Texas Tech University

Multidisciplinary Research in Transportation

Right of Way Mowing Height Research: Literature Review

John Borrelli, Cynthia McKenney, Ron E. Sosebee, and Richard Zartman

Performed in Cooperation with the Texas Department of Transportation and the Federal Highway Administration

Research Project 7-4903-1
Research Product 7-4903
http://www.techmrt.ttu.edu/reports.php

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.: TX 99/7-4903-1	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Right-of-Way Mowing Height Research: Literature Review		5. Report Date: February 1999
		6. Performing Organization Code: TechMRT
7. Author(s): John Borrelli, Cynthia McKenney, Ron E. Sosebee, and Richard Zartman		8. Performing Organization Report No.: 7-4903-1
9. Performing Organization Name and Address: Texas Tech University, Center for Multidisciplinary Research in Transportation, Box 41023, Lubbock, Texas 79409-1023		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.: 7-4903
12. Sponsoring Agency Name and Address: Texas Department of Transportation, Research and Technology, P. O. Box 5080, Austin, TX 78763-5080		13. Type of Report & Period Cover: Deliverable #1
		14. Sponsoring Agency Code:
15. Supplementary Notes:		

16. Abstract:

The focus of this project is to develop practical information and recommendations on the relationship between height and frequency of mowing. There is concern that current mowing practices are not timed to maximize the viability of the mixture of plants 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 is 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 objectives, plots will be established in four locations and responses measured to various treatments of mowing height and frequency of mowing. Measurements will be taken on plant population changes, morphological development, root depth, ground shading, and carbohydrate reserves in plants. In addition, data will be collected on the related issues of mowing height and mower speed versus rooster tails, and on the quantity and size of debris that might impact the choice of mowing height.

17. Key Words: mowing height		18. Distribution Statement: No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 44	22. Price

Form DOT F 1700.7 (8-72)

RIGHT-OF-WAY MOWING HEIGHT RESEARCH: LITERATURE REVIEW

by

John Borrelli, Cynthia McKenney
Ron E. Sosebee and Richard Zartman

Research Report Number 7-4903

Conducted for:
Texas Department of Transportation

by the

CENTER FOR MULTIDISCIPLINARY RESEARCH IN TRANSPORTATION
TEXAS TECH UNIVERSITY

February 1999

IMPLEMENTATION STATEMENT

The results of this project will yield the documentation necessary to verify or provide the scientific information needed to revise CMD's Roadside Vegetation Management Manual with regard to mowing height and frequency of mowing. A Research Report, Project Summary Report, educational materials, and an Internet document on the Texas Tech University's TechMRT Internet site will convey the findings of this project.

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

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view of policies of the Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

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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.

Symbol	When You Know	Multiply By	To Find	Symbol
		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

This progress report present the findings of several literature searches into the relationships between grasses and the height and frequency of mowing. In addition, it contains the description of the sites for the four sets of plots. The data bases searched included TRIS as well as traditional sources including the internet.

The first part of the report provides the location of the plots along with photo of the sites. The plots are located in Tahoka, Lufkin, Andrews, and Brady. Each site appears representative of a geographical areas of Texas and has representative vegetation for the area. Selection of the sites were made with the aid of TxDOT personnel.

The second part of this report contains the literature reviews concerning defoliation of grass by mowing, carbohydrate reserves in grasses, tiller development, mowing height, plant root development, litter, and vegetative wind barriers. Approximately 150 references are cited in the review. The information obtained from this review will help guide the research. As work progresses, additional citations will be found and information gathered on more specific topics.

Selection of Plots

Four sets of plots were selected at Andrews, Brady, Lufkin, and Tahoka. These plots were selected with the aid of Ms. Ann Finley for the Lubbock District, Mr. Kyle Moseley for the Brownwood District, Mr. Herbert Bickley for the Lufkin District, Mr. Robert Watts for the Odessa District. The purpose of the plots is to evaluate the response of grasses to different mowing heights and frequency of mowing. The purpose of the four locations is to allow for diversity of climate, precipitation, and vegetation to be included in the study.

The experimental design will be a split plot with four replications per location. The four locations were chosen near Andrews, Tahoka, Brady and Lufkin, Texas. The main treatment will be three mowing heights at 2, 4 and 8 inches. The secondary treatment will be frequency of mowing. Plots will be mowed once a year (October), twice a year (July and October), or three times a year (May, July, October).

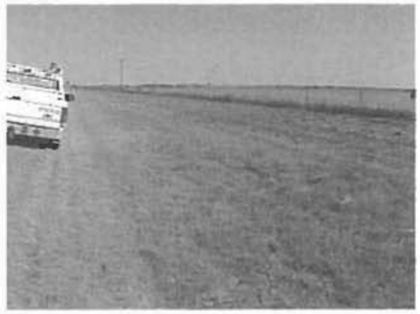
Each plot will be 50 feet long, with a 20 foot border between individual plots. Plot width will be 8 feet to correspond with the swath of the rotary mower. Plots will be randomized with four replicates at each of the four locations. The plots will be located as near to the right-of-way fence as possible to minimize disturbance from unforeseen traffic. The plots will have signage of "no-mow zones" to prevent normal mowing operations from inference with the experimental mowing schedule.

Presented below are the descriptions of the plot locations including pictures of each site. There is no scheduled construction activity within the next 5years for any of the locations. The sites are representative of the conditions existing in each of the districts are should provide the vegetative and climate diversity needed for this study.

View looking south

The plots are in the right-of-way on US 385 and are located as follows: approximately 7.45 mi. north of the intersection of US 385 and SH 158 or approximately 3.17 miles north of the Ector and Andrews County lines. They are just south of the Windmill roadside park.

