month, phonological stages were recorded and related to TNC seasonal trend in order to monitor TNC concentration changes among each stage during the growing season, especially the time when the plants shifted from the vegetative stage to the reproductive stage, i.e., internode elongation. Internode elongation was measured from two plants per plot (for a total of 66 plants/month for each species including blue grama and silver bluestem) and 5 plants/month for little bluestem. Similarly to the method used by Burzlaff et al. (no date) for blue grama, the developing shoot was carefully dissected and the leaf blades and sheath material were removed leaving the shoot apex visible. If the reproductive culm was differentiated and elongated, the leaf sheath of the phytomer enclosing the culm was irregularly shaped and the rudimentary inflorescence revealed. Some shoots (especially the small and thin shoots) in which the apex of the reproductive culms and inflorescences were hard to detect were measured in the field by detecting as early as possible the reproductive stage through jointing or early heading stages.

Internode elongation was considered an important indicator during and after which TNC concentrations could be altered or reduced because no additional leaves (photosynthetic tissue) were produced until reproduction was completed and the plants again became vegetative (Rechenthin 1956). Data were recorded as the date on which internode elongation could first be detected.

Number of Tillers

Number of tillers was measured from three (replications) 0.25 m^2 quadrats per treatment collected twice once before (February) and once after (October) the 2000 growing season. Number of tillers were counted per plant within the 0.25 m^2 quadrat and reported as tiller number per m^2. Tiller number was measured to determine the impact of mowing on the tiller number, potential tiller recruitment, and how tiller number could be related to the TNC concentration, especially after mowing the mid grass species.

Number of Plants

Number of plants was counted (except for blue grama since it was difficult to determine what constitutes a single plant) from three (replications) 0.25 m^2 quadrats per treatment collected once before (February) and after (October) the 2000 growing season. Plant number was reported as number of plants per m^2. Plant number was evaluated to determine the impact of mowing before and after the growing season in an effort to measure death loss due to intensive mowing.

Biomass

Biomass including live standing crop and litter was measured monthly from three (replications) 0.25 m^2 quadrats per plot October 1999 through November 2000. The samples were clipped then immediately placed on ice in the field and transported to the lab, weighed to obtain fresh weight, then placed in a forced air-oven to be dried at 60°C for 3 to 5 days to obtain the oven-dry weight. The amount of aboveground biomass was measured before and after mowing, because the amount of biomass left after mowing could be detrimental to the following season's growth and productivity. In addition, biomass measurements were also important in ascertaining the minimum amount of fuel load available to ignite a fire when planning a mowing scheme to control fire hazards.

Fuel Moisture

Fuel moisture was calculated as the water content (%) of the grasses or residual biomass based on the oven-dry weight obtained from the same biomass measurements above. Fuel moisture is an integral part of a fire control scheme because it gives information about the ignition potential.

Plant Height

Plant height was measured twice from the same samples collected for plant number measurements, once before (February) and once after (October) the 2000 growing season. Height of the grass was measured to evaluate its affect on a driver's line-of-sight vision, especially if the vehicle had to stop along the side of the highway for any reason or in the event large animals might be in the right-of-way.

Data Presentation and Statistical Analysis

Carbohydrate seasonal trends at different phonological stages, biomass and fuel moisture trends were established for the control and at each mowing height and frequency for each species. Treatments including the control were subjected to a split plot arrangement with factorial completely randomized design (CRD) as main plot and time (month) as subplot (repeated measures analysis) including three replicates. Treatments were randomly assigned to plots/replicate.

Analyses of variance were performed to detect significant difference among and/or within treatments for each species for TNC concentrations, tiller number, plant number, biomass, plant height, and fuel moisture. Mean separation using the least significant difference test (LSD) was performed to test significant differences among treatment means of main and/or simple main effects.

Impact of Mowing on the Health and Vigor of Roadside Grasses

Time of mowing as well as height and frequency is very critical in determining the health and vigor of roadside grasses. The health and vigor was evaluated by measuring monthly trends (October 1998 through November 2000) in the total non-structural carbohydrates (TNC) stored in the basal crowns and stem bases of blue grama (shortgrass) and silver bluestem (mid-seral, bunchgrass). Both of the species studied are adapted to defoliation; consequently, that is why they occur in great abundance along highway rights-of-way. Treatments included mowing at stubble heights of 0, 2 (5 cm), and 4 inches (10 cm) one-time-only at the beginning of the growing season (mid May); monthly (mid-May through mid-October), bi-monthly (mid-May, mid-July, and mid-September); tri-monthly (mid-May and mid-August); and one-time-only at the end of the growing season (mid-October). Each treatment was replicated three times and randomly located within the right-of-way at each study location; the plots were mowed with a pull-type mower behind an All Terrain Vehicle.

The impact of intensive mowing was not realized during the first year of the study, but became apparent during the second year. One might conclude from this that if these intensive regimes continued three years, or more, serious impacts would be inflicted on the native roadside vegetation, even to the point of eliminating the native species.

Blue Grama

TNC Trends

Since blue grama occurs as a sod-forming grass as well as a shortgrass, it is adapted to defoliation. Blue grama not mowed, at either stubble height, typically had the lowest levels of TNC during the second growing season after all mowing had ceased (Figure 1). Equally apparent was that frequency of mowing adversely affected TNC storage during the second growing season. TNC levels decreased in order of mowing intensity as follows: monthly<bi-monthly<tri-monthly. Plants mowed one-time-only at the end of the growing season, regardless of stubble height, had the greatest amount of stored carbohydrates.

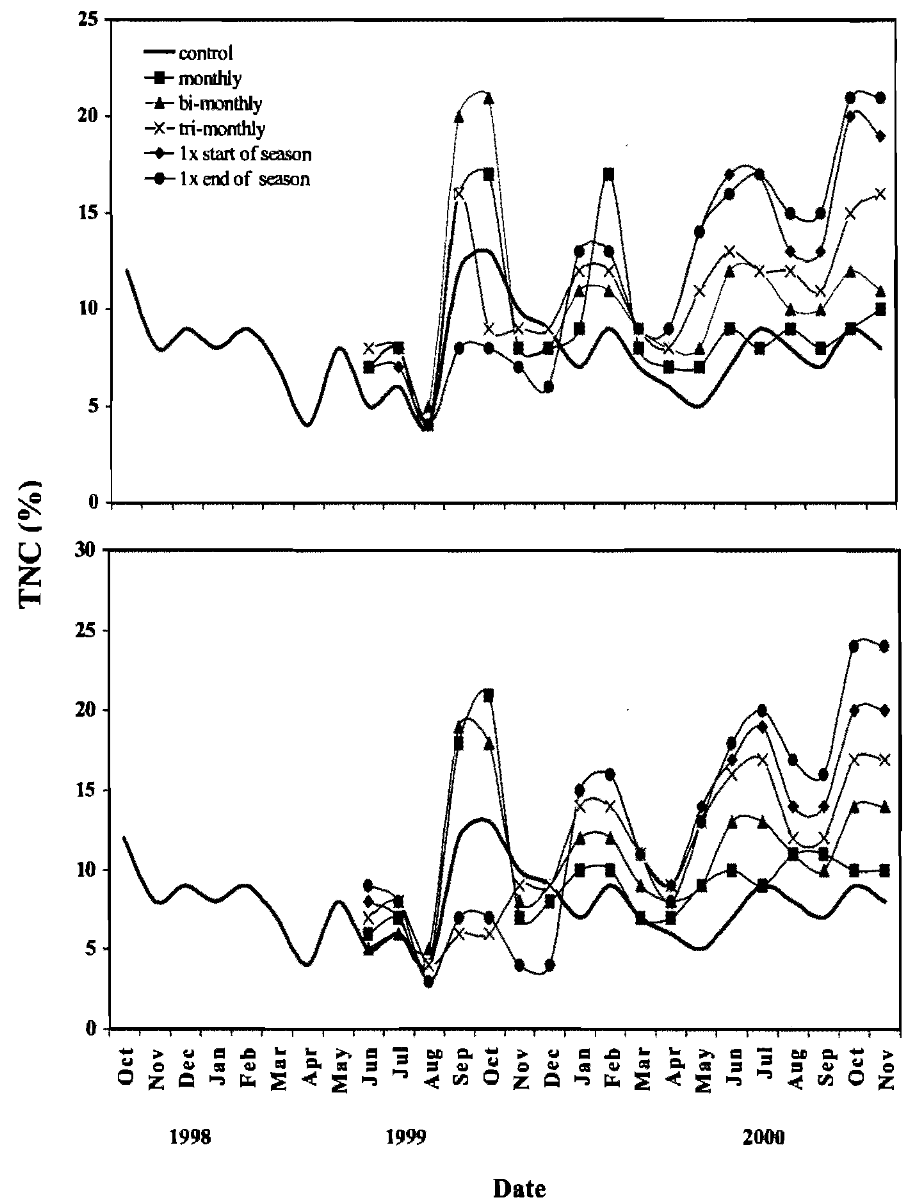

Figure 1. Basal crown and stem base TNC (%) for blue grama at 0, 2-inch (top), 4-inch (bottom) mowing stubble heights at different mowing frequencies

Plants mowed one-time-only at the beginning of the growing season typically had the second highest concentration of carbohydrates throughout the year. Often, plants mowed at 4-inch stubble heights one-time-only at the beginning of the growing season and tri-monthly had carbohydrate levels as high as plants mowed one-time-only at the end of the growing season.

Standing Crop (Biomass: Live Plant Material) Production

Research has shown that a certain amount of residual herbage (live plant material) must be left at the end of the growing season for plant regeneration during subsequent growing season. It is the residual herbage that includes the stem bases and basal crowns where the carbohydrates are stored and new tillers are recruited for subsequent growing season growth. It has been reported that shortgrasses need approximately 300-600 lb/acre residual herbage (specifically, 300 lb/acre for blue grama) to initiate and sustain growth during subsequent growing seasons. If the minimum amount of residual herbage is not left at the end of the growing season, grass growth will be impaired and the population will soon be decimated.

Like TNC levels, the first year mowing impacts were not as severe as those of the second year. After the mowing treatments had been imposed one year, the amount of residual herbage was affected (Figure 2). However, residual herbage in blue grama was higher than 300 lb/acre at the end of the growing season for all treatments except for one-time-only mowing at the end of the growing season, regardless of stubble height. Residual herbage at the end of the growing season in the one-time-only mowing in November was approximately 300 lb/acre. One would expect this effect since mowing occurred after the plants had completed their growth. It is interesting to note that residual herbage at the end of the growing season in plants mowed at 4-inch stubble heights were higher than 600 lb/acre except in plants mowed monthly and also one-time-only at the end of the growing season (in October). Four-inch stubble heights in blue grama, generally, is higher than most of the foliage (leafy material; exclusive of the seedheads).

Tiller Density

Tiller density of blue grama, a shortgrass, reflects the effect of mowing on grasses that elevate their flowering culm (stalk) late in the season. The impact of mowing the first year of the study indicated that no-mowing and mowing at 2 inches yielded significantly fewer tillers than mowing at 4-inch stubble height (Table 1). Likewise, the frequency of mowing impacted the number of tillers produced. At the end of the first year, blue grama mowed one-time-only at the beginning of the growing season (regardless of stubble height) produced the most tillers. Plants mowed one-time-only at the end of the growing season (regardless of the stubble height) produced the fewest tillers.

Interestingly, plants mowed monthly at 2-inch stubble heights produced the highest number of tillers after two mowing seasons. More importantly (since one would probably not recommend mowing at 2-inch stubble heights for a number of reasons), plants mowed one-time-only at the end of the growing season at 4-inch stubble heights produced significantly more tillers at the end of the second mowing season than all other treatments expect those plants mowed bi-monthly (Table 2).

Conclusions

For the health and vigor of blue grama, mowing frequently and at shorter stubble heights is not recommended. Likewise, plant characteristics that confer sustainability and population longevity such as residual standing crop or biomass (live plant material) at the end of the growing season and tiller recruitment also favor less frequent mowing and greater stubble heights. The greatest amount of injury to blue grama can be caused from mowing frequently at <4-inch stubble heights and by mowing in late summer (mid-August) after reproduction is complete and tillers are being recruited. Therefore, for the health and vigor of blue grama (and other shortgrasses), mowing at a stubble height of 4 inches, or more, one-time-only at the end of the growing season is most desirable.

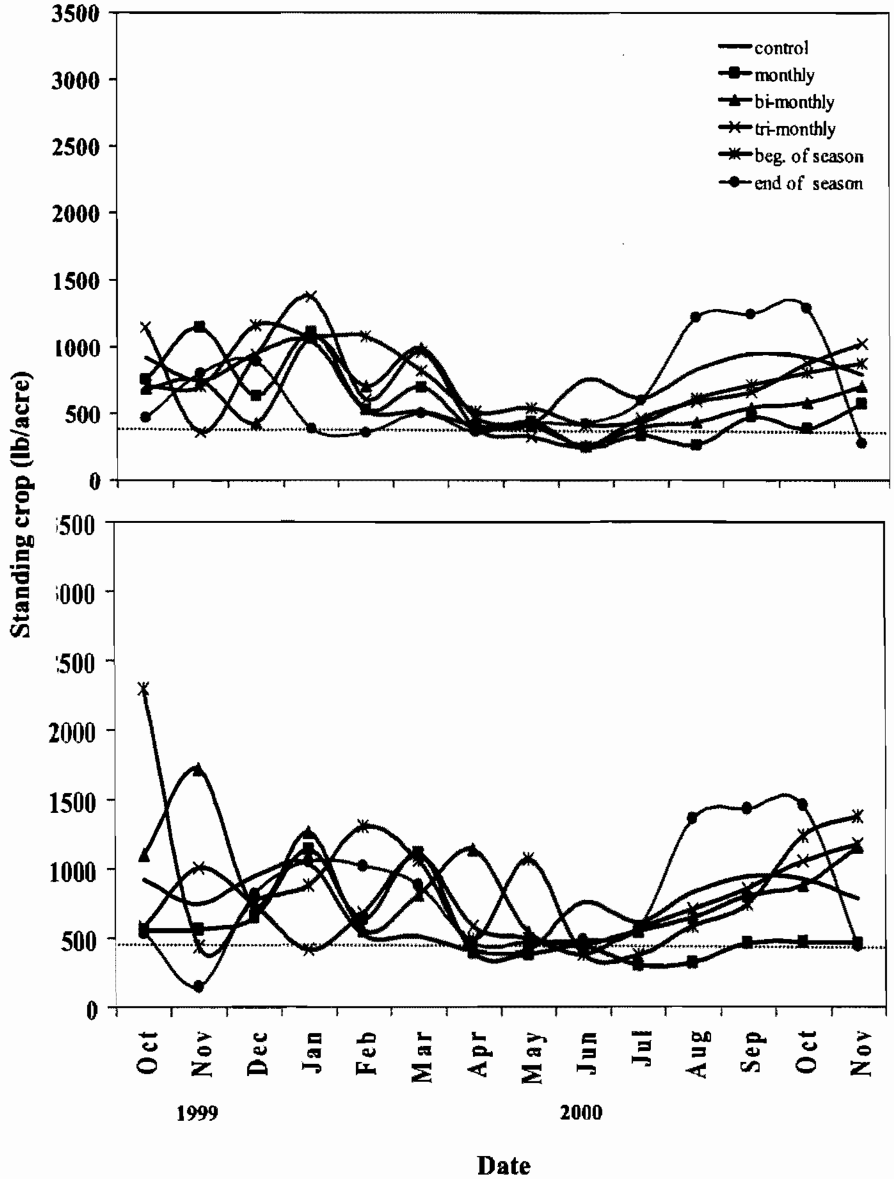

Figure 2. Blue grama aboveground live standing crop biomass (lb/acre) at 0, 2 inches (top) and 4 inches (bottom) stubble heights at different mowing frequencies

-------: residual herbage (lb/acre) required for growth regeneration in the spring

Table 1. Mean tiller density[1] (main effect) for blue grama at different mowing heights and frequencies after 1 mowing season

Mowing Treatment	Tiller Density (Tiller # m^{-2})
Mowing height	
Non-mowed	238 b[2]
2-inch stubble height	232 b
4-inch stubble height	316 a
Mowing frequency	
Monthly	320 b
Bi-monthly	232 c
Tri-monthly	196 c
1x at start of season	392 a
1x at end of season	228 c

[1] Tiller densities were measured after the respective growing season
[2] Within either the mowing height or the mowing frequency treatments, means followed by the same letter are not different at $P < 0.05$

Table 2. Mean tiller density (height x frequency interaction) for blue grama as subjected to different mowing heights and frequencies after 2 mowing seasons

Mowing Treatment	Tiller Density Mowing height 2 inches	 4 inches
Mowing frequency	(Tiller # m^{-2})	
Monthly	224 a[1]	172 b[2]
Bi-monthly	176 b	268 a
Tri-monthly	164 bc	180 b
1x at start of season	204 ab	168 b
1x at end of season	152 c	288 a

[1] Within the 2-inch stubble height among mowing frequencies, means with the same letter are not significant at $P < 0.05$
[2] Within the 4-inch stubble height among mowing frequencies, means with the same letter are not significant at $P < 0.05$

Silver Bluestem

TNC Trends

Seasonal TNC trends in silver bluestem were lowest in the plots of plants not mowed as well as in the plots mowed most frequently (Figure 3). Plants mowed at both stubble heights had the highest TNC concentrations when they were mowed one-time-only at either the beginning or the end of the growing season. Plants mowed bi- and tri-monthly exhibited intermediate TNC concentrations.

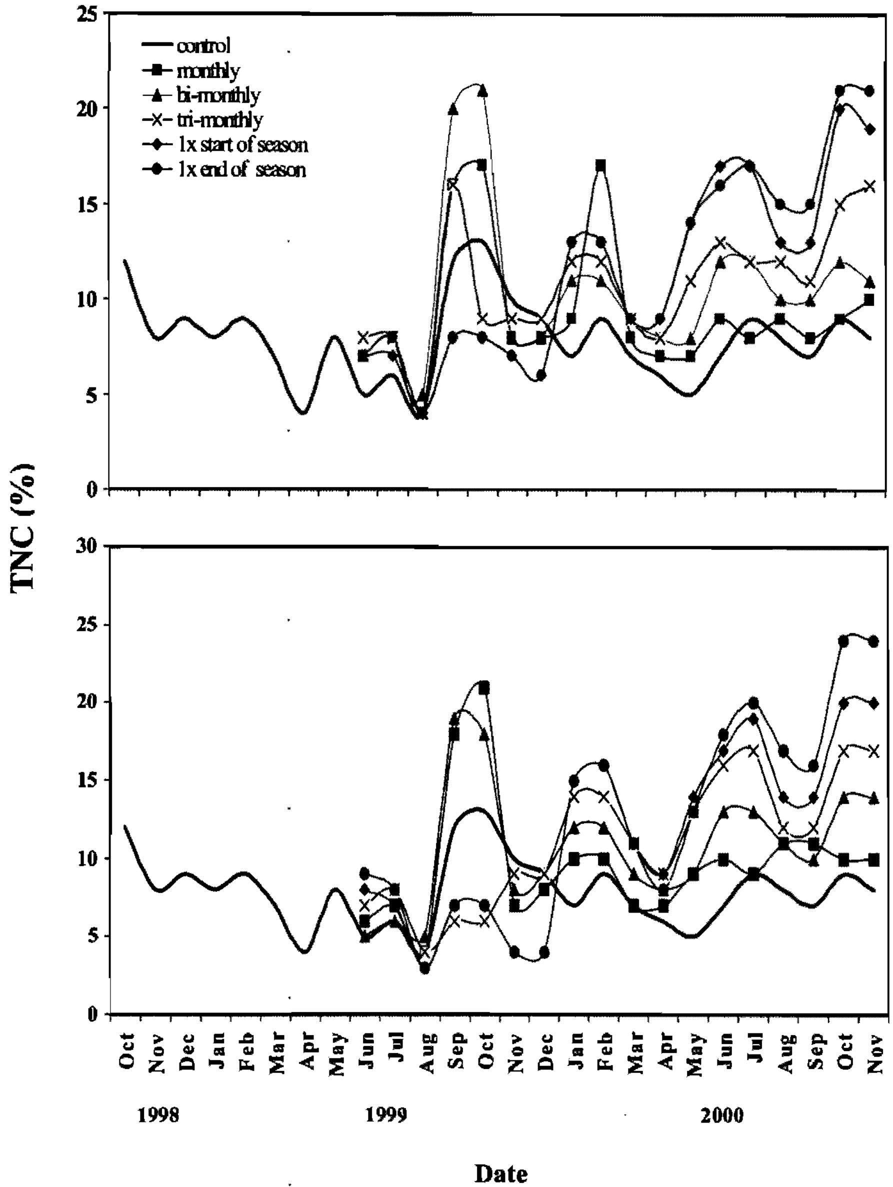

Figure 3. Basal crown and stem base TNC (%) for silver bluestem at 0, 2-inch (top), 4-inch (bottom) mowing stubble heights at different mowing frequencies

Standing Crop (Biomass; Live Plant Material) Production

Residual herbage (live plant material left at the end of the growing season) is at least as important for midgrasses as it is for shortgrassses, probably even more important. Therefore, it is very important that midgrasses have approximately 900-1,200 lb/acre residual herbage left at the end of the growing season to promote tiller recruitment for subsequent growing seasons. This is important for mid-seral grasses such as silver bluestem, just as it is for climax midgrasses [such as little bluestem and sideoats grama (*B. cutipendula*)].

