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16. Abstract
The goal of this study is to identify more effective methods of weed control for ornamental landscape projects on Texas roadsides. The study found that chronic weed problems are the result of a composite of factors from within five categories of activity. The five categories are as follows: 1) the contracting process: in many cases, contractors lacking in appropriate skills win contracts; 2) the types of contractors: private firms, municipalities, community organizations, and state-use contractors presently work on maintenance contracts and each has different skills and resources; 3) the inspection process: inspectors of landscape maintenance contracts are often not sufficiently trained in the specialized needs of plant materials; 4) the design process: there is a lack of a coordinated approach to weed management as part of the design process; and 5) the maintenance process: contracts are written with few specifics regarding weed control. The study presents discussions of each of the factors affecting weed control and makes specific recommendations for the use of each. These issues are outlined in an integrated approach that details the options that are available to a manager or designer and which should be incorporated into the decision-making process for each phase of a landscape project. A key recommendation is for the development of a formal herbicide program for ornamental landscapes which would include the use of both post- and pre-emergent herbicides.

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RECOMMENDATIONS FOR AN INTEGRATED WEED MANAGEMENT PROGRAM FOR ORNAMENTAL PLANTINGS ON TEXAS HIGHWAYS

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Research Report 2970-1F
Research Study Number 7-2970
Research Study Title: Keeping the Beautification Projects Clean

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Texas Department of Transportation

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IMPLEMENTATION STATEMENT

This study discusses the weed problems which are attendant to many roadside landscape projects. Weeds cause a significant amount of extra costs in removal and reflect badly on TxDOT by presenting an unattractive appearance. The recommendations contained in this report will help reduce the incidence of weed problems in both new and existing landscape projects. In addition, implementation of the recommendations discussed in the management outline provided will lead to landscape projects that will be less expensive to maintain over the life of the project and more quickly develop the appearance that was originally intended.

DISCLAIMER

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 or policies of the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

NOTICE

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.

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SUMMARY

As more ornamental landscape projects have been installed on Texas roadways, maintenance needs have become more diverse and demanding. In particular, weedy growth has become an increasingly difficult problem. This study was commissioned to find a way to control weeds to improve the appearance of roadside landscape projects.

A survey was conducted and results showed that virtually every district experiences weed problems and that most were associated with shrubs in beds, tree-wells, and pavers. The survey also found that all manner of control efforts were being applied with only moderate success. It was noted that pre-emergent herbicide usage in landscape plantings was not commonly used and most respondents wanted more information in how to use herbicides. Comments were also received from persons who wanted non-herbicide alternatives. Follow-up visits were conducted to most of the respondent districts.

Problems associated with weeding and general maintenance can be grouped in the following categories.

The Contracting Process

Deficiencies were discovered in the ways that installation and maintenance contracts were written and let to bid. In many cases, contractors lacking the appropriate skills win contracts. Because some of these companies are not even landscape contractors, their ability to help in the development of the project is very limited and sometimes detrimental.

The Types of Contractors

Four categories of contractors presently work on maintenance contracts. Each of these groups have their own distinct characteristics and each requires consideration in the design process. These groups are:

- Private contractors,
- Municipalities and quasi-governmental agencies,
- Community organizations, and
- State-use contractors (MHMR workshops).

The Inspection Process

It was found that in many cases, inspectors of landscape maintenance contracts are not sufficiently trained in the specialized needs of plant materials. This made it difficult for the inspector to properly assess the contractor's work or to be effective in meeting unforeseen problems in the field.

The Design Process

Problems were identified as resulting from decisions made in the design phases of the project. While "low-maintenance" was a goal in most designs, the actual techniques employed seem unrelated and sometimes not effectively communicated to persons responsible to maintain the projects.

The Maintenance Process

Often, contracts are written with few specifics regarding weed control.

No one solution will solve these problems. The researchers recommend that the department focus on developing an integrated approach that would take advantage of a variety of weed control methods while at the same time addressing shortcomings in the administrative side of the issue.

The study presents discussions of each of the factors affecting weed control and makes specific recommendations for the use of each. These issues are brought together in an outline that details the options that are available to a manager or designer that should be incorporated into the decision-making process for each phase of a landscape project.