Figure 1.-Andrews County near Andrews.



The plots are located on the south right-of-way of HY 190 approximately 3.9 miles northeast from the intersection of HY 377 and HY 190.

View looking southwest View looking northeast.

Figure 2.-McCullock County near Brady.

The plots are approximately 1.5 miles from the junction of HY 2497 southwest on HY94. The plots are located on the north right-of-way. The gully is to be repaired.

View in center of plot. View from southwest end.

Figure 3.-Angelina County near Lufkin.

The plots are approximately 6.5 miles west of Tahoka on HY 380. The plots are located on the south right-of-way.

View looking west. View looking east.

Figure 4.-Lynn County near Tahoka.

Review: Defoliation of Grasses

Introduction

Plant response to defoliation has been emphasized because of the extensive use of rangelands as a forage source for both domestic livestock and wildlife. Knowledge of plant response to defoliation has been incorporated into various systems and prescriptions to effectively manage both vegetation and herbivores to minimize the detrimental consequences of grazing and to maintain plant and animal production on a sustainable basis (Briske and Richards, 1995).

Many studies on the effect of defoliation on plant vigor, productivity, and carbohydrate reserves have concluded that frequency, intensity, and season of defoliation could explain most of the plant response to defoliation (Dahl and Hyder, 1977). Consequently, the most favorable leaf replacement can be attained by scheduling the time (frequency) and degree (stubble height) of defoliation to stop the culm growth and promote new tillers (Hyder, 1972).

Grazing may be timed to primarily produce a strong tillering response, harvest a maximum quantity of nutrients per unit area, and improve forage quality for subsequent grazing. It may also be used to manipulate botanical composition, protect and improve adjacent range, or create some other desirable effects (Hyder, 1974).

Other desirable effects of planned defoliation could be practiced to afford protection against fire hazards along highway rights-of-way by maintaining a minimum stand of vegetation with the ability to regenerate after defoliation. Also, restoring an aesthetically pleasing environment is another desirable effect that could be considered.

Although there is a significant amount of literature on the effects of height and frequency of defoliating (mowing) native grasses, most of it does not relate defoliation to either the phenological stage or the physiological status of the plant. Therefore, this portion of the research project is designed to test the effect of height and frequency of defoliation and the time of defoliation on grass response to defoliation. A representative from tall, mid, and short grasses will be selected (to the extent possible) for evaluation.

Literature Review

In general, defoliation of range plants affect many related factors, and it seems unlikely that defoliation may effect one factor without simultaneously influencing the others. This literature review will address a few of the factors such as growth habit, carbohydrate reserves, and tiller development that are affected by frequency and intensity of defoliation throughout the growing season.

Growth Habit of Grasses and Affect of Defoliation on Plant Response

Most grasses exhibit morphological adaptations that permit them to endure partial defoliation. The apical meristem which is the source of new leaves is elevated by stem elongation; therefore, the removal of, or damage to, the apical meristem stops stem elongation and leaf expansion from that axis. Subsequent growth and leaf replacement is delayed until a new stem arises from the basal buds (Hyder, 1972). Removal of the apical meristem stimulates axillary shoot growth regardless of the stage of development of Arizona cottontop (*Digitaria californica* (Benth.) Chase) (Cable, 1982). The concept of apical dominance has been studied by several range scientists to explain the regulation of tillering in grasses, especially in response to defoliation. Removal of the apical meristem stimulates axillary bud growth and promotes tiller initiation. The stimulation of bud growth presumably occurs because the direct inhibitory influence exerted by the apical dominance is removed (Murphy and Briske, 1992).

Range plants which are most resistant to excessive grazing grow in a manner such that their apical meristems are inaccessible to grazing animals. These plants have the appearance of being culmless because of their extremely short basal internodes (often called short shoots) so that the elevated part of a leaf blade can be removed without stopping growth (Dahl, 1995). Defoliating perennial ryegrass (*Lolium perenne*) in the early vegetative stage (stem elongation or flowering stages) produced higher annual standing crop yields than treatments in which plants were defoliated during an intermediate stage of growth when the majority of stem apices had been elevated above the height of defoliation (Binnie et al., 1980). On the other hand, long shoots which elevate their apical meristem early in the growing season and, thus, are exposed to grazing animals always decrease in standing crop under continuous heavy grazing (Dahl, 1995). The grasses in which the growing points reached a height that permits removal of the apical meristem by grazing; e.g. switchgrass (*Panicum virgatum*) decreased as intensity of utilization (grazing) increased, but grasses with growing points at the ground level, e.g. blue grama (*Bouteloua gracilis*) and sideoats grama (*B. curtipendula*) usually increased their standing crop (Branson, 1953). Also, sideoats grama and little bluestem (*Schizachyrium scoparius*) exhibited the ability to tiller because they have many basal short buds along with adventitious roots that supply the needs of newly developed lateral branches, while Indiangrass (*Sorghastrum nutans*) and switchgrass, which have fewer basal buds, were less able to spread or even maintain growth under intensive grazing (Rechethin, 1956).