Silver bluestem that was not mowed in 1999-2000 always had >1,200 lb/acre residual herbage (live plant material) at the end of the growing season (Figure 4).

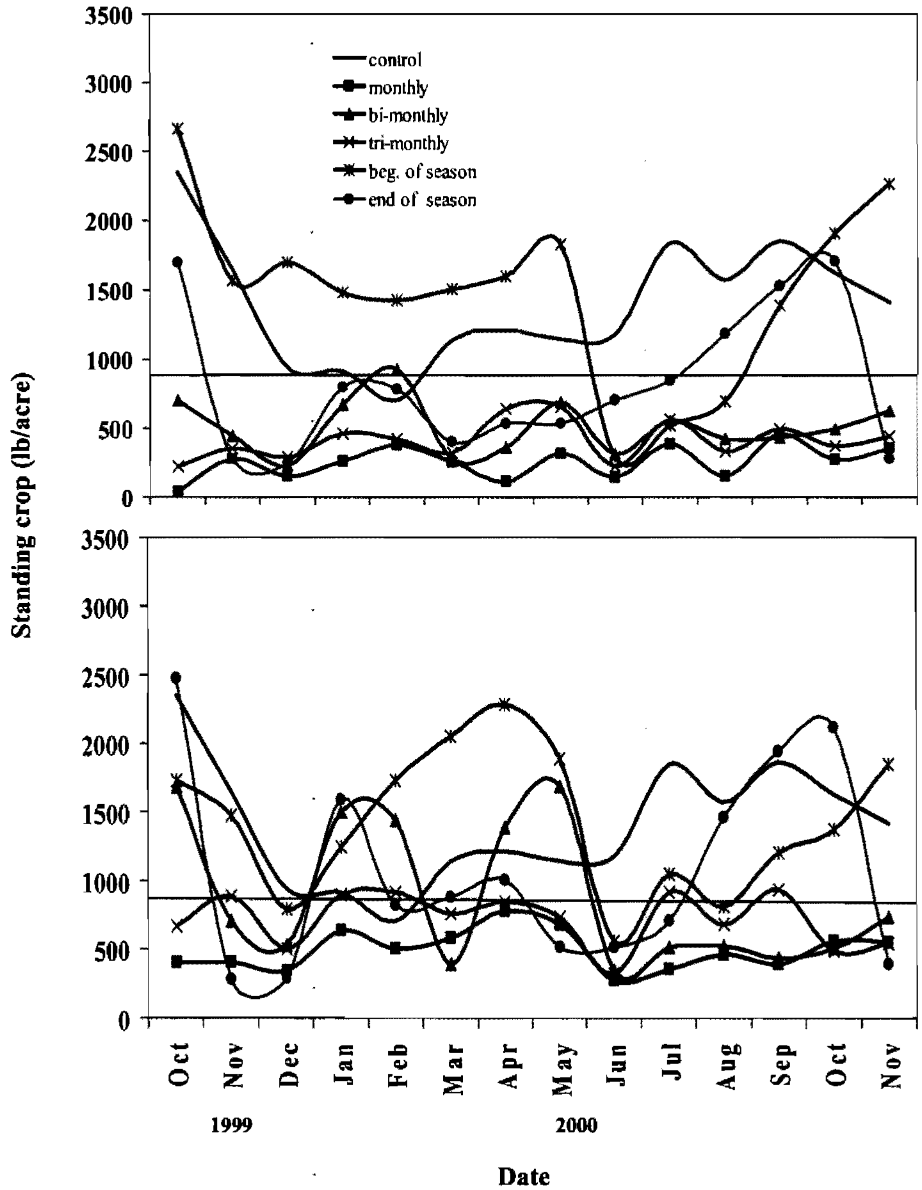

Figure 4. Silver bluestem aboveground live standing crop biomass (lb/acre) at 0, 2 inches (top) and 4 inches (bottom) stubble heights at different mowing frequencies

-------: residual herbage (lb/acre) required for growth regeneration in the spring

Similarly, the standing crop in the plots mowed one-time-only at the beginning of the growing season had >1,200 lb/acre residual herbage. Plots mowed one-time-only at the end of the growing season had <500 lb/acre residual herbage, a potential deterrent to tiller recruitment because there was not sufficient energy available for tiller production. Even though plants mowed one-time-only at the end of the growing season had ample opportunity to store carbohydrates in the basal crowns and stem bases during the growing season, all of that stored energy was removed when the plants were mowed in November. Plots mowed monthly, bi-monthly, or tri-monthly at either stubble height nearly always had <1,000 lb/acre residual herbage.

Although one-time-only mowing at the beginning of the growing season allows maximum production throughout the growing season, flowering silver bluestem at the end of the summer can be very aesthetically pleasing. This might, however, have some drawbacks relative to fire and safety hazards discussed in a later section.

Tiller Density

Tiller density was not different between plants mowed at either 2- or 4-inch stubble heights. There were differences, however, among plants in plots mowed with different frequencies. Mowing at both 2- and 4-inch stubble heights decreased the tiller density in silver bluestem after two mowing seasons (Table 3).

Likewise, there were no differences in tiller densities of plants among mowing frequencies. A reduction in standing crop biomass is reflected in tiller density after the second growing season.

Conclusions

For the health and vigor of silver bluestem (representative of midgrasses), the roadsides dominated by silver bluestem should be mowed one-time-only per year at the beginning of the growing season. Mowing one-time- only at the end of the growing season could have long-term detrimental effects on silver bluestem because of the reduction of stored energy reserves in the stem bases and basal crowns. If, however, one wanted to replace silver bluestem with "more desirable" plants such as little bluestem, sideoats grama, etc., silver bluestem could be eliminated from the roadsides by intensive mowing practices. The mowing practices would have to be modified at such time as the more desirable grasses replaced silver bluestem to enhance the survivability of the more desirable grasses. Unless one plans to manage the roadsides for climax grasses, silver bluestem (or other mid-seral grasses) is very well suited for roadside vegetation and repeated mowing regimes. Mowing all midgrasses should be no less than 4-inch stubble heights. Any mowing below 4-inch stubble height will be detrimental to the midgrasses. Likewise, timing of mowing is very important (even imperative) for maintenance and long-term survival of climax midgrasses).

Table 3. Mean tiller density (main effect) for silver bluestem as subjected to different mowing heights and frequencies after 1 mowing season (1 ms) and after 2 mowing seasons (2 ms)

Mowing Treatment	Tiller Density 1 ms	Tiller Density 2 ms
	(Tiller # m^{-2})	
Mowing height		
Non-mowed	228 a[1]	296 a
	B[2]	A
2-inch stubble height	198 b	163 b
	A	B
4-inch stubble height	217 ab	166 b
	A	B
Mowing frequency		
Monthly	146 b	156 b
	B	B
Bi-monthly	224 a	196 a
	A	B
Tri-monthly	218 a	130 c
	A	B
1x at start of season	232 a	192 a
	A	B
1x at end of season	216 a	150 b
	A	B

[1] Within columns, for either mowing height or mowing frequency treatments, means with the same lowercase letter are not significant at $P < 0.05$

[2] Within rows, for either mowing height or mowing frequency treatment, means with the same uppercase letter are not different at $P < 0.05$

Fuel Moisture/Fire Hazard

Fuel Moisture and the Potential Fire Hazard

One of the concerns of landowners adjacent to highway rights-of-way is the potential of a fire getting started in the right-of-way and moving onto their land destroying vegetation, livestock, and real property. Two questions arise concerning the roadside vegetation and its potential as a fire hazard. One, "Is the fuel moisture sufficiently low to permit a fire to ignite?" and two, "Is there sufficient fine fuel (phytomass; live plant material plus dead vegetation or litter)to carry a fire once it is ignited?"

Research has shown that for vegetation to ignite from a smoldering cigarette that has been discarded along the highway, the fuel moisture must be 13%, or lower. For vegetation to become ignited from an open flame, the fuel moisture must be 33%, or lower. If the fuel moistures are above the two thresholds listed, fires are not likely to be ignited along highway rights-of-way. The second issue concerns the amount of phytomass or fine fuel necessary to carry a fire if the vegetation is ignited. Generally, 1,000 lbs/acre are required to carry a fire.

Fire can sometimes carry however in less-fine-fuel, if the vegetation is continuous such as dry blue grama (sod-form) or buffalograss. Mid and tall grasses create a much greater fire liability than shortgrasses.

Fire hazards of right-of-way vegetation will be largely dependent upon a couple factors. One factor is the amount of precipitation the area has received and two, how green or succulent is the vegetation. In regions of the State that receive limited and erratic precipitation, the probability of fires is much greater than in areas where rainfall is abundant. Fire danger will also increase if the right-of-way has large quantities of dead vegetation or vegetation litter. Intensive mowing mid and tall grasses can leave large quantities of litter that creates more of fire hazard then non-mowed, live vegetation.

<u>Blue Grama</u>

Fuel Moisture

Areas dominated by shortgrasses are areas that generally receive limited amounts of precipitation. Also, these areas typically receive most of their precipitation during the growing season and only minimal amounts during the winter. Therefore, areas dominated by blue grama are subject to ignition of fires along the roadside. Because of precipitation patterns, fuel moisture is quite variable during the summer and very low during the winter or non-growing season (Figure 5). Consequently, fuel moisture of blue grama (and most other grasses) during the winter months of "the dormant" season will nearly always be less than 13%, regardless of stubble height. The one exception is when blue grama is mowed at 2-inch stubble heights one-time-only at the end of the growing season (October). Therefore, fires could easily be ignited from either an open flame or smoldering cigarettes.

Usually, blue grama standing crop biomass was <1,000 lb/acre during the "dormant" season or winter months. Most of the time, blue grama would not have enough standing crop biomass to carry a fire during the winter unless unusual environmental conditions existed (such as very low relative humidity and high winds), especially if the plants were mowed at 2-inch stubble height. Blue grama mowed at the 4-inch stubble height one-time-only at either the beginning or at the end of the growing season often had approximately 1,000 lb/acre standing crop. (Four-inch stubble heights in blue grama would actually remove very little of the herbaceous material most of the time.)

Fuel moisture of blue grama during the growing season, especially during summer months is quite variable, depending upon the precipitation (Figure 5). If the period was dry, the fuel moisture was usually <33%, but usually >13%. It seems apparent that most fire hazards during the growing season would arise from an open flame and not from a smoldering cigarette. Fuel moisture in blue grama that was not mowed (and occasionally when it was mowed one-time-only at the end of the growing season) was always >33% during the growing season. Therefore, non-mowed blue grama would infrequently be a fire hazard along highway rights-of-way during the growing season.

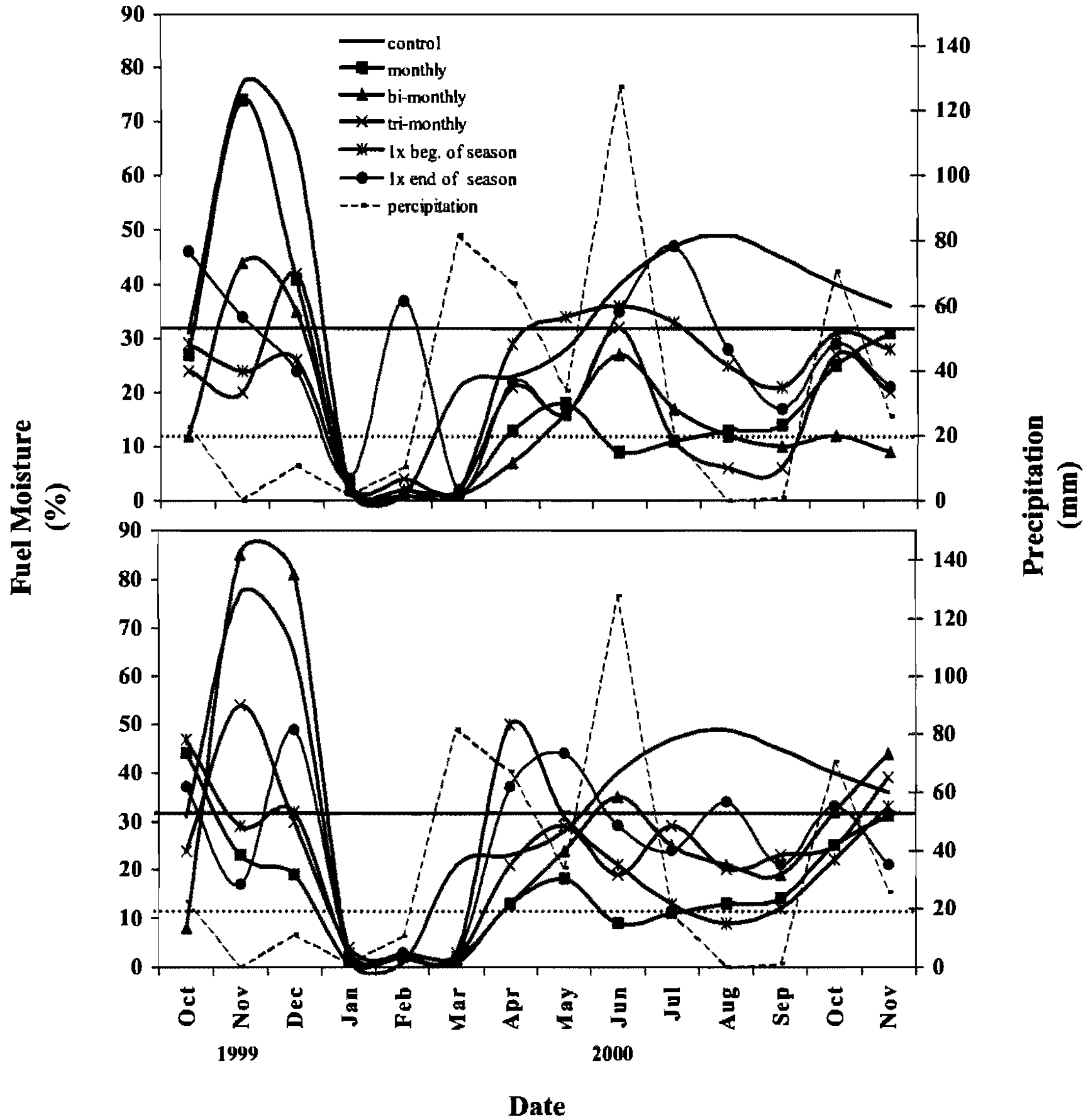

Figure 5. Fuel moisture content (%) of blue grama at 0, 2 inches (top) and at the (bottom) stubble heights at different mowing frequencies

_______: threshold ignition (33 %) by an open flame
-----------:threshold ignition (13 %) by a cigarette

Fine Fuel (Phytomass: Live Plant Material Plus Litter)

Usually, blue grama fine fuel was <1,000 lb/acre during the "dormant" season or winter months. But the amount of fine fuel (live plant material plus grass litter) nearly always exceeded 1,000 lb/acre (Figure 6). The one exception was plots mowed one-time-only at the end of the season at 2-inch stubble heights. Therefore, even though blue grama is a shortgrass and often produces <1,000 lb/acre biomass, the amount of litter increases the amount of fine fuel to levels that can carry a fire if one is ignited.

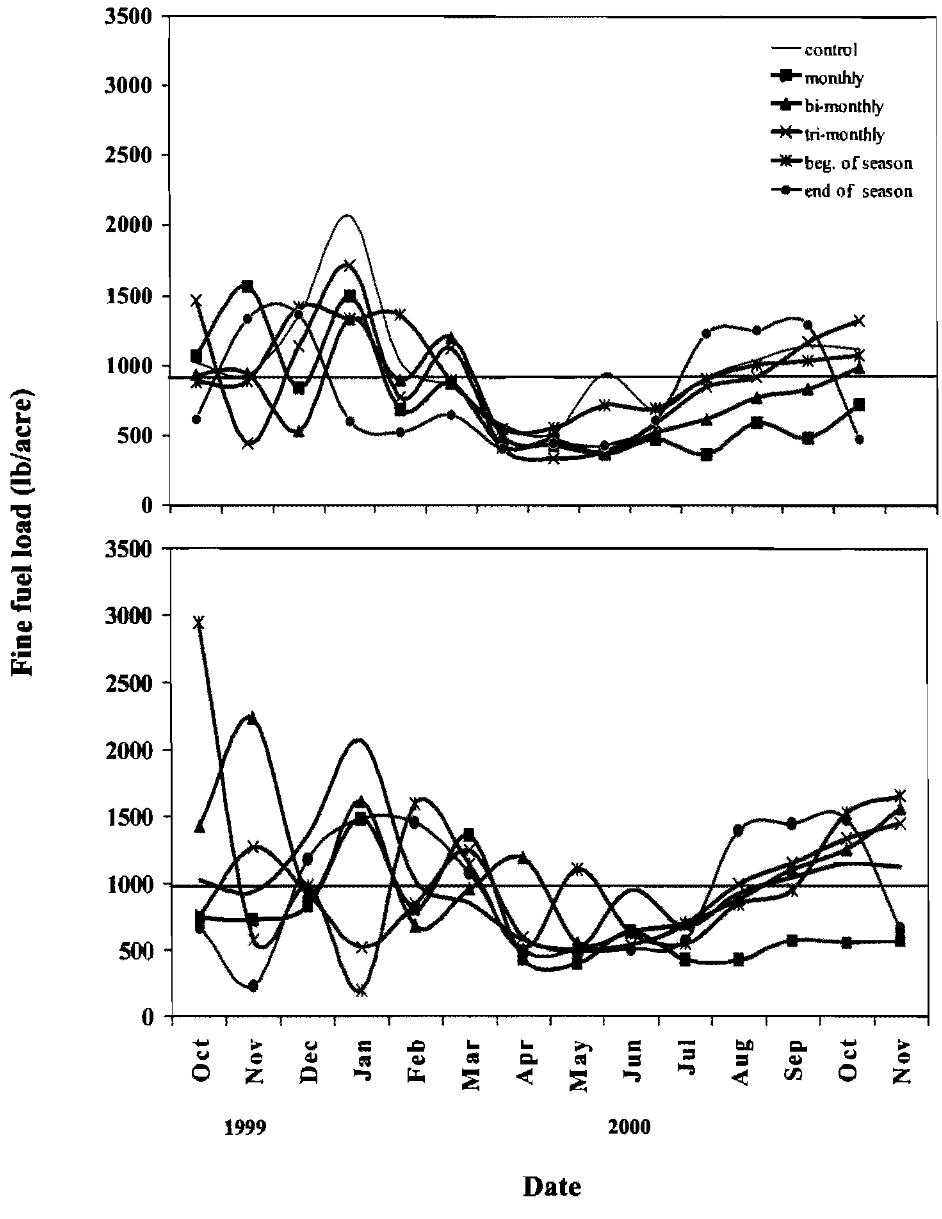

Figure 6. Blue grama fine fuel (phytomass; live plant material plus vegetation;lb/acre) at 0, 2 inches (top) and 4 inches (bottom) stubble heights at different mowing frequencies

----: Optimum fine fuel load (lb/acre) required to carry a fire

Conclusions

Fuel moisture was always low enough (<13%) during January – March to ignite in blue grama from either a smoldering cigarette or an open flame. Usually, the fuel moisture content of blue grama was high enough during the summer in plants mowed at 4-inch stubble height to only ignite from an open flame. If a fire was ignited, adequate amounts of fine fuel were always available to carry a fire. Therefore, fire can always be a hazard, even in shortgrass-dominated roadsides, if the fuel moisture is low enough and the environmental conditions are right.