INTRODUCTION

Landscape projects have been installed throughout the state at an increasing rate over the last ten years. The manner in which some of these projects have been maintained has generated concern due to unsightly appearance or the costs associated with their maintenance. Too frequently, the projects do not develop into maturity as planned or take too long to do so. Frequent problems are that plants die, weeds invade, and irrigation systems work only sporadically. While this study is intended to look specifically at weed problems, many of these issues are interrelated and must therefore be dealt with as a whole.

The most intensive maintenance for a landscape project should only occur in the early years of the project's life. Yet the need for some degree of maintenance will never end. At some point, however, it should be expected that the maintenance level of an ornamental landscape planting will be reduced to a point where minimum care is required and that care being within acceptable budget ranges.

Organization of the Study

The original intent of this study was to identify or develop a methodology to control weeds in landscape plantings. In order to clarify and further define the types of problems encountered in the field, a survey was developed and sent to vegetation managers and landscape architects in each Texas Department of Transportation (TxDOT) district office. The survey results enabled the study team to quickly target the most serious problems and to concentrate in those areas. An analysis of the survey led to a determination that rather than focus on one or more specific techniques of weed control, TxDOT should adopt a broader approach that would integrate a wide variety of techniques into all stages of project development.

The next phase included visits to most of the respondent districts and telephone interviews with the more remote districts. This enabled the team to identify specific details associated

with problems noted in the survey. In addition, the team was able to evaluate the effectiveness of current maintenance practices.

The site visits provided the team with a good picture of the types of problems encountered, how they are presently dealt with, and where the most serious breakdowns in the process are occurring. In some cases, problems could be attributed to design decisions, while in others, improper installation was the chief contributing factor. However, many of the problems were caused by the way landscape maintenance contracts are structured in their specifications, letting, and inspection. This fact led the study team to divide this report into four parts. Part I is a summary of the findings of the survey. Part II discusses the team's findings regarding the contracting, bidding, and inspection phases of a landscape maintenance contract. Part III discusses specific techniques and methodologies related to landscape maintenance. Part IV is an outline of a recommended Integrated Weed Management Program for landscape plantings.

PART I - SUMMARY OF SURVEY FINDINGS

SURVEY RESPONSES

Two copies of the survey (Appendix A) were mailed to each TxDot district office. They were addressed to the district engineer with a cover letter describing the project and asking them to forward the two copies to whomever they felt best qualified to respond. If the district had a landscape architect on staff, a separate survey was mailed to them specifically. The responses were as follows:

Table 1. List of Survey Responses

District	No. of individual responses
Paris	1
Wichita Falls	1
Lubbock	1
Abilene	1
Waco	2
Lufkin	2
Austin	1
San Antonio	1
Bryan	1
Dallas	2
Pharr	1
Laredo	3
Brownwood	1
El Paso	1
Total	19

The heart of the survey was a chart asking the respondent to list a weed problem situation, species, control method, etc. A chart of the responses is presented in Appendix B. Each response that was received is listed. Some districts had more than one entry under a category. (In a few responses some items were left blank and these are reflected in the chart.) This is the type of response we had hoped for but it was not uniform throughout the respondents and needs to be qualified. The number of entries in a category should not be considered an indicator of importance or weight, although it appears to have worked out that way. What is more important is the numbers of districts listing problems under a category. Thus seven districts listed pavers, ten listed planting beds, four listed tree wells, and seven listed shrub plantings. All other categories listed were from two or fewer districts.

As noted above, four major categories were listed by the respondents. These were pavers, planting beds or planters, treewells, and shrub plantings. The following is a summary of the information provided on these topics.

Pavers

Of the seven districts listing this category, five reported weeds growing in pavers as a continuing problem and two described the problem as recurring occasionally. Most felt that these were originating from seeds blown into the areas by winds or mowers but some surface runners and rhizomes were cited. Only one district felt rhizomes were the primary invasion mechanism.

The most common control being used is herbicides. Five districts cited herbicides as only moderately effective while one cited them as minimally effective and three districts rated herbicides as very effective. Two districts rated hand pulling moderately effective while one found the technique very effective. Roundup is the most widely used herbicide. Rodeo and an unnamed pre-emergent were each mentioned once.