Continuous grass growth during the summer could be possible for both long and short shoot plants if proper management is practiced. Timothy (*Medicago sativa*) and brome (*Bromus sp.*) grasses both characterized by long shoots, tend to go dormant when growing points are grazed off too early. At later growth stages, the growing points must be grazed off to activate lateral buds in the root crown to initiate tiller development. While in orchardgrass (*Dactylis glomerata*) and big bluegrass (*Poa ampla Merr.sp.*) (grasses in which their growing points remain at ground level, or below), frequent grazing is necessary to protect the growing points, but a sufficient number of leaf blades must be left to keep the growing point supplied with adequate moisture to prevent drying out (Heppner, 1961). However, clipping little bluestem, big bluestem (*Andropogon gerardi* Vitman), and Indiangrass at any time during the summer reduced yield, but clipping at 3.75-cm stubble height between floral initiation and anthesis was most damaging to the plant (Vogel and Bjustad, 1968).

Clipping little bluestem to 7.5-cm stubble height before internode elongation reduced production; but, clipping the plant to the same stubble height after internode elongation increased production. Herford (1951) also found that clipping to 5-cm stubble height in July increased production, but clipping to 10 and 15 cm on the same date decreased yield because the apical meristem was removed by the 5-cm clipping, but not by the 10- or 15-cm stubble heights (Jameson and Huss, 1958). Clipping the entire basal area of bluebunch wheatgrass (*Pseudoroegneria spicatum* [Pursh] Scribn. & Smith) plants to a 7.6-cm stubble height during the mid-boot phenological stage and the inflorescence emergence stage caused 7.0 and 7.5% declines in live basal area, respectively (Clark et al., 1998).

Carbohydrate Reserves

The major premise for monitoring carbohydrate reserves is to provide an index of potential for regrowth based upon the assumption that these carbohydrates provide the major source of carbon for leaf regrowth. These labile carbon compounds are utilized for plant growth and maintenance when the photosynthetic capacity is limited as demonstrated by the reduction in carbohydrate reserves following defoliation (Coyne et al., 1995). In seasonal comparisons, an inverse relationship is frequently observed with carbohydrate pools increasing during periods of minimal growth and then decreasing during periods of rapid growth (Briske and Richards, 1994). Plants that replenish reserves rapidly after spring "draw down" and regrowth periods and minimize the portion of the growing season with low reserve status were least affected by defoliation and recovered rapidly from severe defoliation. These plants are characterized by a narrow V-shaped curve in TNC trends such as in blue grama (Menke and Trlica, 1981). Defoliation at any time of the year usually effects plant growth by affecting carbohydrate reserve level, however, plants were found to be more affected by defoliation at certain phenological stages than at others (Trlica, 1977). There was a direct relationship between average total carbohydrate levels in the autumn and the amount of regrowth after defoliation. The carbohydrate reserve level in the autumn appears to be a good indicator of defoliation effects during the preceding growing season for some semi-arid species such as needle-and-thread (*Stipa comata*) and Indian ricegrass (*Oryzpsis hymenoides*) (Trlica and Cook, 1971). Also, results indicated that defoliation of mountain plants such as needlegrass (*Stipa lettermanii*), beardless wheatgrass (*Agropyron inerme*), and rabbitbrush (*Chrysothamnus visciflorus*) early in the growing season when the carbohydrate reserves were low was more detrimental than defoliation late in the season when the carbohydrate reserves were high (Donart and Cook, 1970). Moreover, maximum plant vigor in relation to carbohydrate reserves depends upon reserve storage sometime at the end of the growing season for the semi-arid species Indian ricegrass and needle-and-thread (Coyne and Cook, 1970). Monthly defoliation decreased carbohydrate concentrations by about 50% and carbohydrate pools by 80%, respectively, within stems, leaves, and crowns of spotted knapweed (*Centaurea maculosa* Lam.) (Lacey et al., 1994). Complete protection of perennial ryegrass (*Lolium perenne*) from grazing did not increase carbohydrate reserves accumulation when compared to the grazing treatments; however, non-grazing sometimes produced significantly lower carbohydrate concentrations than grazing treatments (El Hassan and Krueger, 1980). Defoliation to short stubble heights led to greater reductions in non-structural carbohydrates. While, with taller stubble heights, stand composition, and non-structural carbohydrate levels improved in big bluestem (Forwood and Magai, 1992).

Both defoliation and drought stresses were found to effect carbohydrate reserve levels in two cool season grasses; crested wheatgrass (*Agropyron desertorum* Fisch. ex Link) Schult.) and bluebunch wheatgrass. Plants exposed to prolonged periods of drought plus defoliation once a year at 5- to 7-cm stubble height may have rapid initial regrowth upon alleviation of both stresses because high amounts of total nonstructural carbohydrates may have accumulated in their storage organs during stress (Busso et al., 1989).

Defoliation Height and Frequency

There is a relatively large amount of information in the literature concerning the effect of height and frequency of defoliation, but almost none of the literature relates the response of defoliation to the phenological stage of the plant. Therefore, only a few references address the relation of defoliation height and frequency to phenological stages.

The effect of defoliation height and frequency on tiller initiation is difficult to generalize; it is easily confounded with phenological development and the seasonal progression of environmental variables (Briske and Richards, 1995). The timing of defoliation in the spring appeared to be the most important factor governing basal crown bud production and regrowth for phalaris (*Phalaris aquatica* cultivar Sirolan) in the following summer (Hill and Watson, 1989). Also, net growth rate declined significantly as the time of clipping (at 10 cm) was delayed July 1 through the April-October growing season in the tallgrass prairie (Gillen and McNew, 1987). It is recommended that pinegrass (*Calamagrostis rubescens*) be grazed for a short time while it is actively growing (early in June) and then later when quiescence is well established (August) to maintain its vigor (Darryl et al., 1980). Moreover, rough fescue (*Festuca scabrella* var *campestris* Rydb) is highly sensitive to grazing when the plant is growing. It has been suggested that the greatest benefit from rough fescue grasslands may be derived by grazing in the fall or winter (Willms, 1991). Total annual forage production on plots clipped during the boot stage was generally lower than on plots clipped during the vegetative or late-flowering stages of development in crested wheatgrass (Miller et al., 1990).