<u>Silver Bluestem</u>

Fuel Moisture

Fuel moisture in silver bluestem was nearly always <13% during November – February (Figure 7). As growth began in March, fuel moisture increased and, was quite variable throughout the summer, but for the most treatments, it remained >33% throughout the growing season, (June – October). Silver bluestem is potentially a fire hazard almost any time during the winter, but usually would not pose a hazard during the summer, depending upon the precipitation pattern. Fires could be ignited from either a smoldering cigarette or an open flame during the winter, but would have to be ignited by an open flame during the summer if a fire hazard existed.

Fine Fuel (Phytomass: Live Plant Material Plus Litter)

Silver bluestem is a bunchgrass that infers discontinuity of vegetation unless there is an abundance of dead plant material or litter intermixed within the bunches of grass. Plots mowed at almost any stubble height except those plots mowed one-time-only at the end of the growing season produce >1,000 lb/acre biomass (Figure 8). If fuel moisture is low enough for a fire to ignite, silver bluestem will nearly always have enough fine fuel to carry a fire.

If fire hazard is a major concern and the objective of mowing is to prevent fires, then silver bluestem should be mowed one-time-only at the end of the growing season (at either stubble height) to reduce the fire hazard during the winter. This is in contrast to the optimum mowing regime for the long-term health and vigor of silver bluestem.

Conclusions

Vegetation management for fire protection along highway rights-of-way dominated by midgrass, or taller grass species, should include mowing at the end of the growing season. This regime would reduce the amount of fine fuel to levels below the 1,000 lb/acre threshold necessary to carry a fire. Winter is the most vulnerable fire season because of the lack of fuel moisture in the dormant herbage. Fuel moisture is usually high enough during the growing season to prevent ignition unless an area has had a long dry period, at which time fuel moisture could drop below the thresholds for ignition.

Height of Roadside Vegetation/Line of Sight Vision

Generally, vegetation is mowed along highway rights-of-way to maintain sight distance requirements, to maintain clear zones, to minimize weather effects such as drifting snow, and to maximize aesthetic quality as noted in the introduction of this report.

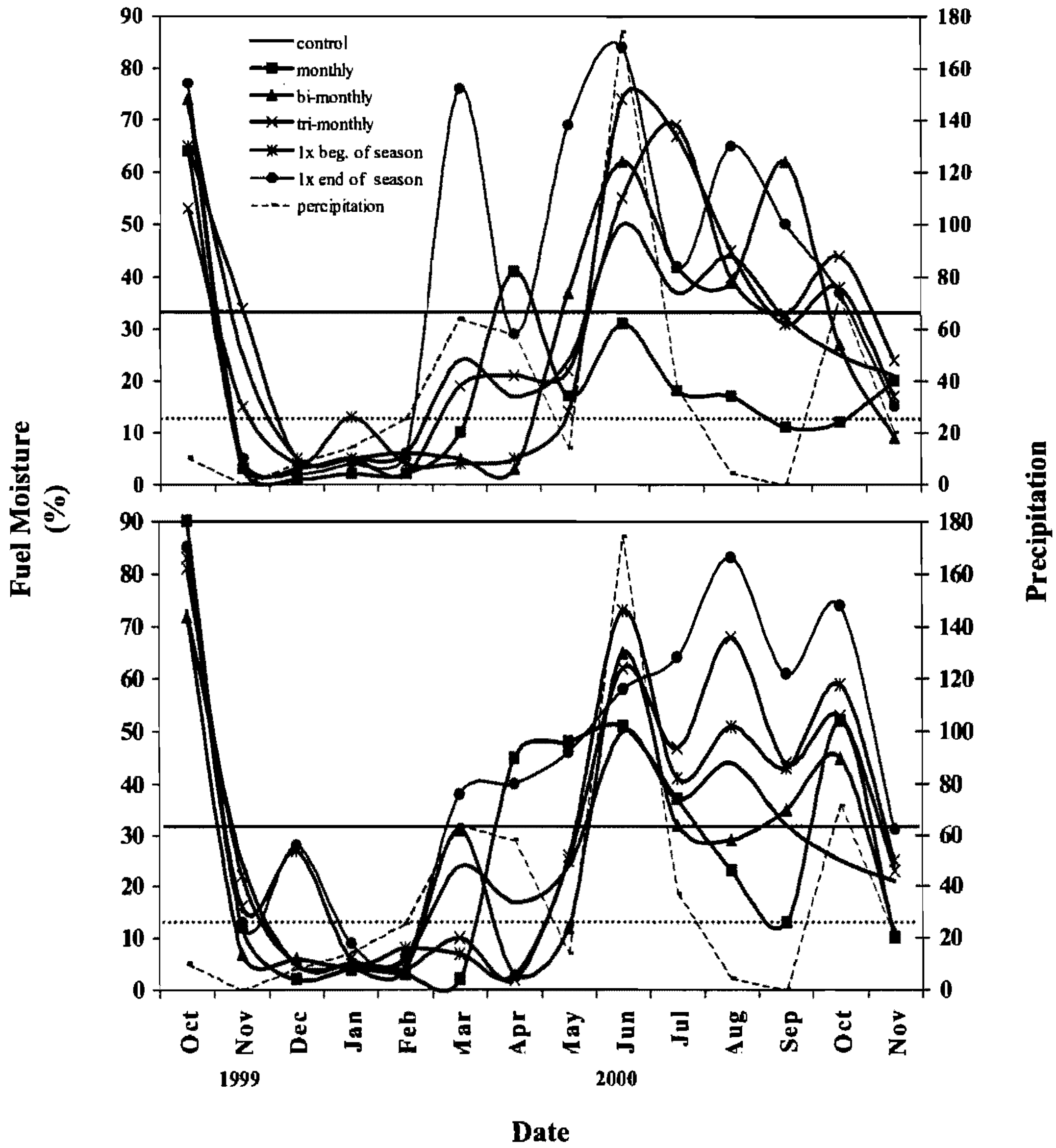

Figure 7. Fuel moisture content (%) of silver bluestem at 0, 2 inches (top) and at the (bottom) stubble heights at different mowing frequencies.

_______: threshold ignition (33 %) by an open flame

------------:threshold ignition (13 %) by a cigarette

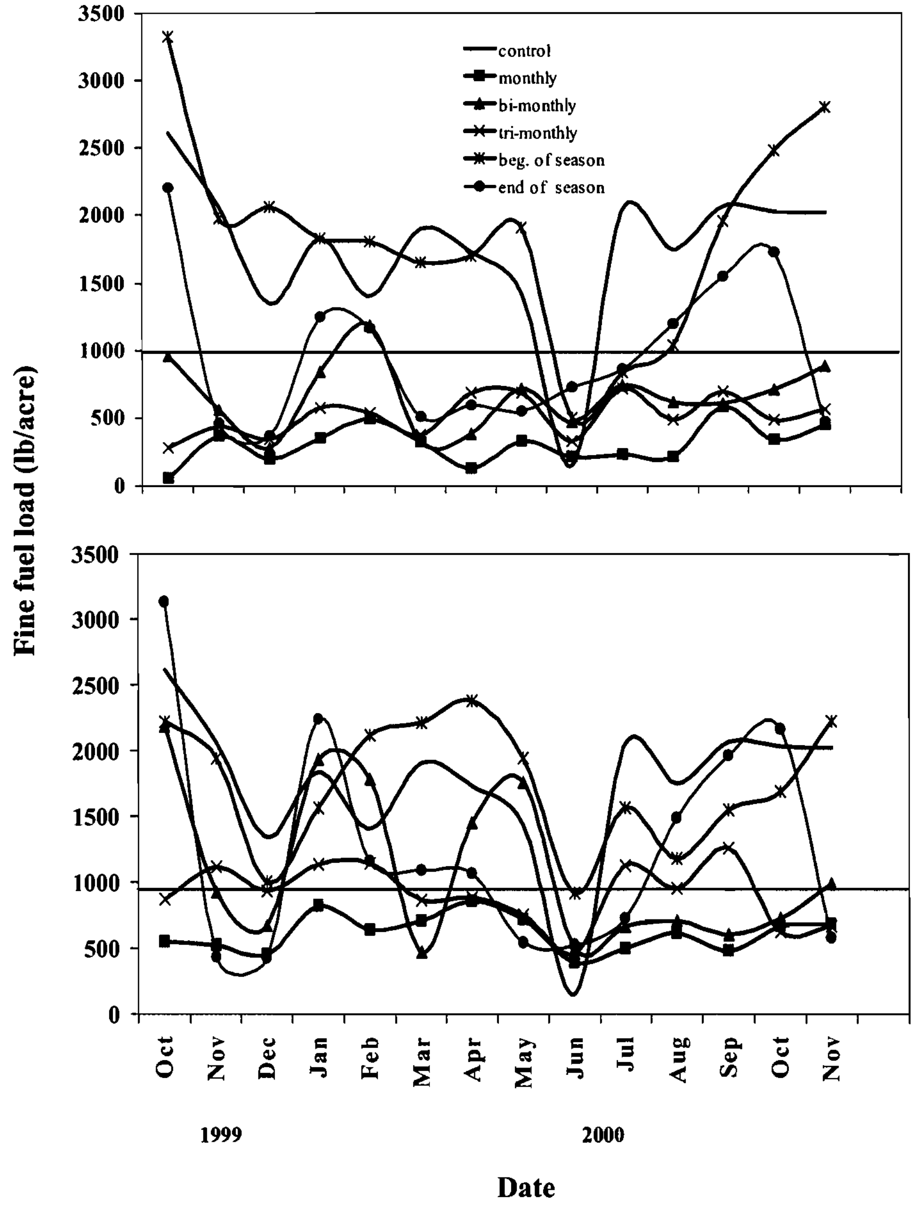

Figure 8. Silver bluestem fine fuel (phytomass; live plant material plus vegetation;lb/acre) at 0, 2 inches (top) and 4 inches (bottom) stubble heights at different mowing frequencies

-------: Optimum fine fuel load (lb/acre) required to carry a fire

Accumulation of biomass along roadsides or allowing the vegetation to grow tall can be a safety hazard by impairing the line of sight of vision or by creating at risk situations if one has to stop alongside of the road. Tall vegetation can hide wildlife grazing or browsing along the highway, as it limits a driver's vision at intersections, hides trash, etc.

Blue Grama

Since blue grama is a shortgrass, by definition, it rarely grows more than 12-18 inches tall. Therefore, even when blue grama is not mowed it usually will not cause a safety hazard due to its height. Results obtained in this study indicated that the tallest blue grama grew was about 14 inches when the plots were mowed one-time-only at the end of the growing season (Table 4). Blue grama in these plots had the opportunity to grow all season without mowing. Plots mowed monthly (not a recommended practice) grew between 6 and 8 inches tall. These heights represent seedhead heights and not the height of the foliage.

Table 4. Plant height[1] (main effect) in blue grama different mowing heights and frequencies after 1 mowing season

Treatments	Plant Height (inches)
Mowing height	
Non-mowed	7.5 a[2]
2-inch stubble height	7.6a
4-inch stubble height	8.7 a
Mowing frequency	
Monthly	8.6 ab
Bi-monthly	10.0 a
Tri-monthly	10.0 a
1x beg. of the season	5.2 c
1x end of the season	6.7 bc

[1] Plant heights were measured after the respective growing season

[2] Values within either the mowing height, mowing frequency treatments followed by the same letter are not different at $P < 0.05$

Silver Bluestem

Silver bluestem could conceivably cause a safety hazard by impairing the line of sight vision. Plots not mowed and plots mowed one-time-only at the beginning of the growing season (allowing the plants to grow unchecked all summer) attained heights of 18-20 inches. Although these heights are not great enough to affect drivers of large vehicles, they could interfere with the line of sight of drivers of compact cars, motorcycles, and bicycles. Therefore, mowing at 4-inch stubble height one-time-only at the end of the growing season would be more desirable in that the height obtained by silver bluestem was an average of only 12 inches high. These heights could also obscure the visibility of wildlife along the right-of-way, intersections, etc.

Conclusions

Blue grama (or any other shortgrass) is not likely to cause a safety hazard due to the height of its growth. Silver bluestem, and any other mid to tallgrass, could cause a hazard.

Table 5. Plant height (height x frequency interaction) means in blue grama different mowing heights and frequencies after the 2000 growing season

Treatments	Plant Height (inches)	
Mowing height	2 inches	4 inches
Mowing frequency		
Monthly	6.0 b[1]	9.0 a
	C[2]	C
Bi-monthly	8.9a	8.5 a
	B	C
Tri-monthly	8.3 a	9.3 a
	B	C
1x beg. of the season	12.0 a	11.7 a
	A	B
1x end of the season	12.0 b	14.2 a
	A	A

[1] Within rows, means followed by the same lowercase letter are not different at $P < 0.05$
[2] Within columns, means followed by the same uppercase letter are not different at $P < 0.05$

Table 6. Mean plant height (main effect) in silver bluestem different mowing heights and frequencies after 1 mowing season (1ms) and after 2 mowing seasons (2 ms)

	Plant Height (inches)	
Treatments	1 ms	2 ms
Mowing Height		
Non-mowed	12.3 a[1]	27.7 a
2-inch stubble height	6.5 b	15.9 b
4-inch stubble height	7.1 b	14.6 b
Mowing Frequency		
Monthly	4.3 b	5.6 c
Bi-monthly	3.9 b	13.3 b
Tri-monthly	5.7 b	16.7 ab
1x beg. of the season	13.8 a	21.5 a
1x end of the season	6.4 b	19.2 a

[1] Values within either the mowing height or mowing frequency treatments followed by the same letter are not different at $P < 0.05$

When silver bluestem produced seedheads, the height reached a maximum of 20 inches (taller grass species would even extend higher than 20 inches up to 5-8 ft tall for some species). However, when silver bluestem was mowed only at the end of the growing season, the height obtained was only abut 12 inches which, generally, would not cause a safety hazard.

Species Composition

Species composition was measured near Tahoka, Andrews, Brady, and Lufkin in association with the commercial-like mowing treatments at each of these locations. Mowing treatments were initiated in May 1999 and repeated as scheduled through 2003. Treatments at each location included three stubble (mowing) heights (0, 2, 4, and 8 inches) and three frequencies (1 time/year, October; 2 times/year, July and October; and 3 times/year, May, July, and October). Each treatment was replicated four times.

Precipitation records for each location are show in Table 6. Precipitation, by month and year, at each location gives an indication of the vegetation response following the mowing treatments. Theses values were obtained from official National Oceanography and Atmospheric Administration (NOAA) reports of precipitation. Annual average precipitation at Tahoka approximated the long-term average (19.7 inches/year) in 1999 and 2002; it was slightly above average (105%) in 2000. Average precipitation in 2001 was approximately 60% of the long-term average.

Average precipitation at Andrews approximated the long-term average (13.7 inches/year) in 2002. The average in 1999 and 2001 was approximately 87% and 65% of the long-term average, respectively. The average in 2000 was about 124% of the long-term average.

Average precipitation at Brady approximated the long-term average (26.1 inches/year) in 2001 and 2002. It was substantially below average (84% of the long-term average) in 1999 and above average (123%) in 2000. Average precipitation at Lufkin was about 95% of the long-term average (46.1 inches/year) in 1999 and above average in 2000 (approximately 111%), 2001 (approximately 126%), and 2002 (approximately 135%).

Species composition was measured in each plot at each geographical location by the frequency method. At the same time that species composition was measured, bare ground (%), vegetative ground cover (%), and litter (%) were also measured. The measurement technique included point data along two transects in each plot. At each point, the data recorded included basally-rooted vegetation, by species, litter, or bare ground. If no basally-rooted vegetation was encountered or "hit" within the point, the nearest rooted plant to the point was recorded for estimating species composition.

Species composition data were categorized into the following groups for comparison (because of the variation in species within the different plots): climax species (by location), secondary species, particular species of interest, and perennial forbs (weeds). All other species comprised such a small percentage of the total species composition, they were not considered for this report. As one would expect, some variability existed (at each location) by years due the weather pattern (primarily precipitation) among years.

Measurements were made in 2000 (except for Lufkin), 2001, and 2003. Surprisingly, there were few differences (that are noted by location) among treatments by years. Climax species of rangeland adjacent to the mowed highway rights-of-way (according the County Soil Survey for the respective counties in which our study sites are located are identified in the section that discusses each geographical region.

Tahoka Location

Climax species of the native rangeland near the study site at Tahoka include blue grama, buffalograss, and sideoats grama, all of which are shortgrass species. The dominant grass that occurred in the right-of-way was silver bluestem (a mid-seral, bunchgrass). It was identified as the primary secondary species for the Tahoka area. Sideoats grama occurred in the right-of-way in small patches. In no treatment was sideoats grama a continuous or significant part of the vegetation.

There was no apparent effect on selected botanical parameters measured from the different mowing treatments. Phytomass (both alive and dead plant material) was not measured. The most obvious effects are based on observations of each individual plot.

Vegetative ground cover decreased across all mowing regimes from 2000-2003. This decrease seemed to be more related to weather (rainfall) patterns rather than any particular mowing treatment. Bare ground concomitantly increased from 2000-2003, but there was no pattern that one could attribute to the effect of mowing. These changes probably also reflect weather patterns. Litter constituted the greatest percentage of ground cover in 2000 and 2001 (usually >65%) and comprised nearly one-half of the ground cover in 2003.

In general, there was no apparent affect of mowing on the climax species present in the right-of-way. The climax species, generally, comprised 10-20% of the species composition and often <10%. Silver bluestem comprised >50% of the species composition in 2000 and 2001. Percent silver bluestem substantially decreased in 2003 which is also reflected in the percent ground cover. The decrease in silver bluestem in 2003 probably is indicative of a very dry year, although precipitation data were not available at the time of report preparation.

Johnsongrass (*Sorghum halapense*) is always a concern of those individuals responsible for "managing" highway rights-of-way. However, Johnsongrass did not constitute enough of the species composition at Tahoka to cause a concern.