Bermudagrass is the most commonly cited weed species in pavers. Others mentioned include johnsongrass, nutsedge, bluestem, sandburs, thistle, spurge, groundsel, and cabbage. Only two districts mentioned johnsongrass as a problem species. This may be due to seed size. We would expect that small-seeded varieties are most easily transported by wind and capable of lodging in the cracks between pavers. Site visits to these districts also found barnyardgrass, crabgrass, and goosegrass in addition to a variety of low, forb weed species.

The districts indicating problems with weeds in pavers also listed herbicides as the most cost-effective measure. However, most of these districts described herbicides as only moderately effective. Thus, the most cost-effective measure is only moderately effective in controlling the problem. This may be due to the fact that seeds are continually blown into the sites, germinating, and requiring re-spraying. Even the one district that specifically mentioned using pre-emergents rated them the same as post-emergents: moderately effective.

Planting Beds and Planters

Ten districts cited weeds in planter beds as a continuing problem. Johnsongrass and bermudagrass were the most common invaders. Other species mentioned were nutsedge, crabgrass, ryegrass, groundsel, spurge, and broadleaf weeds in general. There is no clearly dominant invasion mechanism. Seed, rhizomes, and runners were uniformly cited.

The most common control method is herbicide application. Eight of the ten districts that have problems with weeds in beds use herbicides as their primary control tool. The effectiveness is varied. San Antonio and Lufkin rated herbicides as very effective on bermudagrass and crabgrass but only moderately effective on nutsedges. Most of the remaining districts reported only moderate effectiveness with two finding them minimally effective. Despite the generally low effectiveness rating, herbicides were almost unanimously cited as being the most cost-effective control method.

Four districts reported using weed barriers as a control for weeds in beds. Two rated them moderately effective and one found them only minimally effective. Another commented that they quit using them because "they do not work". Eight districts said they had used hand-weeding as a control method. Of these, only the Waco district reported being pleased with the effectiveness of the practice. Four had minimal success and three had moderately effective results. Hand-weeding, manual labor, or mechanical techniques were consistently cited by all respondents as being the least cost-effective of all options.

Two districts specifically listed flower beds as a recurring problem and the same invader species were cited as were noted for planters. One of these districts had also listed shrub beds so it may be assumed that there is a real difference in the two designations. A flower bed may likely contain more annual plants and thus provide additional problems for control since most herbicides target annual plants. This is not the case in these districts however. Both list herbicides as their main control. Wichita Falls district reports effective results with herbicides on broadleaf weeds but only moderate success on bermudagrass. They report very effective results, however, by using smaller beds and thickly planting them to keep weeds from germinating. Laredo also listed tight planting as very effective in planter beds. Lubbock reported moderate success with herbicides on nutsedge.

Shrub Plantings

Shrub plantings were the second-most cited weed problem. Six districts reported recurring problems and only one reported it as recurring occasionally. Johnsongrass and/or bermudagrass were cited by every district. Ratama, spurge, pigweed, nutsedge, broadleafs in general, and woody plants were each mentioned at least once. Seeds, runners, and rhizomes were the most frequently mentioned invasion mechanism. Birds were mentioned once.

Of the seven districts, five have used hand-weeding. Three found it moderately effective and two found it minimally effective. Four districts said they used herbicides in shrub beds. Of these, only the San Antonio district reported effective control. Two had moderate success

and one had only minimal results. Weed-eater usage was cited by two districts, both of which were minimally effective. The only effective results being reported, other than herbicides in San Antonio, are from the use of closely spaced plantings to eliminate light from the bed surface.

Treewells

Three of the four districts listed treewells as a continuing problem and the other said it was an occasional problem. Seed invasion is common to all but runners and rhizomes are also mentioned. Three of the four districts use herbicides, two listing minimally effective results and one citing moderate effectiveness. The other district cites minimally effective results with hand tools and mulch.

It is surprising that herbicides are not considered effective in this application. With the freedom from having to worry about hitting desirable plants, coverage should be good. In addition, glyphosate-type herbicides are usually very effective on grasses.

Other Problem Areas Mentioned

Other areas mentioned by only one district include railroad tracks, drainage ditches, turf areas, disturbed areas, and pavement joints. While these areas warrant more study, they are clearly distinct from the kinds of problems that are normally generated with landscape projects.

Other Comments

The survey asked if there is any area of information that might be of benefit to the respondent about weed control and called for any comments. These comments are all provided in their entirety in Appendix C. The comments are very interesting and provide a wide range of insights. Of particular note is that over two-thirds of those answering this section asked for more information about weed control, herbicides, plant identification, and planning. Two-

thirds of these are vegetation managers. Three specifically said they wanted to learn more about using pre-emergents.