Forage harvested during the growing season was greatest from plots harvested three or more times in the fall and least when big sacaton (*Sporobolus wrightii*) was harvested in the spring, spring/early summer, and spring/midsummer (Haferkamp, 1982). While defoliating little bluestem at 7 cm, a single defoliation in June or July during the growing season produced the optimum dry matter yield, tiller weight and number, and bud number when compared to a single August defoliation, or two or three early or late defoliation treatments (Mullahey et al., 1990).

Defoliation early at the three-leaf stage of white clover (*Trifolium repens*) decreased the number of growing points by 32% and stolon weights and lengths by 50% compared with delaying defoliation until the nine-leaf stage (Hayes and Williams, 1995). Cutting creeping bluestem (*Schizachyrium stoloniferum* Nash.) at 10 cm above the soil surface significantly reduced dry matter, but there was no significant drop in yield when plants were cut at a 20-cm stubble height (Kalmbacher et al., 1981). Defoliating oats (*Avena strigosa* cv. saia) and ryegrass (*Lolium perenne* cv. Kangaroo Valley) every 6 weeks at a 5-cm stubble height produced the greatest yield (Lowe and Bowdler, 1988). Clipping tall wheatgrass (*Agropyron elongatum* (Host) Beau. 'Jose') every 4 weeks produced greater herbage than clipping every 1 or 2 weeks (Undersander and Naylor, 1987). The optimum time and frequency of defoliation for annual dry matter, and bud and tiller number was a single June or July defoliation for sand bluestem (*Andropogon gerardi* var. *paucipilus*) and a June-August defoliation for prairie sandreed (*Calamovilfa longifolia* (Hook.) Scribn.) (Mullahey et al., 1991). Interrupting growth of northern wheatgrass (*Agropyron dasystachyum*) by defoliation any time during the growing season disrupts production potential that year and the following year (Kowalenko and Romo, 1998). Average yields of northern wheatgrass were higher when the first defoliation was delayed until August and repeated at 6-week intervals (Zhang and Romo, 1994). Dry matter production was greatest under the 4-week/7-cm defoliation regime and least under the most severe defoliation regime (2-week/2-cm) in phalaris and orchard grass (Hill and Watson, 1989). Prairie grass (*Bromus wildelnowii* Kunth cv. Matua) tiller numbers were increased by less frequent defoliation and were greater under the 8-cm than the 3-cm defoliation height (Bell and Ritchie, 1989).

Tiller Development

The ability to tiller or branch from axillary buds without the apical meristem being removed is considered an indication of an efficient forage producer. Richards et al. (1988) found that rapid production of a new photosynthetic canopy immediately following defoliation is critical for response of species which are tolerant of herbivory, especially when defoliated plants must compete with non-defoliated neighbors. Crested wheatgrass is an outstanding example of a species that tillers profusely following defoliation (Dahl, 1995). Rates of tiller growth on defoliated plants may occasionally exceed those of non-defoliated plants. In crested wheatgrass, grazed tillers had higher relative growth rates when grazing occurred prior to internode elongation in the spring than tillers of non-grazed plants (Briske and Richards, 1995). Also, Burzlaff et al. (no date) found that tiller development in blue grama depended on the reproductive culm of a shoot reaching maximum elongation.

Management of Right-of-Way Vegetation

Introduction

Maximizing the effectiveness of controlling vegetation on the highway right-of way is of constant concern throughout the State of Texas. Existing vegetation on the roadsides needs to be maintained in a healthy status for safety and aesthetic considerations as well as to prevent soil erosion with the least amount of inputs. Many factors and interactions influence the vegetation along the highways in Texas. Four diverse geographic regions of Texas have been selected to be evaluated in this study. These four areas were selected to develop practical information on the relationship between height and frequency of mowing and the viability of maintaining vegetation within highway right-of-ways. One of our first priorities was to develop an understanding of the state-of-the art with respect to mowing height effects on plant density, rooting depth, and stand viability. This literature review will concentrate on the management problems of highway vegetation. The literature was found in a diversity of sources that sometimes directly address the problems in question regarding roadside vegetation practice. Many times these data must be interpreted from other literature with similar studies using different methods or species.

In The Highway and the Landscape, Snow presented the general topics of the interrelationship of highways and landscapes (Snow, 1959). The book has specific chapters devoted to the concepts and challenges of having roads in the landscape. Specific chapters address the complete highway (Bugge and Snow, 1959), fitting the highway into the landscape (Cron, 1959), preserving the scenic qualities (Johnson, 1959), the politics of road building (Ingraham, 1959). The most relevant chapter to this particular project is entitled "The functional uses of plants on the complete highway" (White, 1959). In that chapter, White discusses the utility, safety, and public acceptance of plants along the highways. The concerns written about in 1959, are still relevant to highway right-of-way maintenance today.