Although there were no measurements from which to draw the following conclusions, the effect of mowing of some treatments became very obvious as one walked through the individual plots. All treatments in which silver bluestem was mowed at 2-inch stubble heights (regardless of frequency of mowing) were severely damaged. There was very little recovery from mowing and, although the litter comprised the greatest amount of ground cover, the amount of phytomass was substantially reduced. Several of the plots mowed at 2-inch stubble heights appeared nearly devastated. In some cases, where silver bluestem was seemingly severely damaged by intensive mowing, annual forbs and annual bromegrass had begun to invade the plots. If silver bluestem continued to be mowed at 2-inch stubble heights, one could presume that the roadside would soon be devoid of silver bluestem. One could speculate that if silver bluestem were continuously mowed at very short stubble heights, it would be (or could be, depending upon one's objectives) eliminated from highway rights-of-way. At this point in time, it would be anyone's guess at what species might naturally replace silver bluestem if it were eliminated. However, reseeding would be required to replace it with selected, more desired species. Sideoats grama (a more desirable, climax grass) was more apparent in some of the plots mowed at 4-inch stubble heights, or higher.

Andrews Location

Climax grass species on the native rangeland in the vicinity of the Andrews study site is black grama. Much of the adjacent rangeland (and even the borrow pit) has a relatively high degree of infestation of mesquite. As at Tahoka, there was no apparent effect of mowing treatments on the botanical composition at Andrews. Phytomass was not measured.

Vegetative ground cover (basally-rooted vegetation) was quite sparse, always <15% (and often <5%). Likewise, litter was minimal. Bare ground was most abundant (nearly always >50% and, sometimes >75%).

Black grama hardly ever contributed to the species composition in the mowed plots at Andrews. It was more apparent in 2001 than in either 2000 or 2003. By contrast, lower successional species such as sand dropseed (*Sporobolus cryptandrus*), perennial threeawns, (*Aristida* sp.), and fringed signalgrass (*Brachiaria ciliatissima*), and occasionally perennial forbs comprised the largest portion of the species composition (usually >80%). The climatic regime in which the Andrews study site was located is characteristically so dry (<15 inches/year) that once the herbaceous vegetation is destroyed (by whatever means; weather cycles, mowing, etc.), the area often remains denuded for years and is left to erode, or to be invaded by noxious woody species (which are very common).

The observation (which was not supported by measurements of botanical parameters) was that all mowing treatments adversely affected the desirable grass species, especially black grama. Black grama is very sensitive to defoliation and must be mowed or grazed very judiciously to avoid serious damage to the plant.

Brady Location

Climax vegetation on the rangeland in the vicinity of the Brady study site includes sideoats grama, Canada wildrye (*Elymus canadensis*), little bluestem (*Schizachrium saccriodes*), and cane bluestem (*Bothriochloa barbinodis*). Important secondary species include meadow dropseed (*S. asper*), buffalograss, and Texas wintergrass (*Stipa leucotricha*).

Vegetative ground cover was greatest in 2000 and substantially dropped in 2001 and 2003. Even though there is high percent of canopy cover (from the grasses along the roadside), there is minimal basal cover (which is typical, even in relative dense vegetation). Litter accumulation was very high (usually >80% in 2000 and >90% in 2001 and 2003). This much litter could significantly increase fire danger along the roadside. Since there was so much litter, there was essentially no bare ground in any of the plots. Erosion should be minimal with abundance of litter and lack of bare ground.

There were no climax species included in the species composition in any of the plots of this portion of the study. The dominant grass, however, was meadow dropseed. It often constituted nearly half, and sometime more, of the species composition. However, in 2003, meadow dropseed composition was substantially decreased, probably due to the apparently dry weather. Although perennial forbs are showy and often appear to be in great abundance, they never comprised >15%, and usually <10%, of the species composition.

Johnsongrass was a major concern at the Brady location. Johnsongrass was relatively abundant in 2000, but its abundance apparently was not the result of any mowing treatment. The year 2000 was a very wet year at Brady and this probably had more to do with the occurrence of Johnsongrass than any other factor. Johnsongrass typically grows in wetter areas; therefore, any area (regardless of size or mowing treatment) in which water accumulates tends to favor the production of Johnsongrass.

Observations of the mowed plots indicate that intensive mowing at 2- and 4-inch stubble heights severely damaged all of the grasses in the plots, even meadow dropseed. Also, there was a distinct mow-line where Johnsongrass was obvious outside of the plots and not obvious within the mowed plots. And, often Johnsongrass was very abundant between the plots. On occasion there was an abundance of annual bromes (*Bromus* sp.) and other annual weeds in the more intensively mowed plots. Although an observation that 4- and 8-inch stubble heights favor meadow dropseed production, the species composition data don't support this conclusion. But, they surely would if these intensive mowing practices continued for many years.

<u>Lufkin Location</u>

Climax understory vegetation of the pine forests in east Texas in the vicinity of the study site include tallgrass species such as big bluestem (*Andropogon gerardii*) and eastern gamagrass (*Tripsacum dactyloides*). One of the dominant secondary species along most roadsides in the area is bahiagrass (*Paspalum notatum*).

Even in Lufkin which typically receives >45 inches/year, vegetative ground cover of basally-rooted herbaceous vegetation was always <15% in 2001 and 2003 (measurements were not made in 2000), regardless of mowing treatment. There was no apparent differences in the vegetative ground cover that could be attributed the effect of mowing (or lack thereof). Abundance of litter, on the other hand, was very high (often >80%, regardless of the mowing treatment). Consequently, bare ground was minimal (<20%, and often <3%).

Big bluestem was encountered in the study plots at Lufkin. However, eastern gamagrass occurred in the plots. As a general rule, eastern gamagrass occurred in greater abundance in the mowed plots than in the non-mowed plots. Often eastern gamagrass comprised >10% of the species composition and sometimes it comprised as much as 25-30%. These data need to be considered in context of eastern gamagrass growth habits. Observations of mowing at 2-

and 4-inch stubble heights appeared to be devastating to eastern gamagrass, as well as other grasses in the mowed plots. Since eastern gamagrass is a tallgrass species, it typically cannot tolerate repeated, intensive defoliation (either via grazing or mowing).

Bahiagrass occurred most frequently in the species composition, usually >40% and sometimes >80%. However, there was no apparent pattern of abundance that could be attributed to mowing, or lack thereof. Since bahiagrass is a mid-seral species, it is well-adapted to defoliation, consequently, it is dominant along many roadsides in east Texas.

Johnsongrass was present in some of the plots, but usually comprised only insignificant amounts of the species composition. Its presence or abundance was apparently not related to any mowing regime. Common bermudagrass (*Cynanon dactylon*) occurred in most treatments (usually <10%). And, perennial forbs comprised <5% of the species composition, but followed no apparent pattern to the mowing regime. As noted previously, observations of mowing at 4-inch stubble heights were particularly damaging to all grasses in the right-of-way, particularly eastern gamagrass.

Conclusions

It is apparent that the mowing practices along nearly all roads throughout Texas have eliminated the native, climax grasses. Likewise, if one wanted to reseed the roadsides with the native climax grasses adapted to the respective environmental regime, the mowing practices would have to modified to accommodate the growth habits of the selected grasses and their ability to respond to time and frequency of defoliation as well as stubble height of mowing, not planned for the convenience of the mowing crews.

In areas where tallgrasses are the dominant native, climax species, mowing regimes must be planned very judiciously for the protection of the tallgrasses. The highway rights-of-way are generally dominated by mid-seral species (often introduced or exotic) because, by definition mid-seral grasses 1) produce more 2) on less resources (less and more erratic precipitation) 3) in a shorter time period than climax species. And, they are usually more tolerant of repeated defoliation (by whatever means). Therefore, to change the vegetation complex along the roadsides in Texas, the mowing regimes must also change.

General Conclusions

The height and frequency of mowing roadside vegetation (predominantly grasses) is very important in keeping and maintaining the grasses desired along roadsides. Height of mowing for all grasses should not be less than 4-inch stubble height even for shortgrasses such as blue grama. Any stubble height <4 inches removes stem bases and basal crowns in which carbohydrates are stored for tiller recruitment and initiation of new growth in the spring (or whatever time of year growth begins).

Likewise, time and frequency of mowing are also very important. For the health and vigor of both short-and mid-grasses, mowing one time per year either at the beginning or at the end of the growing season or mowing every three months allows the grasses to store more carbohydrates in the stem bases and basal crowns than any other mowing regime. The more frequently that either short- or mid-grasses are mowed, the more likely the grasses are to be permanently injured or even killed (this is even truer for taller grass species). Mowing every month or every two months causes a reduction in stem base and basal crown carbohydrates; which eventually will be to the detriment of the grasses.

If fire hazard is a major concern, then the roadsides should be mowed (no less than 4-inch stubble heights for the health of the grasses) at the end of the growing season to reduce the fine fuel load to <1,000 lb/acre (the threshold for carrying a fire). Since fuel moistures are low enough (<13%) during the winter to ignite the grass (either short- or mid-grasses) from either smoldering cigarettes or an open flame, one's goal should be to keep the fine fuel below the amount that will carry a fire. Even though the amount of fine fuel exceeds 1,000 lb/acre during the summer, the fuel moisture contents are usually high enough that fires are not as likely to be ignited, unless the area has had a period of hot, dry weather.

If line of sight or visual obstruction is a major concern, the mid-grasses should be mowed either at the end of the growing season or mowed on three-month intervals throughout the growing season. Short-grasses infrequently cause visual obstruction or roadside hazards due to their height.

ROOT DENSITY STUDY

The purpose of this TxDOT study was to evaluate the influence of mowing highway rights-of-way in four diverse climatic areas--Andrews, Brady, Lufkin, and Tahoka--of Texas (Figure 9). This project began in 1999 and continued through 2003. The four research areas were examined separately to determine significance of the variables being investigated at that particular location. Root density numbers at the four location sites were compared in this long-term mowing study. Frequency of mow and mowing height were the treatments evaluated. Each treatment was replicated four times at each site. Frequency of mow consisted of mowing selected plots zero, one, two or three times annually. The mowing height consisted of mowing the rights-of-way plants at 2, 4 or 8 inches. Plots were mowed with a commercial mower set at the prescribed heights. The non-mowed plots were considered control plots.

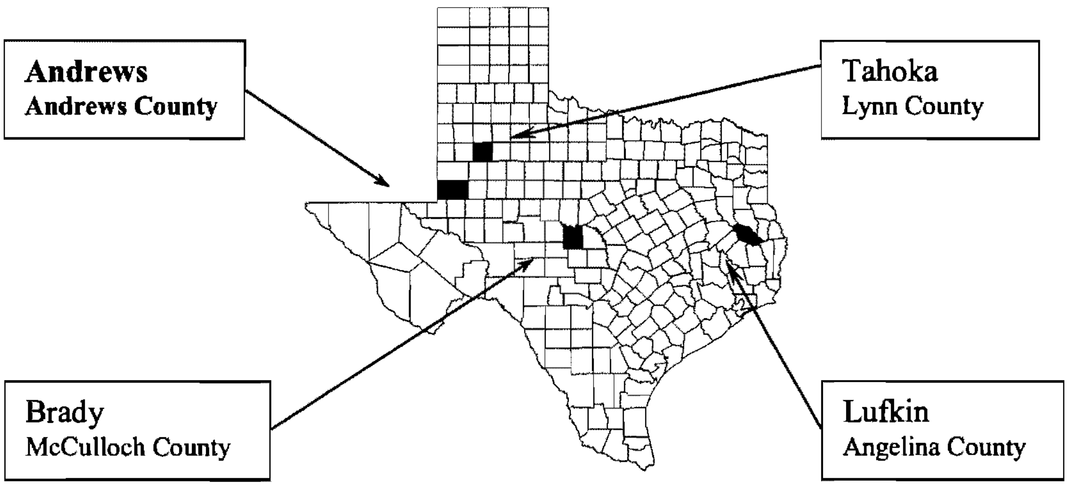

Figure 9. Map of locations evaluated.

Soil Sampling and Root Analysis Materials

The core method of collecting soil samples was chosen for this project. Equipment used to take soil core samples included a 3 ft. soil probe referred to as the JMC Environmentalists Subsoil Probe Plus. Soil samples were contained within 36-inch long tubes with a 1.3-inch diameter [PETG co-polyester liners (plastic tubes)]. The soil probe and plastic tubes were purchased through Clements Associates Inc. [Dept. CN 1992 Hunter Ave, Netwon, IA 50208 USA]. Soil samples were taken to a 26 inch soil depth or to refusal depth in eight-inch intervals. Once the soil sample was contained within the plastic tubes they were sealed on top with red plastic caps, and on bottom, with black plastic caps.

Field samples were taken to the laboratory for root analysis using the Core-break method (Böhm, 1979). A serated knife was used to cut the plastic tubes at eight-inch intervals (0-8, 8-16, 16-24 and 24-26) for each soil sample. The top portion of the soil sample, with vegetation debris, was not used for analysis. At the eight-inch cut, two breakage faces of the soil sample were seen. The separate tubes were then capped differently and relabeled to distinguish them later for root analysis.

Root Analysis

After the tubes have been cut and labeled, roots were counted using a modified Core-break technique. There were two individual tubes broken at each depth, unless the tube sample was smaller than 8 inches or was the end of the sample. The breakage face of the two individual tubes was examined and counted separately for root numbers. At the cut, a half an inch of soil sample inside the tube was removed. This volume of soil material was broken into smaller pieces and all root segments were counted.

Measuring half-inch above and below the several depths allowed for calculations of roots. After the half-inch measurement was marked on the entire section of the tube, that portion was placed on a white piece of paper for root counting. Soil was broken up carefully to expose hidden roots and make roots more visible. Once counts were made for the first broken tube the number was recorded. Then the second broken tube of the same plot and depth was counted and recorded. These two root numbers were averaged to give a single root number for the depth.

After these root numbers were averaged, the root numbers were divided by a root factor to correctly calculate the area of the round tube. The diameter of the plastic tube was 1.3 inches and the radius (r) of the plastic tube was 0.65 inches. The area (A) of the tube was calculated by the formula: $A = \pi * r^2$. The area of the tube was calculated to be equal to 1.327 in^2. This root factor number gave the estimated number of roots per square inch at the particular depths.

Root number, with depth, was the dependant variable that was analyzed as a function of the independent variables of (1) location, (2) frequency of mow, and (3) mowing height. Until the completion of 1999, no treatment effects were possible and these data sets were not used. Data collected from 2000 through 2003 were combined into one figure per depth per location. While data were collected to 26 inches or refusal depth, only the 0 to 8 inch-depth values will be presented.

<u>Andrews</u>

The Andrews, Texas site was located in West Texas (Figure 9) and was the driest area of all of the research plots receiving an average of 14 inches of precipitation. Andrew's plots were on U.S. highway 385 southeast of the city of Andrews. The global positioning (GPS) coordinates were N32° 7.89' and W102° 27.92'. The dominant grasses of these plots were little bluestem (*Schizachyrium scoparium*), Lehman lovegrass (*Eragrostis lehmanniana*), and three-awn (*Aristida*). This site represented the more arid portions of the state. The root density means for the one, two or three mow treatments are presented in Figures 10, 11 and 12.

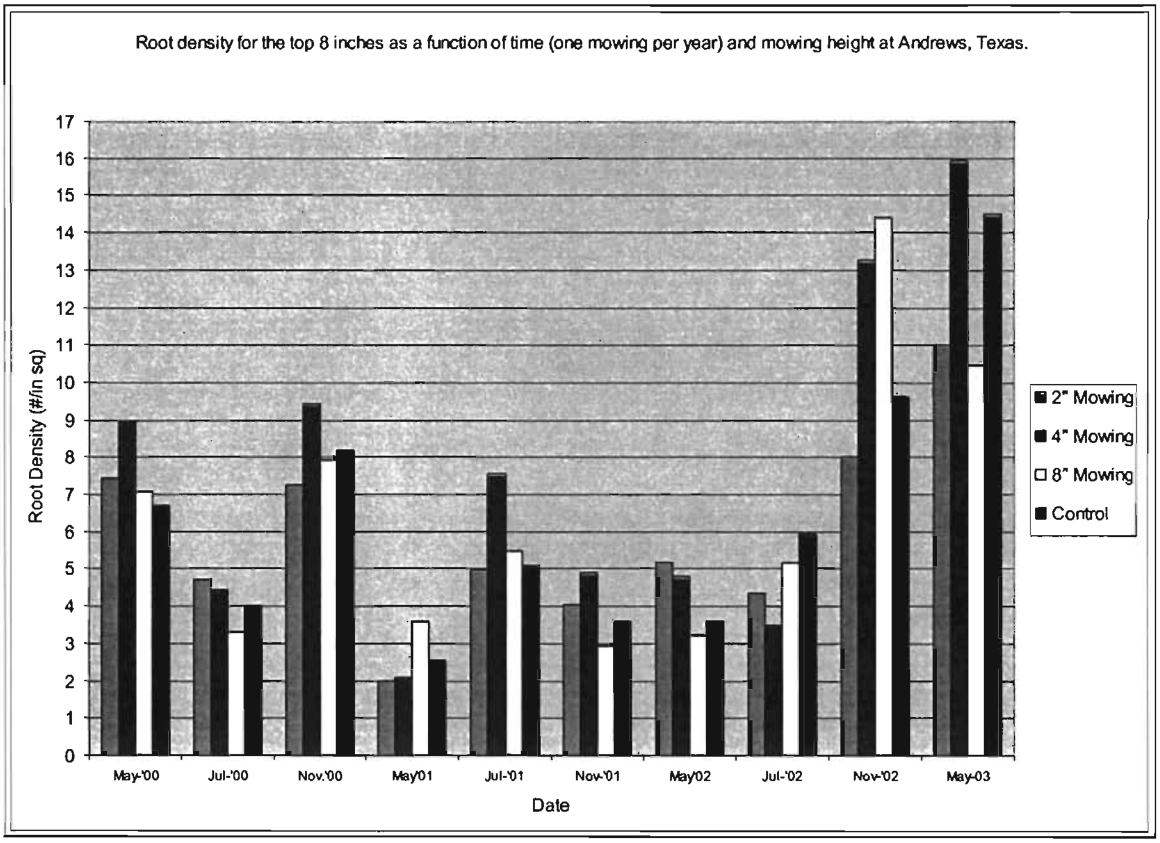

Figure 10. Root density at Andrews, Texas for one mow per year treatment.