Respondent Profile

A composite picture, made of these responses, would describe the average respondent as a vegetation manager with over five years experience (Appendix D). This person would have consistently recurring problems with weed control in landscape projects, specifically planter beds, tree wells, pavers, and shrub beds.

The most widely used control method (Appendix E) is herbicide application although the results are only moderately successful and sometimes only minimally effective. Other options besides herbicides have been tried with some success but these are not used routinely as a control method.

This person actively pursues more information (Appendix F) to address these problems and to be better at their job. Most of this information comes through TxDOT training and the TxDOT Vegetation Management Manual, but books, magazines, and chemical companies are also important resources. Despite these resources, this person feels that there are other things that could be done but they 1) don't know what it is or 2) are aware of it but not sure how to use it. This person would generally like to know more about pre-emergent herbicides and how to use them but would also like more solutions that do not involve herbicides at all. They are familiar with many of the plants of their area but would like to be able to identify more species.

TYPES OF COMMON MAINTENANCE PROBLEMS

The following photographs present some representative types of weed problems and a short discussion of some possible causes and remedies. In addition, photographs of some successful projects are also presented.

Figure 1. Weeds Encroaching Planting Bed.

This attractive project design has some serious design flaws which are going to be a continuous problem. The location of irrigation risers along the edge of the bed without anything to protect them from mowers will likely lead to broken risers. The lack of an edging for the bed at the base of the planter will require constant edging and herbicide use to keep bermudagrass from invading and overrunning the junipers, as it has already. The plants in the bed can be easily accessed and weeded but at the time of this photo, lack of maintenance has led to invasion by numerous weed varieties. Most are annuals and as they go to seed the problem will be compounded.

Figure 2. Weeds in Crapemyrtle Planting.

The weed barrier in this planting is covered with a layer of soil. Weeds are well-established and are growing through the fabric. A layer of mulch would probably not prevent weed invasion for long because the plants, (crapemyrtles) do not become dense enough to shade out weeds or big enough to cover the entire bed.

Figure 3. Weed-infested Grass Planting.

This planting includes a variety of ornamental grasses. Now it has been invaded by weedy grasses and so the use of herbicides is precluded. Either a tremendous amount of hand-weeding is required or replacement of the grasses with a different plant type will be necessary. The above-ground irrigation risers have been broken and their spray pattern is too indiscriminate, allowing water to encourage weeds in the pavers.

Figure 4. Grass-invaded Bed of Native Plants

While most native plants are very hardy, few are dense enough to prevent grasses and weeds from establishing. This planting has been invaded by bermudagrass to the point where the only realistic option left is to mow down the plants and maintain a turf median.

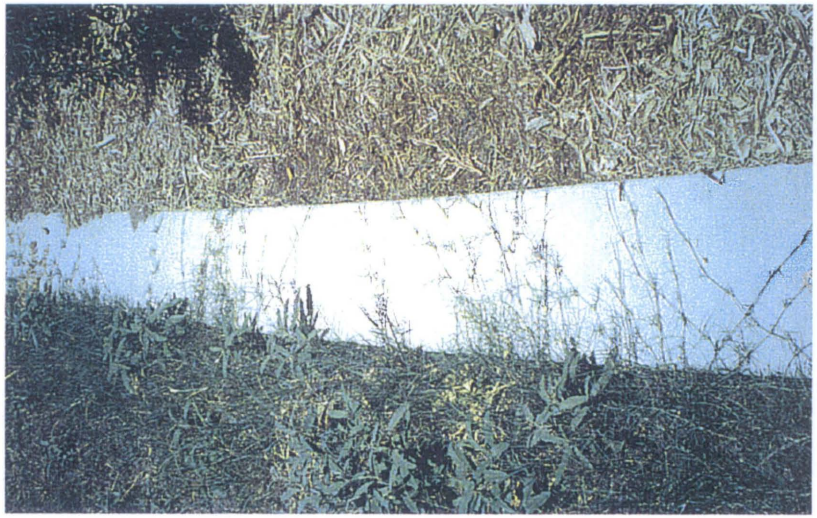

Figure 5. Grass Encroaching over Concrete Edge

This 200 mm concrete edge is being rapidly overrun by the adjacent bermudagrass. Were the top of the edging higher above grade than it is, many of the runners would grow alongside the edge instead of over the top. Also, runoff from the slope to the left could top the edge and bring in a crop of seeds.