There are numerous general turfgrass management references available in book, journal article, nonrefereed article and web site formats on the subject of management of roadside vegetation. General text references include Beard, 1973 (Turfgrass Science and Culture); Duble, 1996 (Turfgrasses: Their Management and Uses in the Southern Zone); Madison, 1971 (Practical Turfgrass Management); Schroeder, 1996 (Turf Management Handbook); and Turgeon, 1999 (Turfgrass Management). Cogburn (1995) TxDOT mowing guidelines would be an example of a refereed journal article on the subject. Nonrefereed articles or handbook type publications would be those such as Turfgrass Maintenance and Establishment: A Student Handbook (Penn. State Univ., 1968); Desirables and Weeds for roadside Management--a Northern Rocky Mountain catalogue (Meier and Weaver; 1977); Giving Nature a Hand booklet (TxDOT, 1999); Roadside Vegetation Management Manual: A volume of the Infrastructure Maintenance Manual: Manual Notice 93-1 (TxDOT, 1993); and Roadside Vegetation Management Manual: Manual Notice 96-1 (TxDOT, 1996). World Wide Web formats are now rapidly supplanting the traditional manuals as methods to disseminate the roadside management information. Several of the web addresses are as follows: http://www.dot.ca.gov/hq/LandArch/ and http://plants.usda.gov/plantproj/plants/index.html.

Mowing Height

Plant growth is a function of many environmental and management components. The environment is a function of the climate of the area and the soil resources of that area. Climate cannot be controlled, in general, other than by irrigation and/or drainage that are not pertinent to this document. The climatic factors are evaluated in this project by the selection of four different geographical regions to conduct this study. Soil resources are generally a function of the native resources and the history of the highway's construction at that location. These resources can be amended by the addition of fertilizer or liming materials. As these practices are generally not considered to be justifiable due to the acreage encompassed, these factors will not be included in this review. The factors of soil compaction, mowing height and mowing frequency on vegetation growth and the detrimental influences of roadway management practices will be discussed.

The primary management tool available to the Texas Department of Transportation (TxDOT) is mowing. Parameters such as mowing height, mowing frequency and mowing time can be controlled and prescribed. Many publications have been devoted to explaining these phenomena and there is not one solution to all situations. A review monograph (Turfgrass, Waddington et al., 1992) reviews the general physiology; soils and water; and management of turfgrass. The monograph has physiology chapters related to ecological aspects (Watschke and Schmidt, 1992); energy relations and carbohydrate partitioning (Hull, 1992); salinity (Harivandi et al., 1992); and physiological effects of temperature stress (DiPaola, 1992). The soils and water chapters relate to nutritional requirements (Turner and Hummel, 1992) and water requirements (Kneebone et al., 1992). The management chapters address energy conservation (Busey and Parker, 1992); integrated pest management (Bruneau et al., 1992); and plant growth regulators (Watschke et al., 1992). This review monograph does not, however, address the management implications of mowing to any great extent.

Mowing is the most fundamental practice utilized to maintain the aesthetics and safety functionality of the highway right-of-way. While herbicides may be incorporated into the overall management program (McCully and Bowmer, 1971), mowing provides a uniform surface for viewing traffic and any potential hazards to driving. Since mowing defoliates the plants, many physiological changes of the vegetation occur. While maintaining visibility, mowing must not deplete the carbohydrate reserves of the plant material to such an extent that the vegetation dies. The criteria for selecting the mowing height and frequency are physiological condition and growth habit of the vegetation as well as safety considerations such as visibility and flammability.

The choice of mowing height is dependent on the physiology and the timeliness of the mowing (Clapp, et al., 1964; Cogburn, 1995; Davis, 1967, Kneebone, 1966).

Mowing has been reported to increase succulence of the above ground portions of the plant and increase the quantity of chlorophyll per unit area (Madison, 1962). Other reports indicate decreased leaf width with mowing (Harrison, 1931; Mitchell, 1955; Mitchell and Coles, 1955; and Robertson, 1933). Closely mowing turfgrass generally produces a finer, denser foliage, but has less underground roots (Biswell and Weaver, 1933; Turgeon, 1999).

Mowing vegetation short has been reported to make the vegetation more susceptible to heat and water stress (Salaiz et al., 1995). This susceptibility is probably due to decreased carbohydrate synthesis and storage (Bukey and Weaver, 1939; Dodd and Hopkins, 1958; Everson, 1966; and McCarty and Price, 1942). Practices such as strip, modified full and full width mowing are all management tools to be utilized in highway right-of-way management. Heat stress induced problems would occur more often with the late spring and summer mowing that in the final clean cut that occurs after the first frost in the fall. Razmjoo et al. (1996) report that grasses improve when mowing height is increased. Fluck and Busey (1988) state that low mowing heights requires greater amounts of fertilizer input to give the same benefit as allowing the mowing height to be raised.

Mowing height dramatically affects the root development (Briswell and Weaver, 1933; Burton et al., 1963; Crider, 1955; Everson, 1966; Goss and Law, 1967; Graber and Ream, 1931; Harrison, 1931; Harrison, 1934; Harrison and Hodgson, 1939; Juska and Hanson, 1961; Law, 1966; Madison, 1962; Robertson, 1933; and Sprague, 1933). Carter and Law (1948) and Branson (1956) observed that defoliation had a negative effect on root development. Branson observed that herbage removal of range grasses decreased yields of tops and roots as removal intensity increased. Defoliation more dramatically influenced root development than shoot development. The effects of root production were observed by Branson (1956) on blue-bunch wheatgrass. Root production of the control plants was observed to be more than 100 times greater than the clipped plants. Carter and Law (1948) observed similar results when they clipped other perennial grasses at different intervals. They reported that clipping at 30-day intervals severely retarded root and top growth of all species. Graber and Ream (1931); Harrison (1931); Harrison (1934); Harrison and Hodgson, (1939); and Hughes, (1937) all reported decreased rhizome growth as a function of mowing warm season grasses.