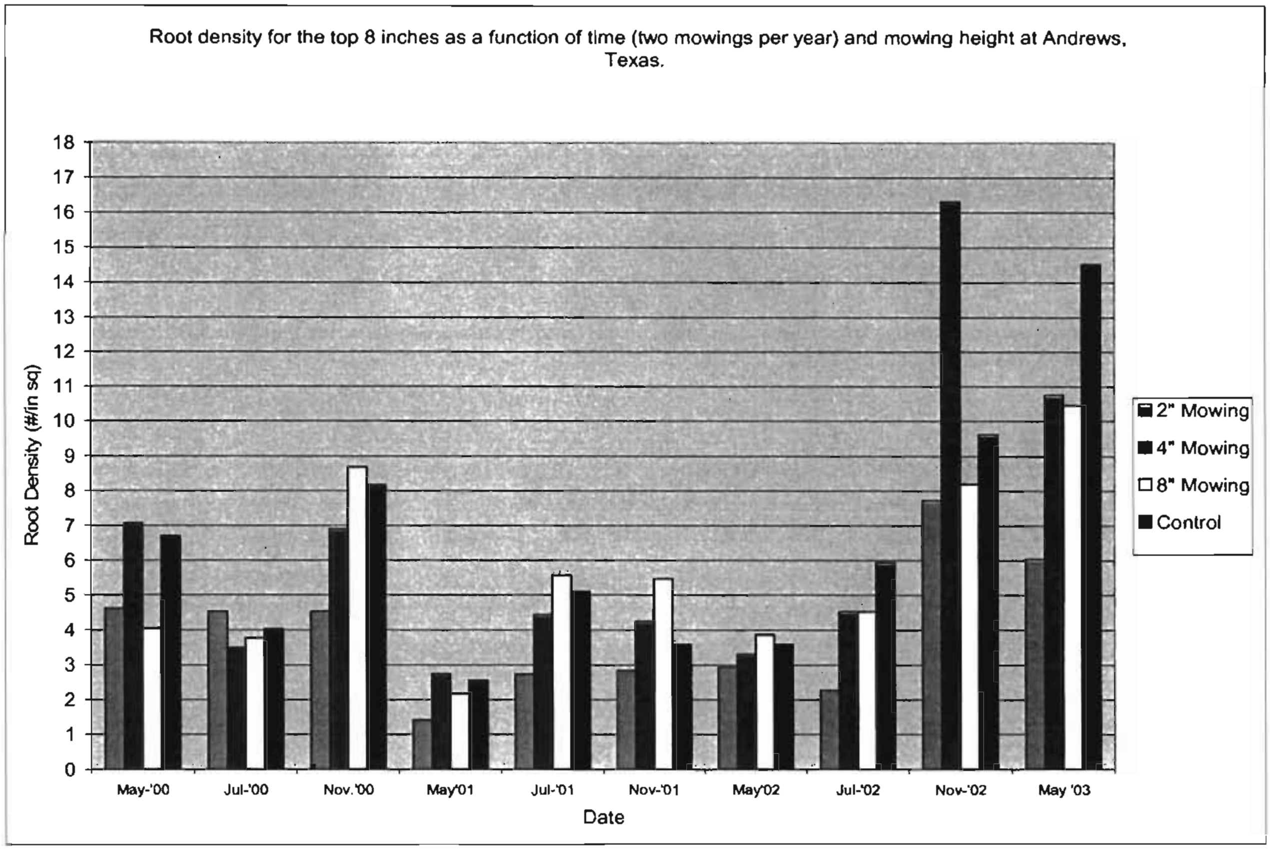

Figure 11. Root density at Andrews, Texas for two mows per year treatment.

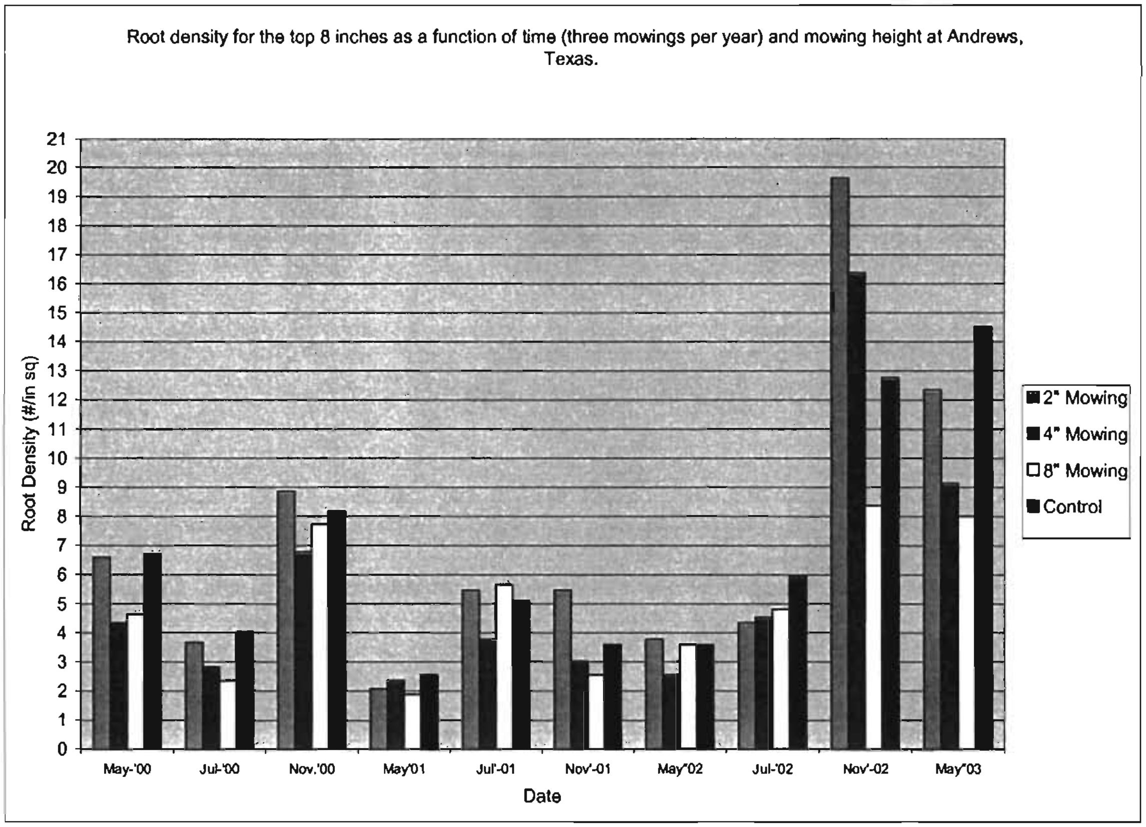

Figure 12. Root density at Andrews, Texas for three mows per year treatment.

The root number data for the 0 to 8 inch depth sampling indicates that mowing treatments were similar. Therefore, no mowing treatment was better than any other treatment at this site. Mowing for safety would be required when necessary depending on the rainfall received on a yearly basis. Personal observations of the plots would indicate that mesquite control could be a problem. Mesquite should be controlled by herbicide applications and not by mowing.

Brady

Brady, Texas is located in the approximate geographic center of Texas (Figure 9) and receives approximately 23 inches of precipitation annually. The Brady plots were located approximately 8 miles east, north-east of the city on U.S. Highway 190. GPS coordinates were N31° 11.889' and W99° 14.060'. The grass vegetation that covered most of these plots was meadow dropseed. The root density data at the 0 to 8 inch depth are presented in Figures 13, 14, and 15.

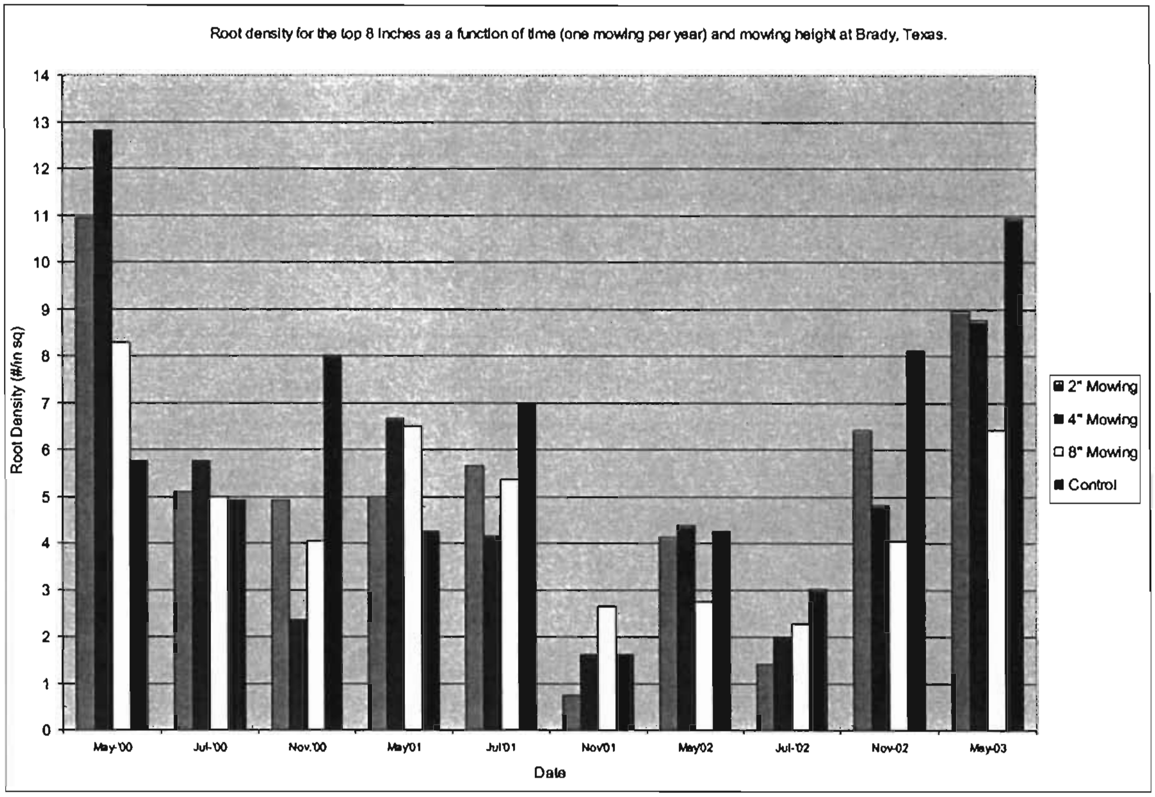

Figure 13. Root density at Brady, Texas for the one mow per year treatment.

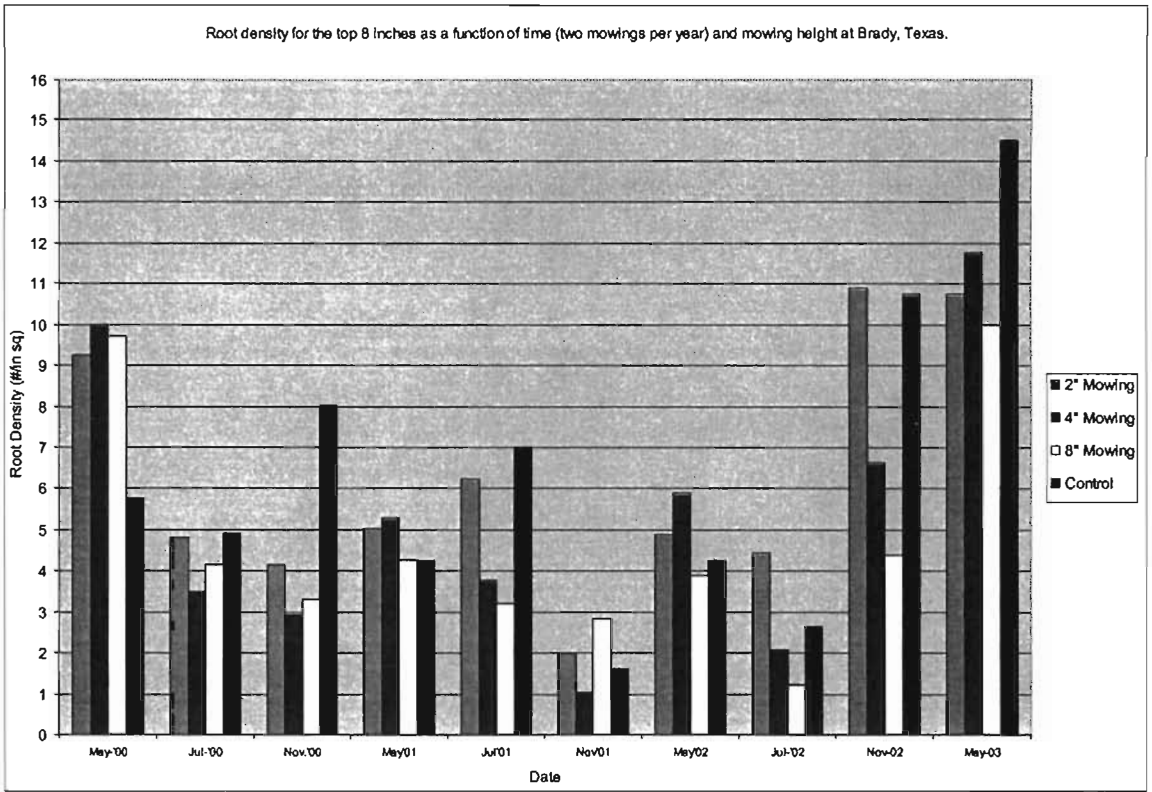

Figure 14. Root density data at Brady, Texas for the two mows per year treatment.

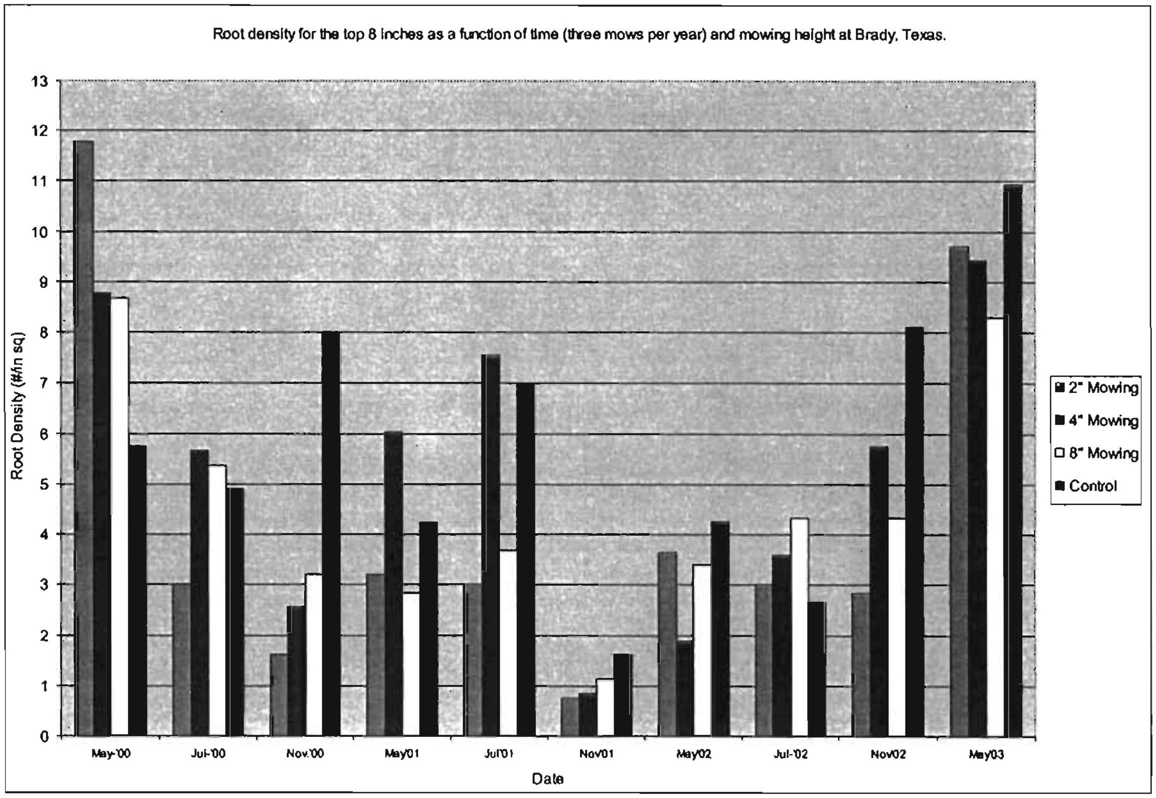

Figure 15. Root density at Brady, Texas for the three mows per year treatment.

Lufkin

The third location to be discussed will be the Lufkin site. The Lufkin plots were located approximately 6 miles west of the city on Texas Highway 94. The GPS coordinates were N31° 17.574' and W94° 52.014'. This site was located in the east Texas piney woods (Figure 9) and is the location that receives the greatest amount of precipitation, 41 inches. The dominant grass type in the plots at Lufkin is bahia grass (*Paspalum notatum*). Root density data for the 0 to 8 inch depth are presented in Figures 16, 17 and 18.

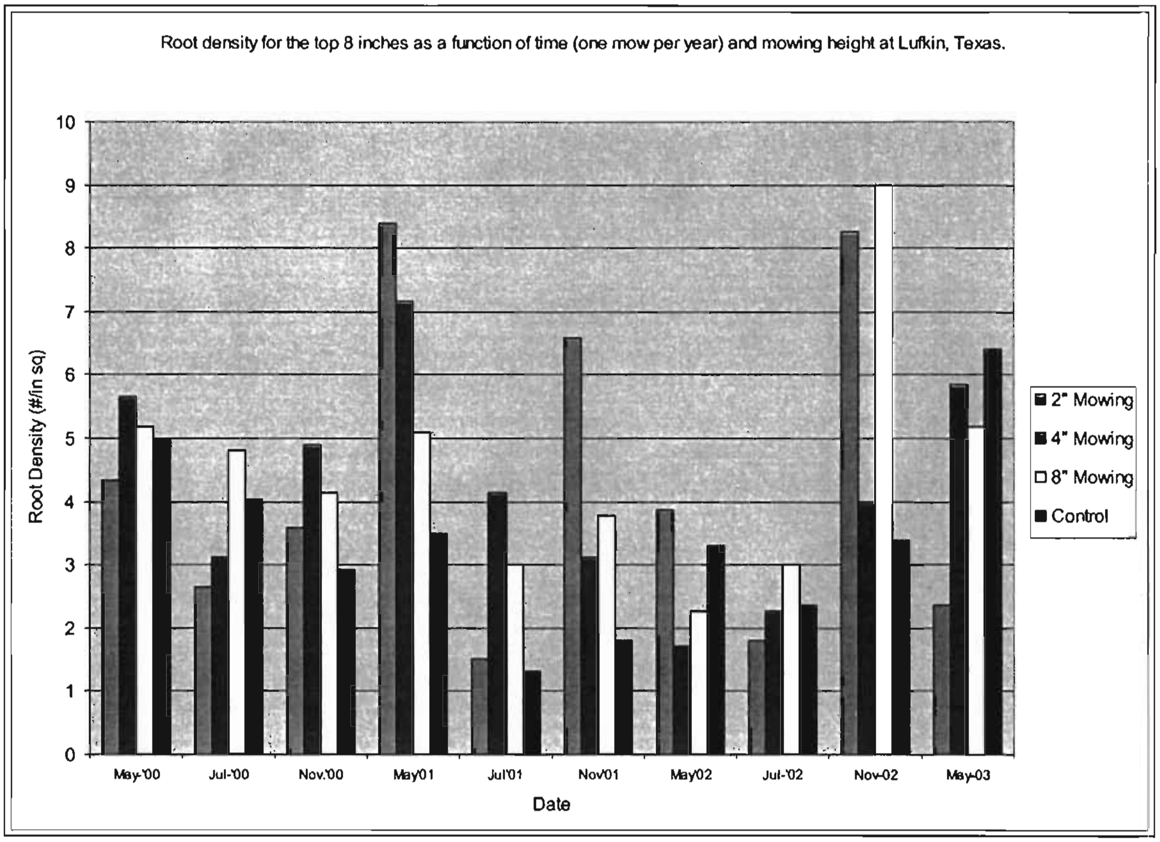

Figure 16. Root density at Lufkin, Texas for the one mow per year treatment.