Figure 6. Grass-filled Planting Bed

Many of the shrubs in this bed are probably doing poorly due to the increased shade at one end: a plant selection problem. The steel edging is inadequate in keeping bermudagrass out of the bed and the lack of effective weeding (or lack of enforcement) has led to a bed in need of a costly rehabilitation.

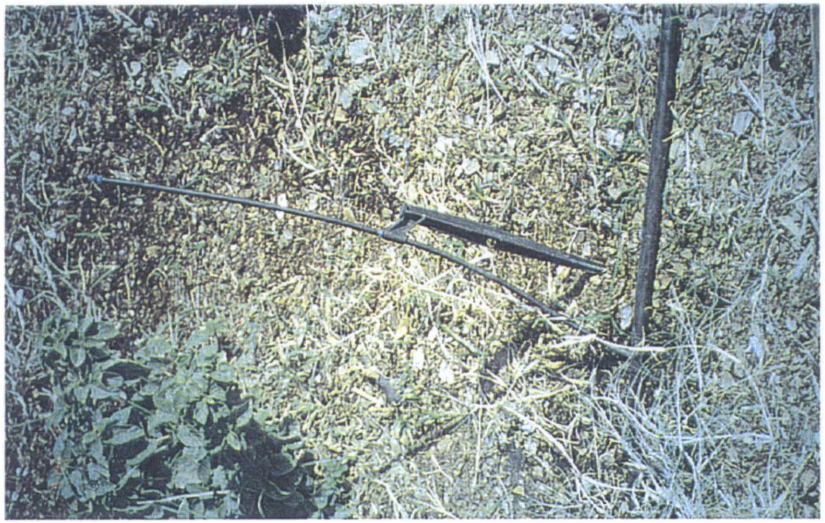

Figure 7. Irrigation Riser

This is an irrigation riser in the bed shown in Fig. 6. Some areas of the bed are very wet while others are bone dry. The wispy riser is very susceptable to winds and vandalism. In addition it is very difficult to direct the spray.

The bed has a weed barrier but the bermudagrass is doing well anyway. The mulch layer has too many fine particles and is not thick enough.

Figure 8. Groundcover Planting

This attractive groundcover of asian jasmine is very effective at preventing most weed invasion. However, bermudagrass is seen in some places. A light application of a selective herbicide will control this problem.

The lower part of the photo shows a bent piece of steel edging that was probably snagged by a lawnmower. It is now a hazard.

Figure 9. Median Planting of India Hawthorne

This median planting is comprised of india hawthorne, crapemyrtle, and a juniper groundcover. Hawthorne is proving to be a very durable plant. It is responsive to good care, long-lived, and attractive. This shrub should be used more often in roadside plantings.

Crapemyrtles also do better in situations such as this where the root system is shaded.

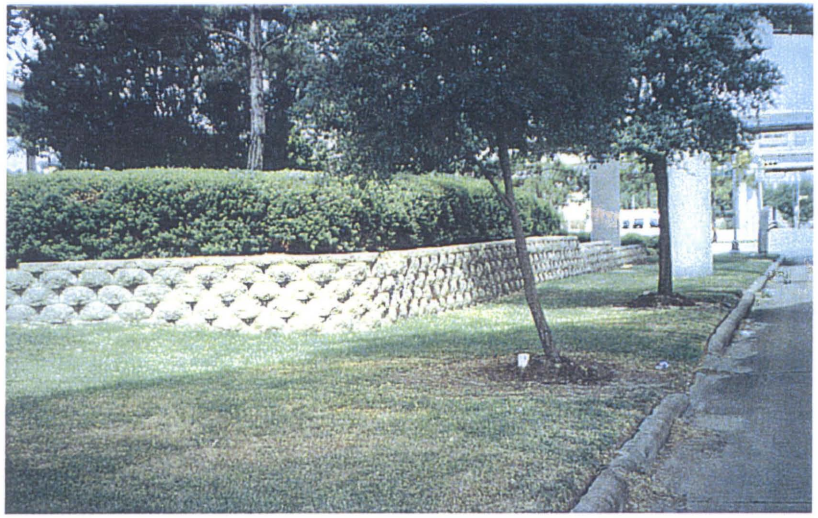

Figure 10. Shrubs in Raised Planter

This raised planter is separated from the bermudagrass below and forms a well-drained medium for the plants.