Roadside vegetation is not only important for safety and aesthetics, but also in the control of erosion. There are many general references that cover the topic of vegetation and soil erosion (Crovetto, 1996; Hudson, 1995; Larson, et al., 1983; Schwab et al., 1996; and Troeh et al., 1980). For Texas, there are several relevant articles that evaluate erosion control on highway right-of ways (McCully and Bowmer 1967,1969). There are also environmental and economic considerations of maintaining an aesthetically pleasing highway right-of-way (Pimental et al., 1995). Vegetation absorbs the kinetic energy of raindrop impact and buffers the soil from this erosive action (Krenisky et al., 1998; Lattanzi et al., 1979). Velocity of runoff is also diminished with good surface cover (Hart, 1974). Vegetation also acts to minimize the wind impact on the soil surface in those areas susceptible to wind erosion (Skidmore and Siddoway, 1978).

Plant Root Development

The first environmental factor to be discussed will be the influence of soil physical factors on plant root development. The physical properties of soil bulk density, compaction, texture, shear strength and structure influence the rooting habits of plants. High bulk density soils (bulk density is soil mass divided by total dry soil volume) dramatically limits the rooting of plants growing along highways. Phillips and Kirkham (1962) studies indicated that densities less than 1.3 g/cm^3 were of little restriction to plant root growth. As densities increase, the root length density (length of root per volume of soil) decreases linearly. Soil compaction, which directly decreases pore volume has been shown to decrease root distribution. Phillips and Kirkham (1962) and Schuurman (1965) report that soil compaction reduced root growth by reducing the pore volume and increasing the mechanical impedance. Meredith and Patrick (1961) report the use of farm equipment such as the tractors that mow the roadsides can cause compaction to such an extent that roots cannot penetrate the soil. Schuurman (1965) determined that whether a root was capable of penetrating a compacted soil depended both on the root's ability to penetrate the pore and the force necessary to push the soil particles aside. The mechanical obstruction offered by the cohesion of the soil particles was one of the main components to root development. Roots must push the soil particles aside to widen a pore enough to permit penetration.

Soil texture plays a major role in the penetration by the root. In moderately fine textured soils, the root development was decreased 40% between the least and most compacted zones (Meredith and Patrick, 1961). They reported that for medium textured soils, root penetration ceased when large pores were less than 2% of the soil matrix. Meredith and Patrick (1961) reported that even though large pores may be destroyed by compaction, if aeration is adequate, the soil is generally plastic enough to permit root penetration. Their field observations indicated that the effects of compaction was usually less permanent in a fine textured soil than in medium textured soils. In Texas, Gerard et al. (1972) reported that root elongation in clay soils decreased with increasing soil strength, particularly for soil strength's exceeding 1 MPa. For moderate strengthen soils, they reported better root penetration than for either low or high values of mechanical impedance soils. High root length density was promoted along the deformed zones or cracks in the dry soil. Taylor and Burnett (1964) observed that soil strength alone controlled the growth of roots through moist soil. They observed that soil strength of 2.5 to 3 MPa at field capacity prevented root penetration but roots will grow through a layer of soil at 1.9 MPa at field capacity. Barley (1963) reported those soils resist local deformation caused by roots when the soil strength is too great.

Hendrickson and Veihmeyer (1931) and Portas and Taylor (1976) determined distribution of roots as influences by soil-water content. Hendrickson and Veihmeyer (1931) reported that roots would not grow in soils drier that 1.5 MPa. Portas and Taylor (1976) observed that as soil water potential decreased from -0.6 to -90 MPa, root length decreased. They further reported that roots responded rapidly when the water content was increased.

Type of soil structure also influences the distribution of roots. White and Lewis (1969) evaluated the effects of soil structure on the distribution of several native grasses. They attempted to determine the effects of structure in dense, clay textured soils. They were able to correlate root system growth habits with soil structure by knowing the type of root system associated with the various grass species. The dense clay soil had larger more compact structural peds when dry than when wetter. Nearly dry ped aggregate size determined the width of the desiccation cracks in the soil. With small peds, the cracks were more numerous and had narrower widths than if the peds were larger. The size of the finest ped aggregate was an important factor as far as the root growth was concerned. Larger peds bordered by irregular cracks in the dense clay soils caused more root damage than the smaller peds of the clayer soils.

White and Lewis (1969) further observed that the shape of the soil structural unit was a major influence on root distribution. They determined that roots were stretched most frequently along prismatic structures where vertically oriented cracks form. Horizontal cracks, which were usually narrow due to the overlying weight, tended to counteract prism formation. Vertically growing roots cross fewer cracks than roots growing horizontally. Plants that have a vertical rooting habit, should be able to maintain a more stable population than those plants with a horizontal rooting habit. This difference would be due to their ability to adapt to soil structures with a vertical orientation. White and Lewis concluded that soil structures determined the distribution of grass species in clay soil by permitting better utilization of water.

A factor of equal importance to highway right-of way vegetation is the soil chemical properties and amelioration of these problems or corrections of deficiencies. Again, there are many general references that address these problems but, for the most part, are not typically utilized in right-of way vegetation management (Follett et al.,1981; Tisdale and Nelson, 1975; and Troeh and Thompson, 1993). Only in the most drastic cases in which a severe soil problem is encountered, are remedial actions taken (Thompson and Zartman, 1997).

There are also interactions between the fertility of the soil and mowing height. Harrison (1931) reported that different clipping heights affected the amounts of roots produced. In those grasses most susceptible to damage by mowing, it was not the cutting off the growth buds that was detrimental to growth. It was the gradual diminished carbohydrate reserves that lead to starvation beyond which the plants could not maintain themselves. Nitrogen fertilizer was reported to alleviate this problem to some limited extent (Razmjoo et al., 1996). Mortimer and Ahlgren (1936) not only evaluated fertility and mowing height, but also examined the irrigation effect. Irrigation may be used to modify the detrimental effects of mowing, but is generally not used along roadsides.