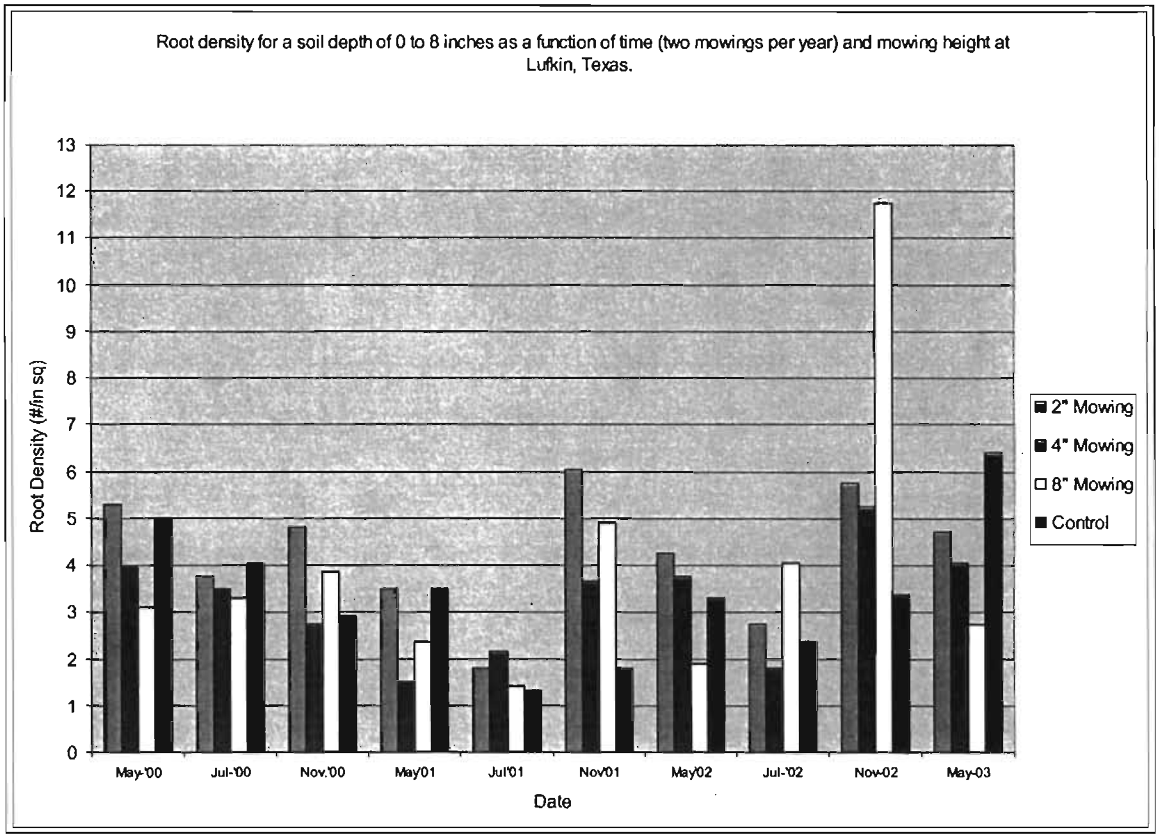

Figure 17. Root density at Lufkin, Texas for the two mows per year treatment.

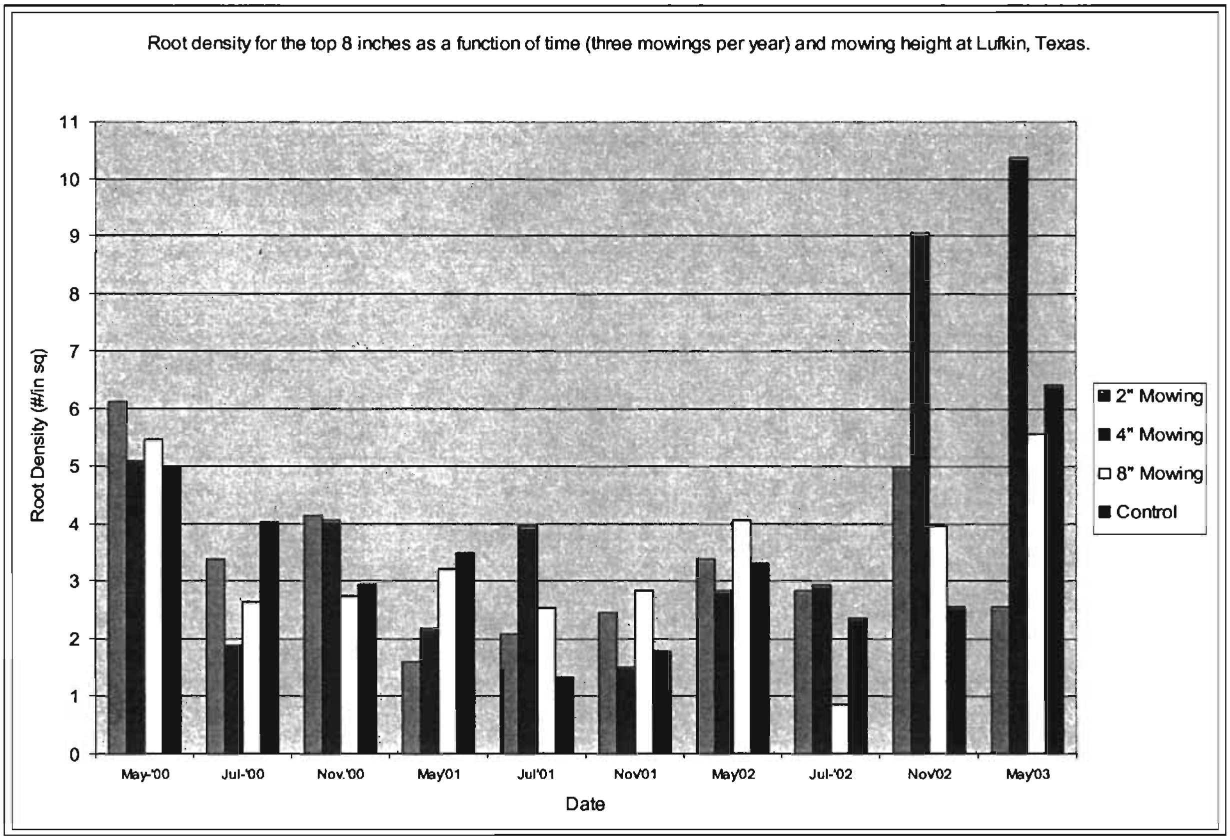

Figure 18. Root density at Lufkin, Texas for the three mows per year treatment

Tahoka

The final plots to be discussed in this report will be those located near Tahoka, Texas (Fig 9). The Tahoka plots are located 11.4 miles west of the city on 380. The GPS coordinates were N33° 10.01' and W101° 54.683'. The vegetation that dominates these plots was mostly silver bluestem (*Bothriochloa saccharoides*) with infrequent amounts of sideoats grama (*Bouteloua curtipendula*) and blue grama (*Bouteloua gracilis*). This site was located in semiarid, Southern High Plains region of Texas. This site has an average annual precipitation of 19 inches, which was between the locations of Andrews and Brady's annual precipitation amounts. Root density data as influenced by depth were evaluated with the imposed treatments of mowing height, frequency of mow and their interaction. The root density data for the 0 to 8 inch depth are presented in Figures 19, 20, and 21.

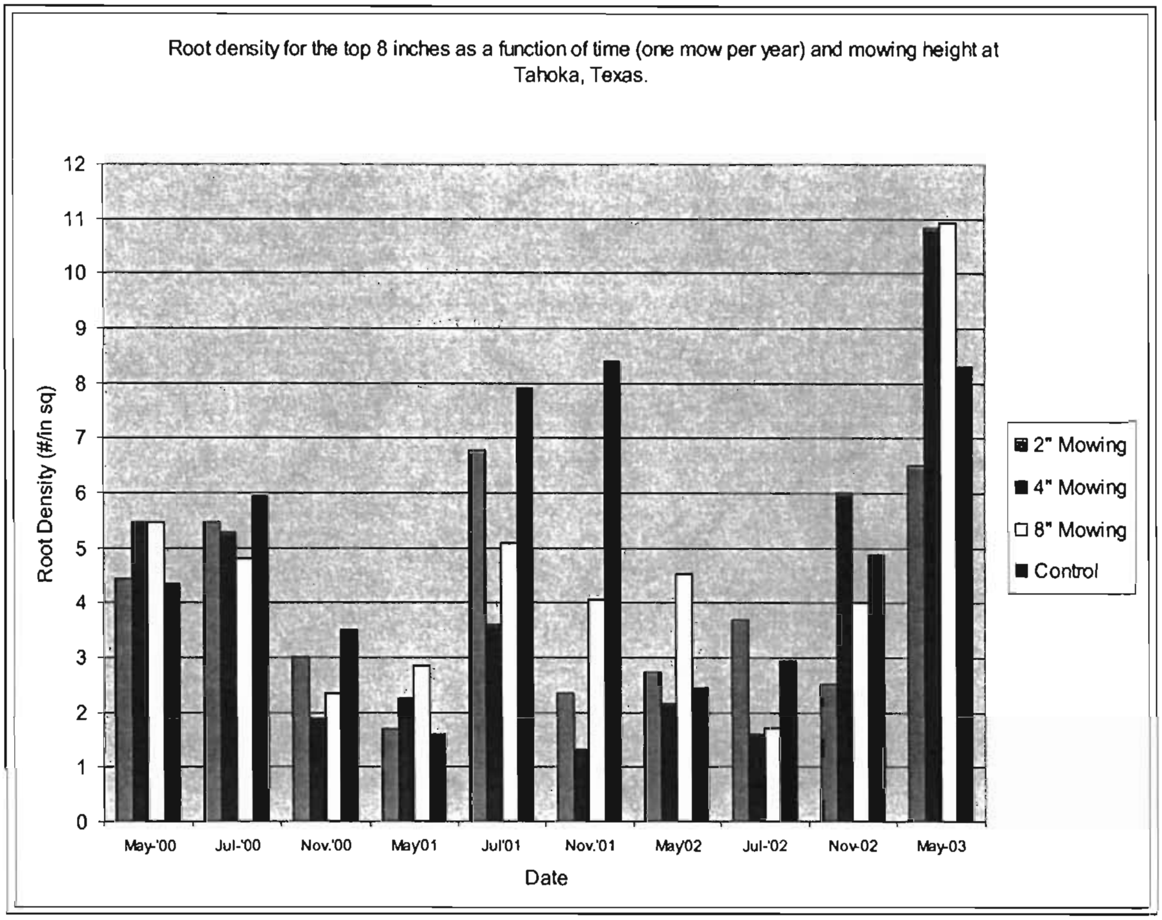

Figure 19. Root density at Tahoka, Texas for the one time per year treatment.

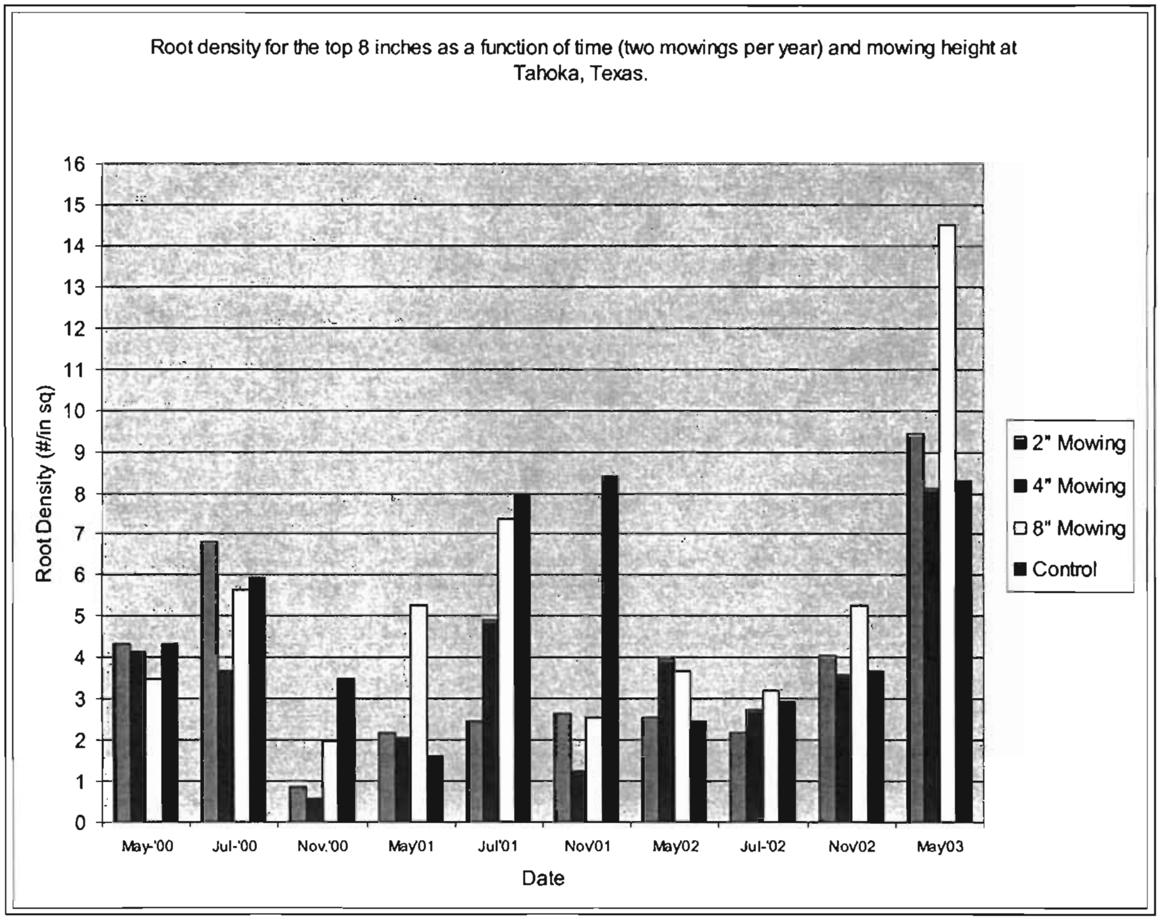

Figure 20. Root density at Tahoka, Texas for the two mows per year treatment.

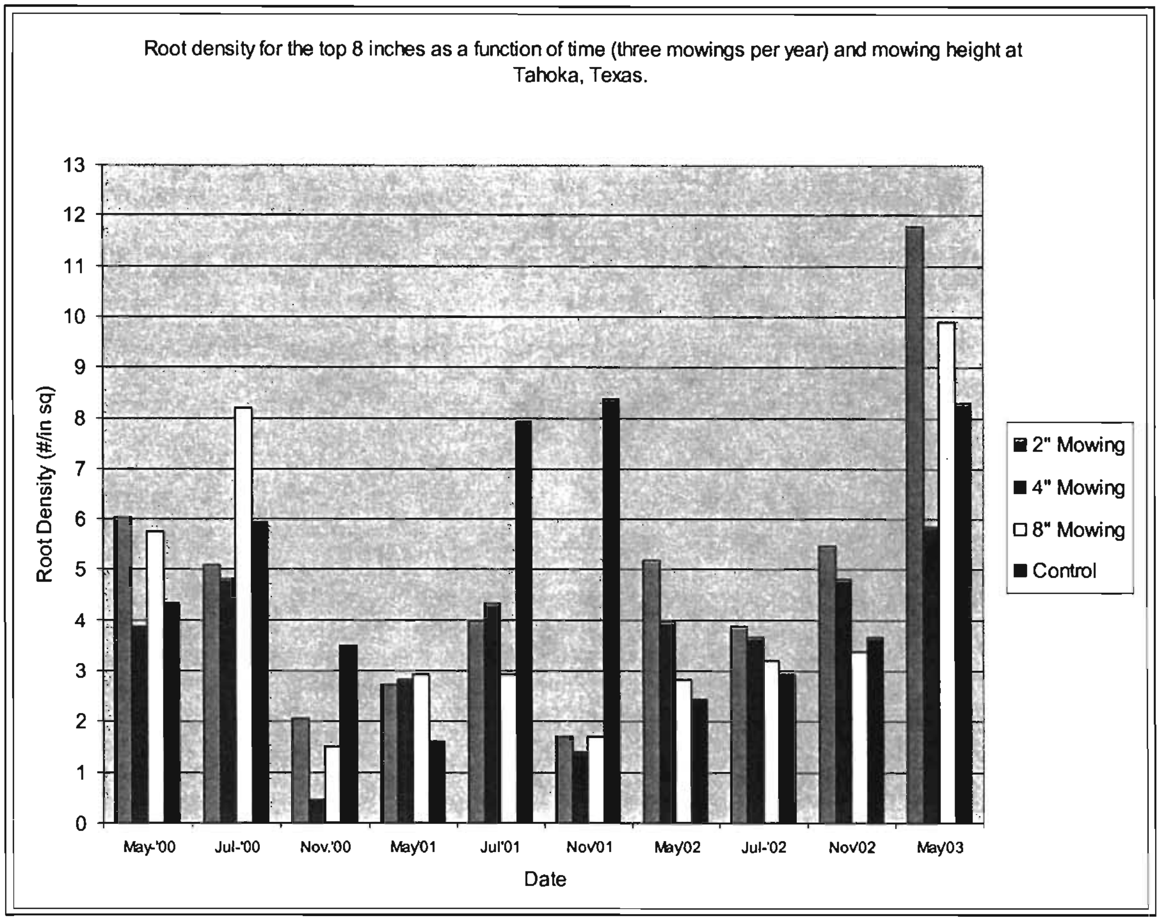

Figure 21. Root density at Tahoka, Texas for the three mows per year treatment.

Summary

Different mowing heights and frequency combinations of mow were compared using root density as a function of depth results at four right-of-way locations in Texas. These research sites were located along right-of-ways near the towns of Andrews, Brady, Lufkin, and Tahoka. Locations were chosen to represent the different climatic and environmental regions in Texas. There were 40 plots with randomized treatments and controls replicated four times at each location. A sample was collected in each plot, at each site and roots were examined and counted at 8, 16, 24 inch and greater than 24-inch depths.

One treatment of this study included mowing height of 2, 4, and 8 inches and controls. The second treatment was frequency of mow that included mowing certain plots zero, one, two, and three times annually. The control plots (zero mowing frequency) were never mowed and served as control plots. Root density results from the applied mowing height and frequency combination treatments were collected from each location and evaluated statistically.

The first difference noticed in the statistical analysis was that each year was significantly different and therefore, each year's root density data were evaluated separately. Furthermore, combined soil depths were significant by location besides for data at the Andrews location during 2000. The 8-inch and 16-inch depths had the highest root density numbers of the soil depths. In general, grasslands have shallow rooting profiles in which 60 to 70% of the roots are located in the upper 30 cm (12 inches) of soil (Jackson et al., 1996. Oecologia. 108:389-411. Results of the means of the root density data for all the locations combined (and all depths combined) indicated that Brady was similar in value to Lufkin and Tahoka.

It was noticeable visually that the Andrews site had detrimental effects to the area vegetation when mowing frequency was increased (three times annually) and the mowing height was low (2-inch mowing height). The Andrews site showed the greatest decrease in root density numbers from 2000 to 2001. Overall, Andrews had the greatest root density numbers of all the research plots.

Recommendations

From the root density data collected and through other collaborative studies within this research study, recommendations can be made. Based on the diverse vegetation community, climatic changes, and other environmental differences between the year 1999 and 2003, a concise mowing management plan was difficult to develop. Precipitation is very important to the growth of shoot and root growth. The precipitation data for years were not the same, and therefore, making specific mowing practices for each research location unrealistic. Mowing height and frequency of mow recommendations for Texas rights-of-way, therefore, should be based on the annual rainfall and type of vegetation growth at each site.

MOWING SPEED AND ROOSTER TAILS

Introduction

A great deal of effort and money is used to mow the vegetation in highway rights-of-way. Vegetation is desirable as it helps to control soil erosion, acts as a vegetative filter strip for treating storm water runoff, improves recharge of groundwater, stabilizes dust, reduces noise and glare, and provides a safe shoulder for vehicle operation (Beard and Green, 1994). In addition, there are aesthetic benefits of vegetation management including the creation of aesthetic vistas using low maintenance natives that provide color (Langvad, 1969; Nelson, 1978). These aesthetic vistas are also considered to be a safety factor for drivers by reducing fatigue of monotonous views and providing safe sight lines (Integrated Roadside Vegetation Management Program Task Force, 1997; Nelson, 1978).

Generally, the vegetation is mowed to maintain sight distance requirements, maintain clear zones, prevent trees and brush from encroaching, minimize weather effects such as drifting of snow, reduce fire hazards, and maximize aesthetic impact. While safety considerations are paramount, aesthetics often dictate many current practices especially the maintenance of wildflowers that often determine the timing of the first mow. The uniformity of cut is also a vegetation management issue especially where rough terrain or compression by tractor tires result in skips or irregular mowing heights. The objective of this section of this paper is to report on a series of experiments designed to measure the number of pop-ups or rooster tails (vegetation that is not cut at the desired height after a 24-hour plant rehydration period) for different forward speeds and height settings of the mower.

Pop-ups make a mowed area look rough and esthetically unappealing. Seldom is this mowing quality issue a safety concern. When such poorly mowed areas are identified, agencies may ask the contractor to re-mow the areas. This increases the cost to the contractors and ultimately the agencies because contractors will factor into their bid prices the cost of re-mowing these areas.

Excessive pop-ups appear to be caused by several factors including roughness of terrain, forward speed of the mower, compression of the vegetation by the tractor tires, condition of the cutting blade, vegetation type and density, grade of the slope being mowed, and the desired cutting height. Factors such as the type of vegetation and terrain cannot be changed; however, contractors do have control over the forward speed, the condition of the mower blades, and to some degree the mowing height setting on their mowers.

Methods

A series of experiments was conducted at two locations in Central Texas—approximately 15 miles north of Brady on highways FM-1028 and FM-502 and approximately 10 miles north of Waco on FM-933. One trial or experiment was performed at Brady in June 2000 and 2 trials were performed at Waco in June 2001 at distinctively different locations. Each trial consisted of 45 plots with 3 speeds (2, 4, and 6 mph), 3 set heights (4, 6, and 8 inches), and 5 replications in a completely randomized design. The plots were one width of the mower (15 ft) and 100 feet in length. The actual width of cut was 13.5 to 14 ft because the drivers overlapped the shoulders by 1 ft to 1.5 ft. Sampling was conducted in the middle 25 feet (length) by 1-width of each plot.

For each trial, a contractor for TxDOT was used to mow the plots. Each operator had several years of experience and used a Ford 6610 tractor with a 15-ft bat-wing mower. At Brady, a Bush Hog 2615 mower was used while at Waco a Bush Hog 3615 mower was utilized. Figure 22 illustrates the relatively uniform right-of-way at Brady and Figure 23 illustrates the less uniform characteristics of the right-of-way at Waco.

Figure 22. Mowing a Smooth Side Slope at Brady, Texas

Figure 23. Right-of-Way at Waco

The mowing height for each of the three trials was set in the field by measuring the verdure (remaining aboveground plant tissue after mowing). Three mowing heights (4, 6, and 8 inches) were included in the study reflecting the precision available using Bush Hog mowers settings. The areas selected for the calibrations were relatively smooth. Blocks on the control piston were used to reset the mowers at different heights as they moved from plot to plot. Mower speed was measured using tire revolutions on pavement. Because the side-slopes of the highways were stable and hard, it was assumed that there was very little speed change due to tire slip. Each operator used the same gear and revolution per minute (rpm) to set the tractor speed between the various plots. The power take off (pto) from the tractor was operating at the rpm recommended for the mowers. According to the Bush Hog Manufacturing Company, the blade tip speed should average 15,268 fpm (feet per minute) at a pto speed of 540 rpm's.

Pop-up counts and actual cutting heights were measured the next day approximately 20 to 24 hours following mowing. This allowed for the plants to rehydrate from the evaporative demand of the day and resulted in some plants becoming erect. A pop-up was considered to be any plant that was cut 2 to 3 inches or more above the average cut height. Strips (several pop-ups in a row) were noted although they are not reported on in this paper. To maintain uniformity, the same person was used to count all the pop-ups for all trials. The average height of the verdure was measured in three locations: at the top of the side slope adjacent to the shoulder, in the middle of the swath (generally the middle of the side slope), and at the bottom of the swath (generally at or near the drainage ditch). The three measurements were averaged to determine the mean height of cut for the plots.

Sites for the trials were purposely selected to have a significant amount of Johnsongrass (*Sorghum halepense*) as we assumed at the outset of the experiment that the coarse-textured Johnsongrass would create more pop-ups than a finer textured grass. Percent ground cover of Johnsongrass was visually estimated for each plot and ranged from plots predominately composed of Johnsongrass to plots that were nearly void of the species.

Results and Analyses

The average number of pop-ups for the three different trials and for the nine combinations of speed and height are presented in Table 7. A cursory review shows that the least number of pop-ups for each trial occurs for the 4-inch cutting height with the lowest number of pop-ups occurring for a 2-mph speed and a 4-inch cutting height treatment (2/4). The highest number of pop-ups occurs for the highest speed and highest cut (6 mph and 8 inches or 6/8). It is interesting to note that at two commonly recommended speeds and cutting heights (4/6 and the 4/8) the number or pop-ups are relatively high. To gain greater insight into the results, an analysis of variance (ANOVA) was conducted on the data.

The experiment as conducted had the complexity of three forward mowing speeds, three mowing heights, five replications, and three locations. To extract the relevant information, an ANOVA was used to evaluate the variance between the three groups. The speed was considered the primary group, the height was the subgroup, and the locations were considered the subsubgroup. The statistical analysis was made according to the procedures of Sokal and Rohlf (1969). This analysis determined the location accounted for 52 percent of the variation while the height accounted for 42 percent of the variation. Tractor speed contributed 6 percent of the total variation. The large amount of variation between repetitions was expected given the diverse nature of the three locations. However, this showed that the terrain was a major factor in variation of the number of pop-ups one can expect. The relationship between speed and height appears significant as was identified in the cursory examination of the data.

Table 7. Average Number of Pop-ups for Given Speed/Height Treatments

Speed/Height (mph/inches)	**Pop-ups**			
	Brady	**Waco No.1**	**Waco No. 2**	**Average**
2/4	16.6	38.2	23.0	25.9
2/6	23.0	78.6	88.4	63.3
2/8	22.6	105.2	70.4	66.1
4/4	19.8	45.6	64.6	43.3
4/6	27.2	88.0	75.8	63.7
4/8	37.2	93.2	91.8	74.1
6/4	24.6	53.0	65.0	47.5
6/6	58.4	95.6	97.6	83.9
6/8	59.8	146.8	73.8	93.5

In the evaluation of treatment means from the combined trials, Duncan's multiple range test (DMRT) was used to determine significant differences at the 5 percent level. This test showed that the 6 mph with 8-inch treatment (6/8)and the 2/4 treatments were significant different from the other treatments. Mean separation using the least significant difference test (LSD) showed the 6/8 and the 6/6 treatments were significantly different from all other treatments. While these results are not as strong as expected originally, one must consider that more than half of the variation in this experiment was caused by the location or terrain differences used for the experiment.

The trial at Brady is important to evaluate because the terrain was relatively smooth with a 6:1 side slope and a smooth transition from the shoulder to the side slope (see Figure 22). A cursory examination of Table 8 shows there were increases in the number of pop-ups with the increase in mowing height within a given speed and an increase in pop-ups with the increase in speed for a mowing height. From the ANOVA for the Brady trial, there were significant differences for the 6/8, 6/6, 4/8, and the 4/2 treatments using DMRT. The same significant differences were shown using the LSD test with the 2/4 treatment as the control treatment. One conclusion that can be reached is that reducing forward speed when a coarse textured, thick-stemmed grass like Johnsongrass is encountered can lessen the number of pop-ups. As shown in Table 9, there was not a meaningful difference in Johnsongrass ground cover between treatments and this is not the cause of variation in pop-ups. The authors noted that the stems of Johnsongrass had a visual impact close to 10 times that of fine-stemmed grasses. Johnsongrass is also one of the taller grasses that re-grows quickly making its visual impact even more dramatic (see Figure 24).

The actual height of the verdure did exhibit a trend of increasing in height as the speed of the mower increased. The grass stems evidently are bent over increasingly as

Table 8. Pop-up Trial at Brady, Texas

Speed/Height (mph/inches)	Mean Number of Pop-ups[1] No. per approx. 340 ft^2	Difference for Control[2]	DMRT[3]
2/4	16.6	-	d
2/6	23.0	6.4^{ns}	cd
2/8	22.6	6.0^{ns}	cd
4/4	19.8	3.2^{ns}	cd
4/6	27.2	10.6^{ns}	cd
4/8	37.2	20.6*	c
6/4	24.6	8.0^{ns}	cd
6/6	58.4	41.8**	ab
6/8	59.8	43.2**	a

[1] Average of 5 replications.

[2] The 2-mph - 4 inches is the control for this test.

[3] Any two treatments (speed/height) having a common letter are not significantly different at the 5% level of significance (Ducan's multiple range test).

** = significant at 1% level (LSD).

* = significant at 5% level (LSD).

^{ns} = not significant

the speed of the mower increases. This has been observed many times in the past and appears to remain true today as well.

Results for the two trials at Waco are shown in Tables 10 and 11. There was a discrete step in elevation caused by re-paving the road surface that was between 4 to 12 inches thick. This, in the opinion of the authors, caused increased variability in the number of pop-ups as it impacted how level the mowing equipment could be pulled across the plot.

Figure 24. Pop-ups of Johnsongrass

Even with this increased variability, the 6/8 and the 2/4 treatments were significantly different from the other treatments. The site was visited approximately three weeks following the experiment and the Johnsongrass had grown several inches above the rest of the vegetation creating a much greater visual impact than the other species (see Figure 25).

Figure 25. Regrowth of Johnson Grass after three weeks.

Table 9. Ground Cover of Johnsongrass and Height of Verdure

Speed/Height	Ground Cover (%)			Height of Verdure (in.)		
(mph/inches)	Brady	Waco 1	Waco 2	Brady	Waco 1	Waco 2
2/4	54[a]	41	42	4.7[b]	5.0	4.7
2/6	34	57	32	6.1	6.6	6.5
2/8	66	46	46	8.9	8.4	8.7
4/4	53	59	33	5.1	5.1	5.8
4/6	54	50	36	7.3	7.3	6.9
4/8	55	49	39	8.9	8.8	8.6
6/4	58	48	37	4.7	5.7	6.2
6/6	52	43	40	6.9	7.3	7.7
6/8	55	40	37	9.8	10.0	9.0

[a] Average of 5 replications.

[b] Average of 3 measurements per plot and 5 replications.

The mower used at Waco had blades that were used for several days prior. There were noticeable notches on the blades from encounters with rocks or similar objects and the blades were worn ¼ to ½ inch. The operator stated that the blades were still good and would be allowed to wear back approximately ½ inch before replacing them. Tuck et al. (1991) from a simple comparison observed a dull blade might only operate at 50-60 percent efficiently while a well-maintained blade (relatively new and sharpened) might operate around 90 percent efficiently. This could be part of the reason why there were more observed pop-ups at Waco than at Brady.

Table 10. Pop-up Trial No. 1 at Waco, Texas

Speed/Height (mph/inches)	**Mean Number of Pop-ups[1] No. per approx. 34 ft^2**	**Difference for Control[2]**	**DMRT[3]**
2/4	38.2	-	d
2/6	78.6	40.4^{ns}	bcd
2/8	105.2	67.0**	ab
4/4	45.6	7.4^{ns}	cd
4/6	88.0	49.8*	bcd
4/8	93.2	55.0*	abc
6/4	53.0	14.8^{ns}	bcd
6/6	95.6	57.4*	abc
6/8	146.8	108.6**	a

[1] Average of 5 replications.

[2] The 2-mph - 4 inches is the control for this test.

[3] Any two treatments (speed/height) having a common letter are not significantly different at the 5% level of significance (Ducan's multiple range test).

** = significant at 1% level (LSD).

* = significant at 5% level (LSD).

^{ns} = not significant

Table 11. Pop-up Trial No. 2 at Waco, Texas

Speed/Height (mph/inches)	**Mean Number of Pop-ups[1] No. per approx. 340 ft^2**	**Difference for Control[2]**	**DMRT[3]**
2/4	23.0	-	g
2/6	88.4	65.4**	abc
2/8	70.4	47.4*	abcdef
4/4	64.6	41.6^{ns}	abcdefg
4/6	75.8	52.8*	abcd
4/8	91.8	68.8**	ab
6/4	65.0	42.0^{ns}	abcdefg
6/6	97.6	74.6**	a
6/8	73.8	50.8*	abcdef

[1] Average of 5 replications.

[2] The 2-mph - 4 inches is the control for this test.

[3] Any two treatments (speed/height) having a common letter are not significantly different at the 5% level of significance (Ducan's multiple range test).

** = significant at 1% level (LSD).

* = significant at 5% level (LSD).

^{ns} = not significant

Conclusions

The quality of roadside mowing is impacted by several factors. Mowing height, forward tractor speed, vegetation composition, and terrain all play an important role in determining mowing quality. First, there is a significant interaction between the tractor speed and the height setting on the number of pop-ups. The number of pop-ups becomes greater when increasing both cutting height and the speed of the mower. If pop-ups are considered to contribute to the reduction in the aesthetics of a mowed area, then it would be desirable to decrease both the forward tractor speed and cutting height. The forward speed is a factor that is controlled by the operator and certainly has a great impact on the cost of mowing given the added cost of re-mowing an area that looks "rough" because of the number of pop-ups. When conducting the experiment, the authors could visually identify the 4/8 treatments by their "rough" appearance without referring to the plot plan.

Operators cannot further reduce the cutting height as mowing height impacts the type of vegetation that will dominate in the right-of-way. The current TxDOT recommendation is a cutting height of 7 inches, although there are variations from county to county. Observations made by the authors found that consistent mowing at a two-inch height will cause the dominance of short grass species such as Bermudagrass (Cynodon dactylon). Bermudagrass is more damaging to the pavement than the taller species of grass such as K. R. bluestem (Bothriochloa ischaemum) or Bahiagrass (Paspalum notatum). These observations were supported by the discussions held with several vegetation managers for TxDOT.

The observation that Johnsongrass has 10 times the visual impact (due to the coarse leaf blades and thick stems) as compared to thin-stemmed grasses which makes the presence of this grass a mowing consideration. The results of this study indicate that operators should slow to near 2 mph when mowing Johnsongrass or any other tall, coarse species. The slower speed would limit the occurrence of pop-ups and reduce the likely hood of needing to re-mow an area. This practice is at least partially adopted and was confirmed by the contractor at Waco who stated that he instructs his operators to reduce the mower speed when mowing dense stands of Johnsongrass.

In summary, a forward speed of approximately 4-5 mph is the suggested optimum with pull behind rotary mowers to ensure sufficient cuts with minimal pop-ups (McCormick, 1999). Based on the results of this experiment, a speed of 4 mph and set cutting height of 6 inches would be recommended. The actual height of cutting would be 7 inches according to the results shown in Table 9. This would meet the recommendations made by TxDOT and would have a minimal number of pop-ups according to the results shown in Table 1. Having an unworn edge on the mowing blade also improves the appearance of the mowing job. Vegetation composition and terrain also contribute to the overall mowing quality rating; however, these two factors are outside of the control of the contractor.

THE AFFECT OF VEGETATION HEIGHT IN RIGHT-OF-WAYS ON SNOW DRIFTING

Introduction

The primary purpose of vegetation on the side-slopes of highways and in the right-of-ways is to control soil erosion and for the stability of the side-slopes (Hunt and Deschamps, 1995). Vegetation, however, can act as a wind barrier and can create drifting on the lee side of the barrier. Vegetation is commonly used as a wind barrier (Black et al., 1971). When vegetation acts as a wind barrier in the right-of-way of a highway, it can create a snowdrift that extends on to the driving lanes creating a hazardous condition. The height of the vegetation after the final mowing is the height of the vegetative barrier that will create a snowdrift during a wind-snow event.

The mowing height is related to the type of vegetation (primarily grass) desired to be maintained in the right-of-way. If the vegetation is cut relatively high (7 to 9 inches), the medium and tall grasses have an opportunity to establish and be part of the plant community in the right-of-way. If the vegetation is mowed short (~2 inches), short grasses will predominated and the medium and tall grasses will tend to disappear from the plant community. Thus, the decision of the Vegetation Manager on the height of mowing will dictate both the type of vegetation that will predominate in the right-of-way and the height of the vegetative wind barrier that will exist during the winter snow season.

Provided below is the relationship between barrier height and porosity with respect to snowdrifts on the lee side of the wind barrier. The understanding of wind barriers and drifting have progressed allowing for reasonable predictions of snowdrifts caused by both vegetative and man-made wind barriers.

Height and Porosity of Wind Barriers

Wind barriers are important for controlling both the movement of snow and the movement of soil (Greb, 1980; Skidmore and Hagen, 1977). Vegetative wind barriers have been recognized as being effective for reducing soil erosion and trapping water in the drifts that develop on the lee side of the barriers (Black et al., 1971). The main factors affecting the size and shape of the lee side drifts are the height and porosity of the barrier.

Borrelli et al. (1989) developed a mathematical relationship between the height, length of protection, and porosity for wind barriers. While the Borrelli et al. (1989) were concerned with soil erosion, the relationships can be applied the development of snow drifts behind a wind barrier. According to Greeley and Iversen (1985) the behavior of wind-blown dry snow is the same as sand. Greeley and Iversen (1985) stated that the average diameter of drifting dry-snow is 0.15 to 0.20 mm or with in the particle size range of dune sand.

A wind barrier causes a loss of momentum in the air stream. Because air at atmospheric pressure is essentially an incompressible fluid, a loss of momentum implies a reduction in wind speed. The reduction of wind speed causes the snow to deposit and form a drift. The greatest reduction in wind speed occurs approximately 6 barrier heights (6H) downwind from the barrier (Tabler, 1980). The wind profile is essentially reestablished to ambient conditions at approximately 26 times the height of the barrier downwind from the barrier.

Tabler (1980) developed an equation that predicted the length and height of drift for saturation conditions—the largest drift possible for the given porosity and height of the wind barrier. The equation developed by Tabler (1980) is

$$\frac{y}{H} = 0.13 + 0.402\frac{x}{H} - 0.0602\left(\frac{x}{H}\right)^2 + 0.003691\left(\frac{x}{H}\right)^3 - 1.0854\times10^{-4}\left(\frac{x}{H}\right)^4 + 1.2498\times10^{-6}\left(\frac{x}{H}\right)^5 \qquad \frac{x}{H} < 26.6 \tag{1}$$

where H = height of wind barrier (ft)
y = depth of snow (ft)
x = length of snow lee drift (ft)

Borrelli et al. (1989) developed a formula that predicted the leeward wind velocity downwind from the wind barrier. The formula developed by Borrelli et al. (1989) is

$$\frac{U_L}{U_o} = 1 - Ae^{-0.0876\frac{x}{H}} \tag{2}$$

where U_L = the leeward wind velocity at a height of 0.5H for location L (ft/sec)
U_o = the upstream wind velocity at a height of 0.5H (ft/sec)
H = height of the barrier (ft)
x = the distance downstream from the barrier (ft).

The coefficient A is a function of porosity of the wind barrier. The equation for A is

$$A = 1.217 - 4.81\times10^{-3}P - 7.39\times10^{-5}P^2 \tag{3}$$

where A = the coefficient A in equation (2)
P = porosity of barrier in percent.

The formula developed by Tabler (1980), equation (1), gives essentially the same length of drift as the formula developed by Borrelli et al. (1989), equation (2), but in slightly different form. The two equations produce the same length of drift for conditions where the wind downwind of the barrier is 90 to 95 percent of the ambient wind speed or the wind speed on the windward side of the wind barrier. As the wind speed approaches ambient wind speed (approximately 90 to 95 percent of ambient), the wind can now transport the snow and deposition ceases.