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 snow drift 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 which will create a snow drift 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 which will exist during the winter snow season.

Provided below is the relationship between barrier height and porosity with respect to snow drifts on the lee side of the wind barrier. The understanding of wind barriers and drifting have progressed allowing for reasonable predictions of snow drifts 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 snow drift. 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

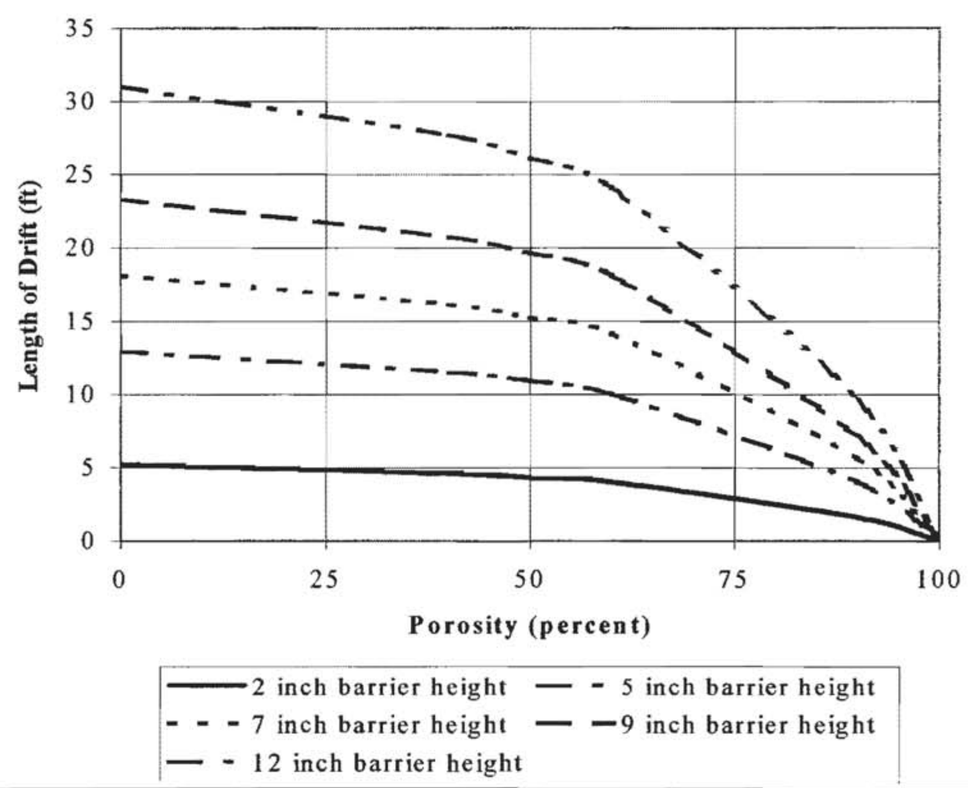
Raine and Stevenson (1977) used vertical slats to make wind barriers of different barriers. Raine and Stevenson (1977) tested the wind barriers in the field and in a wind tunnel. The wind approached the barriers at right angles. Other researchers have used vegetative strips and have measured the porosity 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 1.-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 wind breaks 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.

Litter Review

Introduction

Overall, the search of literature for documented sizes of litter in the right-of-way for Texas proved fruitless. In the literature found, it did not appear to be any significant quantities of large litter objects to pose harm to either the operator, the mowing unit, or a passerby (Syrek, 1986). Previous studies generally documented a large quantity of aluminum cans, small paper objects, and plastic wrappers with little or no count of larger, less frequent objects (auto parts, construction materials, etc) (Finkner, 1969; Syrek, 1986; Syrek, 1989; Syrek, 1990; and Vesilind, 1976). In no studies were there found to be significant amount by composition of large bulky items greater than the data from the survey of litter in California which reported approximately 38% of all litter on the roadside consisted of possibly harmful or detrimental objects (Syrek, 1989). It can be speculated that through the combination of strong litter awareness programs such as Texas Adopt a highway Programs, litter amounts in the state of Texas are lower than the majority of other states (Syrek, 1990).

Review of Major Litter Surveys

Several major litter surveys and Studies were identified during the literature background search. Of these studies, the 1969 National Study of the Composition of Roadside Litter contributed largely to the viewpoint of litter composition of right of ways (Finkner, 1969). Within this study, the Highway Research Board instigated a project to "obtain objective and adequate information regarding the composition and nature of litter scattered along the primary rural highways in the United States." Underlying this study was the main goal to gather and utilize data concerning the composition and nature of litter in the United States. Low participation throughout the nation led to the involvement of only 29 states, with Texas being one of the participants. Of the information gathered from these states, several generalized observations of litter composition were made.

A composition stratum of litter outlined that approximately 13% of the litter consisted of such items of concern as tires, lumber and other unclassified large objects, while 16% of the items were cans, and 6% was composed of bottles of various types and 59% was represented by the presence of paper items. Of this study, other generalizations such as the conception that there was a general trend of increasing litter volume with an increasing number of lanes. State by State reports were given, and of our concern, Texas' composition data along the right of ways were reported as follows composition:

Paper Items	48.59%
Cans	27.12
Number of Misc.	15.81
Bottles and Jars	5.33

The miscellaneous items included such items of interest as lumber or construction items, auto parts and accessories, tires and other unclassified objects, all of which would present a serious concern to mower safety if a higher percentage per total litter items. Information provided by Mr. Robert Watts indicates that the current TxDOT policy is to collect all large objects as encountered by TxDOT maintenance personnel. This practice essentially reduces the potential of encountering large objects in the process of mowing to a very low probability.