Equation (1) is for a wind barrier with 50 percent porosity, for a vertical-slat fence, and for the drift at saturation conditions (maximum drift size). This information can be used to determine the wind speed reduction existing at the terminal end of the snowdrift. Using this information the ratio of U_L/U_o is 0.92 for x/H of 26.5. Tabler (1980) states that for the wind speeds encountered in nature, the drift shapes are independent of the wind speed. This is fortuitous because wind speed does not need to be factored into the equations to predict the length and depth for the maximum drift that can develop downwind from a wind barrier.

If we assume that the drift will not develop for a ratio of U_L/U_o greater than 0.92, then equation (2) can be used to estimate the length of a drift for wind barriers of different heights and different porosities. This assumption can be justified because sand and snow being transported by wind are essentially the same size and develop the same drift patterns (Greeley and Iversen, 1985; Pugh and Price, 1954). Furthermore, the length of the lee side drift is independent of wind speed for wind speeds of concern (Tabler, 1980; Woodruff and Zingg, 1952).

Porosity of Vegetative Barriers

Raine and Stevenson (1977) used vertical slats to make wind barriers of different barriers. Raine and Stevenson (1977) tested the wind barriers in the field and in a wind tunnel. The wind approached the barriers at right angles. Other researchers have used vegetative strips and have measured the porosity of the barriers. Hagen and Skidmore (1971) determined the average porosity for pampagrass to be 73 percent, a single row of sudangrass 49 percent, a double row of sudangrass 34 percent, a single row of grain sorghum 60 percent, a double row of grain sorghum 55 percent, and forage sorghum 58 percent. These plants are relatively tall and are large stemmed plants. Based on drag coefficients, Hagen and Skidmore (1971) stated that narrow plant windbreaks have relatively uniform porosity and drag coefficients similar to vertical-slat fences. One could conclude that a row of Johnsongrass skipped by a mower would be similar to forage sorghum. Furthermore, Moysey and McPherson (1966) stated that the shape of a barrier has less effect on leeward velocities than barrier porosity. While Johnsongrass may not have the same profile as sorghum, it should produce similar drifts providing the porosities are the same.

Black and Siddoway (1971) used tall wheatgrass barriers to trap snow in agricultural fields. The wheatgrass was planted in double rows with an estimated porosity of 40 percent. The effective height, H, was approximately 2.5 feet. The snow drift (if assumed to be maximum or at saturation) was 25H giving a U_L/U_o of 0.9 according to equation (2). Wheatgrass has relatively small stems and leaves in comparison to sorghum or sudangrass and is similar in structure to most grasses predominating in the right-of-ways of Texas highways. A double row of grass is probably very similar to the grass immediately adjacent to the shoulders of a highway. Thus, the wind barrier created by grass immediately adjacent to a shoulder would not have a porosity any greater than 40 percent for grass cut uniformly in height.

Simulation of Vegetative Wind Barriers Adjacent to Shoulder

Presented in Figure 1 are the length of drifts for various height of barriers and barrier porosity. The height of barrier is the most important factor in determining the length of drift for porosities between 0 and 50 percent. For porosities greater than 50 percent, both the height of barrier and the barrier porosity are important factors.

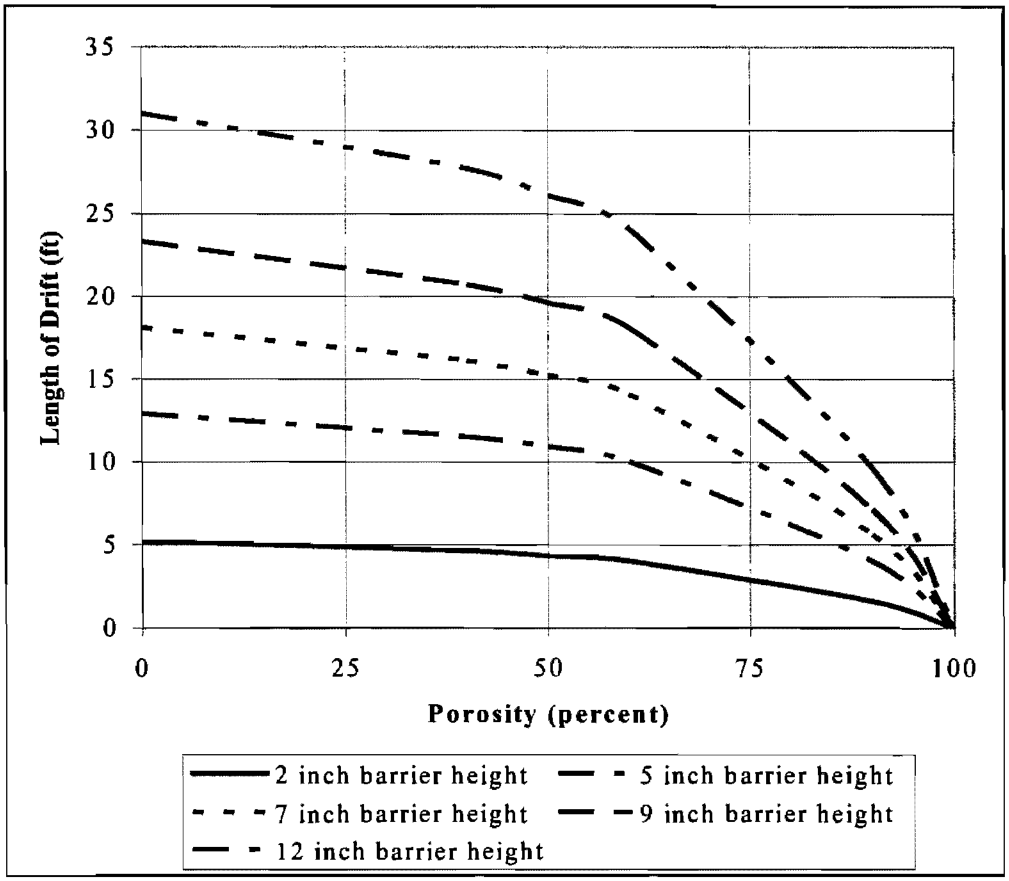

Figure 26. Length of Drifts

For a good stand of vegetation adjacent to the shoulder of a highway, the porosity can be assumed to be 0 percent. This would be especially true for short vegetation (< 5 inches). For taller vegetation, there is significant porosity in the upper portion of the canopy and the overall porosity is probably near the values reported by Hagen and Skidmore (1971) for double rows of sudan grass or between 20 and 40 percent.

If rooster tails exist adjacent to the shoulder, the porosities would be similar to those reported by Hagen and Skidmore (1971) for single and double rows of sorghum and pampagrass. For a rooster tail that is 12 inches in height and with an assumed porosity of 75 percent, a drift of approximately 18 feet could result for a significant snow-wind event. This would potentially create a drift that could encroach onto the driving lanes.

Given equations (1) and (2) and a reasonable estimate of the porosity of the vegetation, one can estimate the length of the potential drift. The length of the drift provides an assessment of the hazard that could result from selecting the mowing height adjacent to the shoulder of the road. It also provides a measure of the risk created by rooster tails adjacent to the roads. This assumes that the highways are designed such that the wind clears the snow from the driving surface as recommended by Pugh and Price (1954).

The mowing height of the grass in the right-of-way more than 30 feet from the driving lanes will not add to the risk of drifting. Any drifts created by the vegetation would not reach into the driving lanes. One should be cognizant that if the vegetation is 7 inches in height, it would require a snow fall of greater than 7 inches or an accumulation of more than 7 inches before there would be any drifting potential.

Summary

Between the literature for wind breaks for wind erosion of soil and for wind breaks to control the drifting of snow, there is substantial knowledge concerning the effectiveness of vegetative wind breaks to control drifting of snow (Borrelli et al., 1989; Hagan and Skidmore, 1971; and Tabler, 1980). The most important parameter needed for vegetative windbreaks is the porosity of the vegetation. Black et al. (1971), Hagen and Skidmore (1971), Moysy and McPherson (1966), and Raine and Stevenson (1977) all reported porosities for vegetation including single-row and double-row strips of vegetation. The equation developed by Tabler (1980) and Borrelli et al. (1989) allow the prediction of the length of the potential drift and the depth of snow if needed. The body of knowledge appears scientifically sound and can be used for decision making without any great risk.

Roadside Maintenance Survey

A roadside maintenance survey was designed to help identify priorities and concerns that individuals may have with the care and maintenance of roadside vegetation. Questions addressed three main topics—safety, vegetation, and appearance. Out of the 61 people who answered the survey 68.9% are female, 81.9% are 40 years or older, 57.4% are from a two person household, 49.2% live more than 5 miles from town, 86.7% are Caucasian, and 54.9% have an income greater than $60,000.

Survey Questions About Safety

The following questions concerned safety related to vegetation in the rights-of-ways:

1. Roadside safety is more important than appearance of the vegetation.
2. Current vegetation management practices create a safety hazard for drivers.
3. Mowing to reduce the hazard of fire is the most important consideration.

Responses for the three survey questions regarding safety are displayed in Table 12. Most (67.2%) of the persons who responded to the survey feel roadside safety to be a greater concern than appearance. Answers to the second safety question indicate 70.5% either do not feel that current vegetation management practices are a safety hazard or are neutral. Mowing to decrease the hazard of fire is of primary concern for 64% of the survey respondents.

Table 12. Percentages of Frequency Distributions for Safety Questions Asked in the Roadside Maintenance Survey.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N
Roadside Safety More Important than Appearance	41.0%	26.2%	26.2%	6.6%	0.0%	61
Current Practices are Hazardous to Drivers	9.8%	19.7%	27.9%	24.6%	18.0%	61
Mowing to Prevent Fires is of Primary Consideration	41.0%	23.0%	26.2%	8.2%	1.6%	61

Mann-Whitney U (MWU) tests were performed to determine the influence of demographics on answers to survey questions. Demographics are not a factor for the first and third safety questions, $p \leq .05$. However, statistics show that gender and education influenced respondents answers to the second roadside survey safety question (Table 13). Though women as a group are split in their opinion, they are more than twice as likely to feel that current roadside vegetation management practices create a safety hazard to drivers when compared to men (Table 14). The majority of respondents with baccalaureate degrees and higher (65.6%)

disagreed that current vegetation management practices are hazardous, but those who have some college education and less (53.6%) feel that they are hazardous.

Table 13. Influence of demographic characteristics on the perception that current vegetation management practices create a safety hazard for drivers.

	Gender	Age	Location	Education	Income
N	61	61	61	60	51
MWU Statistic	253.5	450.0	420.0	185.5	238.5
Asymp. Sig.	0.020	0.824	0.505	0.000	0.104

Table 14. Influence of Gender and Education on whether current vegetation management practices create a safety hazard for drivers.

	Women	Men	some college or less	baccalaureate degree or higher
Agree	35.7%	15.8%	53.6%	9.4%
Neutral	31.0%	21.1%	32.1%	25.0%
Disagree	33.3%	63.2%	14.3%	65.6%

Survey Questions About Vegetation Management Practices

The following questions relate to the perceived management of vegetation on rights-of-way:

1. I am concerned about the impact vegetation management has on wildlife.
2. Current vegetation management practices show a wise use of limited financial resources.
3. I am pleased with how the roadside vegetation is managed in this area.

The results for the three above three questions are in Table 15. The impact of roadside vegetation management practices on wildlife is a concern to 55.7% of those who answered the survey. The second and third questions address the level of satisfaction for vegetation management practices. Those who agree or strongly agree that financial resources are being used wisely (47.5%) are nearly equal to those who are neutral (40.7%). A majority (60.7%) feel pleased with their local vegetation management practices.

Table 15. Percentages of Frequency Distributions for Safety Questions Asked in the Roadside Maintenance Survey

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	N
Financial Resources Are Used Wisely	13.6%	33.9%	40.7%	10.2%	1.7%	59
Are Pleased With Local Practices	24.6%	36.1%	29.5%	6.6%	3.3%	61
Importance of Impact on Wildlife	31.1%	24.6%	34.4%	4.9%	4.9%	61

Of the three vegetation management practice questions, only the third has a demographic influence as calculated by the MWU test (Table 16). Respondents with a baccalaureate degree and higher are more satisfied (75%) with their local roadside vegetation management than those with less education (43%) (Table 17).

Table 16. Influence of demographic characteristics on how pleased they are with local roadside vegetation management.

	Gender	Age	Location	Education	Income
N	61	61	61	60	51
MWU Statistic	344.5	407.0	409.0	279.0	260.0
Asymp. Sig.	0.374	0.632	0.398	0.009	0.220

Table 17. Influence of Education on satisfaction with local roadside vegetation management.

	some college or less	baccalaureate degree or higher
Agree	42.9%	75.0%
Neutral	39.3%	21.9%
Disagree	17.9%	3.1%

Survey Questions About Appearance

Four appearance issues were addressed in the roadside Maintenance survey.

1. The appearance of the roadside is very important to me.
2. Entrance corridors to our community should be maintained at the same maintenance level as the general roadside.
3. Occasional strips of grass that pop back up after mowing are acceptable
4. Mowing to maximize wildflower displays is desirable.

Table 18 summarizes these responses. A vast majority (85.3%) agree or strongly agree that roadside appearance is very important. Respondents for the most part (70.5%) agree that maintenance of entrance corridors should be kept at the same level as the general roadside. Occasional strips of grass that pop back up after mowing are not acceptable by very few (4.9%). A vast majority (86.7%) desire mowing practices that will maximize wild flower displays.

Table 18. Distributions for appearance questions from the Roadside Maintenance Survey (N=61).

Appearance	Importance of Appearance	Have Same Maintenance for Roadside and Entrance Corridors	Acceptability of Post-Mowing Popups	Mow To Maximize Wildflower Displays
Strongly Agree	65.6%	47.5%	31.1%	55.0%
Agree	19.7%	23.0%	39.3%	31.7%
Neutral	11.5%	19.7%	24.6%	6.7%
Disagree	0.0%	8.2%	1.6%	5.0%
Strongly Disagree	3.3%	1.6%	3.3%	1.7%

As illustrated in Tables 19 and 20, MWU tests show that there is no correlation between demographic data and answers to appearance questions 1 and 3. Questions 2 and 4 are significant for income and age, and education, respectively. A vast majority (75.0%) of those who earn less than $60,000 annually feel that entrance corridors should not be maintained at the same level as the general roadside (Table 21). Most respondents (60.7%) with an annual income greater than $60,000 agree that they should be maintained at the same level. Those over the age of 50 are more likely to agree (87.1%) that entrance corridors and the general roadside be maintained at the same level than those under the age of 50 (53.3%). Respondents who have a baccalaureate degree or higher are 22.8% more likely to want mowing practices that get the most out of wildflower displays.

Table 19. Influence of demographic characteristics on whether entrance corridors should have the same amount of care as the general roadside.

	Gender	Age	Location	Education	Income
N	61	61	61	60	51
MWU Statistic	312.5	266.0	399.5	409.5	226.0
Asymp. Sig.	0.149	0.002	0.312	0.542	0.053

Table 20. Influence of demographic characteristics the desirability of mowing to maximize wildflower displays.

	Gender	Age	Location	Education	Income
N	60	60	60	59	50
MWU Statistic	345.0	349.0	354.0	292.0	297.0
Asymp. Sig.	0.435	0.099	0.113	0.018	0.807

Table 21. Influence of yearly income and age on whether entrance corridors should be maintained at the same level as the general roadside

	Less than $60,000/yr	More than $60,000/yr	Younger than 50 yrs	Older than 50 years
Agree	75.0%	60.7%	53.3%	87.1%
Neutral	25.0%	21.4%	30.0%	9.7%
Disagree	0.0%	17.9%	16.7%	3.2%

Table 22. Influence of Education on desirability of mowing to maximize wildflower displays.

	some college or less	baccalaureate degree or higher
Agree	74.1%	96.9%
Neutral	11.1%	0.0%
Disagree	14.8%	3.1%

The data for this survey was taken from 61 respondents from various parts of Texas. Response rate for individual questions varied from a maximum of 61 to a minimum of 51. The low response rate came from the demographic question that asked for annual income. Demographics significantly influenced several of the questions as calculated by a MWU test.

RECOMMENDATIONS

Provided below are recommendations related to mowing height, fire hazard, mowing speed, and drifting of snow or sand across the highway.

Mowing Height

The general recommendation that a mowing height of approximately 7-inch height was supported by the results of this project. The following findings support this recommendation:

- Dominant short-grasses such as blue grama and buffalograss are relatively non-affected by mowing unless mowing results in very short stubble heights.

- For mid-seral and tall grasses, defoliation (not severe) does not cause severe injury to grasses if they are in the vegetative (short-shoot) stage. However, if they have shifted from the vegetative stage to the reproductive (long-shoot) stage, they can easily be damaged by, and ultimately killed by short mowing (<4 inches).

- For blue grama, mowing frequently and at shorter stubble heights is not recommended. The greatest amount of injury to blue grama can be caused from mowing frequently at <4 inch stubble heights and by mowing in late summer (mid-August) after reproduction is complete and tillers are being recruited. Therefore, for the health and vigor of blue grama (and other short-grasses), mowing at a stubble height of 4 inches, or more, one-time only at the end of the growing season in most desirable.

- As shown for silver bluestem, any stubble height <4 inches removes stem bases and basal crowns in which carbohydrates are stored or tiller recruitment and initiation of new growth in the spring or whatever time of year growth begins.

Fire Hazard

There are no mowing regimes that will absolutely prevent fires within the rights-of-ways. If fire hazard is a major concern, then the roadsides should be mowed (no less than 4-inch stubble heights for the health of the grasses) at the end of the growing season to reduce the fine fuel load to <1,000 lb/acre (the threshold for carrying a fire). Since fuel moistures are low enough (<13%) during the winter to ignite the grass (either short- or mid-grasses) from either smoldering cigarettes or an open flame, one's goal should be to keep the fine fuel below the amount that will carry a fire. Even though the amount of fine fuel exceeds 1000 lb/acre during the summer, the fuel moisture contents are usually high enough that fires are not as likely to be ignited, unless the area has had a period of hot, dry weather.

Mowing Speed

There is a significant interaction between the tractor speed and the height setting on the number of pop-ups or rooster tails. The number of pop-ups becomes greater when increasing both cutting height and the speed of the mower. A forward speed of approximately 4-5 mph is the suggested optimum with pull behind rotary mowers to ensure sufficient cuts with minimal pop-ups. Based on the results of this study, a speed of 4 mph and a set cutting height of 6 inches would be recommended. The actual height of cutting would be 7 inches according experimental data.

It was observed that Johnsongrass has 10 times the visual impact (due to the coarse leaf blade and thick stems) as compared to thin-stemmed grasses. The results of this study indicate that operators should slow to near 2 mph when mowing Johnsongrass or any other tall, coarse species. The slower speed would limit the occurrence of pop-ups and reduce the likely hood of needing to re-mow an area.

Snow and Sand Drifting

For most climates and locations in Texas, the recommendation of a 7 inch mowing height appears to be sound and one that encourages the establishment of mid-seral grasses. However, in those climates where snow frequently occurs, a recommendation of a 2 inch mowing height on the shoulder may be justified based on the potential for drifting snow. The cut stubble or verdure acts as a vegetative barrier. From the model developed using various field studies, the length of a snow drifts for the heights of the verdure of 2, 5, 7, 9, and 12 inches are 5, 13, 18, 23, and 31 feet respectively for a low percent barrier porosity. Any height of verdure above 2 inches will potentially create a drift that will go across the driving lanes of a highway. It also points out the wisdom having a late fall mow for those areas where snow frequently occurs.