Another contributing data source to the literature search was Syrek (1986). Since the date are most current, and the survey originated from Texas, these data can be easily correlated to current Litter conditions along the right-of-ways. Although a major emphasis was placed on the actual change and reduction in litter volume rather than individual litter object compositions, this information still represented positive and valuable information. An overall reduction of 29% in litter was determined to have been achieved or "the largest of any 13 year-old trend comparisons surveys performed bye the Institute for Applied Research." The litter counts described were divided into two part with the first being to compare the data with prior surveys of litter (considered to be a calibration process). The second 'count' governed the tabulation of four divisions of litter: cans, bottles, other deliberate litter (convenience products and packaging) and accidental litter. The considerable reduction in annual litter was determined to have been contributed to by the strong and intensive implementation of anti-litter programs such as public advertising and adopt a highway programs. Other highlights of the Texas survey suggested that of the actual litter along the roadsides, 34% of it could be seen by a pedestrian walking along the shoulder at a brisk pace. This study also examined other areas of interest such as the likeliness of one age group to litter more than another and what type of vehicle was the largest litter contributor, most of which were irrelevant to the concern of the current research project on the height to mow grass in the right-of-ways.

There was a similar survey of litter in California (Syrek, 1989). Syrek (1989) mainly concentrated on the change in beverage containers with in a years time span, and also touched on the composition breakdown of roadside litter. The Department of Conservation findings stated that by compositions (%), take-out food containers, cups, napkins, etc. composed the largest single product group found in the study. A decrease of 72% of bottles and cans from the previous year was noted following the introduction of the Recycling Act. The general breakdown of the estimated material compositions of California litter is listed below by percent composition:

Possible Significant items (percent)	
Wood lumber, pallets, signs	19.35
Rubber tires, Molding, Seals	14.10
Ferrous metals	2.6
Nylon rope, plastic pipe, other	1.02
Total	37.07

Non-hazardous items (percent)	
Glass bottles	23.20
Paper	16.26
Other	12.12
Aluminum cans	6.11
Plastics	5.23
Total	62.99%

In contrast to the surveys discussed earlier in other states, Syrek (1989) identified possible harmful objects comprise slightly under 40% of all litter items.

Another important and significant state study originated from the Louisiana Litter Survey of 1990 (Syrek, 1990). This study covered the collection of data from 110 locations around the state of Louisianna, documenting such instances as indiscriminate dumps. According to Syrek (1990), the largest single product identified in the group of litter in Louisiana was found to be take-out packaging, cups, napkins, plates, bags, etc., composing a total of 62% by composition. General data were collected which stated the occurrences of vehicle parts, and debris, construction materials, and wood pieces, comprising an approximate 10 percent (by composition) of all liter identified during the survey. An approximately 1 percent decline in food packaging in Louisiana and other states was noticed, while a 1-2 percent increase in construction material/wood materials was notice for 1986. Embedded within this study was a comparison of Louisiana's "Indiscriminate Dump Encounter Rates" with those of other states. This information could then be used to draw a conclusion to the frequency per state to have an occurrence of a so called indiscriminate dump, or litter objects which would be of concern when mowing on the right of ways.

The data mentioned is listed below in terms of number of indiscriminate dumpings per 1000 miles of driving:

Louisiana (1990)	30.4
Hawaii (1988)	28.2
Florida (1989)	23.8
Pennsylvania(1984)	15.5
New York(1984)	13.9
Oregon (1986)	7.6
*Texas (1989)	5.6
California (1985)	3.9
Washington (1987)	1.7
Nebraska (1985)	1.0

It should be noted that Texas has a considerably low value of indiscriminate dumps per 1000 miles. It should also be noted that Syrek (1990) visited Texas and stated in the report that there was a low level of indiscriminate dumps in Texas. The contributing factors were speculated to be a strong public broad cast of the "Don't Mess with Texas" propaganda either by sign, TV, or radio.

One final relevant state survey was examined—a study conducted in Michigan (O'Toole, 1979). The litter study counted items larger than a cigarette package, in a effort to exclude smaller items such as gum wrappers or pull tabs. The method for classification centered around the division of 5 items: paper, plastic, cans, bottles and miscellaneous objects (auto parts, tires, lumber etc.). A general reference of composition was created, and our area of concern—large possibly harmful objects were accounted for. These items comprised the composition survey in 1968, 77', 78' and 79 to be 21.23%, 18.70%, 9.45%, and 10.44% consecutively out of all litter items. Once again, the amount and occurrence of undesirable objects (detrimental to the mowing operation) appears to be low enough to disregard as being of major concern.

Of the litter items studies in several cases, the litter items aluminum and paper products were found to be the greatest contributing factor. These items ranged from anywhere to ground level to approximately 4 inches in height. The items examined offer little resistance to the mowing blade.

Summary

Of the right-of-ways documented in the extensive literature search, it was determined that there is an infrequent, and rare occurrence of large, hazardous litter/trash objects along side the highways to cause rise of concern unless the mowing height was dropped below approximately 4 inches. This reduction in height which would encompass a larger portion of possibly harmful litters along side the highways. Should the optimum mowing height surpass a minimum of 3-4 inches, more concentration might then be placed on the amounts and quantity of litter items and or composition stratum.

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Texas Tech University | Lubbock, Texas 79409
P 806.742.3503 | F 806.742.4168