The white irrigation riser housing is a maintenance problem and the trees are old enough to do without the mulch rings since their feeder roots are now well beyond the saucer.

Figure 11. Pampasgrass on Slope

The pampasgrass on this slope is providing attractive cover while being generally weed-free. There are some gaps where plants have died but these can be replaced.

This bed has no mulch layer but does have a vegetation barrier installed.

Figure 12. Prostrate Junipers on Slope

This slope is covered in a mature planting of a low-growing juniper. This type of plant can be seen growing successfully in roadside plantings all over the state.

PART II - THE GENERAL CONTRACTING PROCESS

The researchers found many of the weed maintenance problems were caused by inadequate landscape maintenance contracts. Three aspects of this process which must be considered are as follows:

- Type of contractor the process attracts;
- Type of activities the contract covers; and
- How well the contract is inspected and enforced.

TYPES OF MAINTENANCE CONTRACTS

TxDOT currently uses the following three methods of contracting for maintenance of landscape projects:

Private Contracts

- Private contracts are those let to private contractors through the competitive bid process. These types of contracts originate in two ways. Often, the landscape installation contract will include a separate bid item for landscape maintenance that begins after the 90-day establishment period ends. This item can be written for any length of time, but 15 months is common. After this extended maintenance period has expired, or after the 90-day period if no extended period is provided, a new maintenance contract may be let. These contracts are often of two growing seasons duration.

State-Use Contracts

- State-use contracts are those contracts awarded to organizations affiliated with Mental Health & Mental Retardation (MHMR) agencies that provide work environments for their residents. These contracts are awarded based on a negotiated fair-market price with the agency.

Community Agreements

- Community agreements are those contracts whereby a city or civic group agrees to assume responsibility for the maintenance of specific project sites.

These agreements may include any or all levels of maintenance, including full-width mowing, weeding, and irrigation system maintenance.

The contracting method used varies greatly across the state and depends on the types and numbers of projects, the relationship between TxDOT and the cities involved, the commitment of local civic groups, and the availability of MHMR workshops.

TYPES OF CONTRACTORS

The qualifications and skills of a contractor vary and there are some significant differences.

State-Use Contracts

The general consensus within the department regarding these contracts is: 'if the foreman is knowledgeable and effective, he can do good work'. If this condition does not exist then they are generally disliked and decried due to their high cost and poor performance. Unfortunately, the instances of good leadership on the crews is infrequent. Also, the skills available within these organizations are very limited. Some districts use these groups only for simple operations such as litter-pickup. These groups cannot generally provide herbicide applications and their understanding of plant materials and irrigation requirements is often nonexistent.

Maintenance Agreements with Cities, Quasi-governmental Agencies, and Civic Groups

Contracts with city governments have distinct advantages over other types of contracts *if all goes well.* If a city feels the appearance of their community is tied in to the appearance of the highway system and they have the commitment and resources, the city can be, by far, the best choice for performing the maintenance of landscape projects. Some cities are now doing the maintenance themselves. The best examples are Wichita Falls, Bellmead, and numerous small cities in the Pharr district. In most cases, cities use parks department personnel so the skill levels can be very high. If the general public wants their highways to look good then this pressure may be enough to keep the city's commitment high. However, budgets and

public opinion do change. While this seems to be a rare occurrence, this possibility should be addressed when considering these types of agreements.

Quasi-governmental agencies such as chambers of commerce often have high levels of commitment to perform well but their resources may be more limited than those of the city. Their leadership, commitment and funding sources must be considered.

Civic groups such as garden clubs, merchants associations, and beautification committees are often good partners. While these groups can be the flighty, poorly funded, and most variable in commitment, good ones are capable of building some effective partnerships. Ironically, it seems that the most effective citizen maintenance groups may be those with the smallest bureaucracy, fewest members, and highest average age. At this lowest level of community participation the researchers found only one instance of an individual who was retired and used a project as a source of activity and community service. They may not take kindly to formal agreements but they may be very dependable and the quality of their work may be very high. These instances are obviously isolated and the projects small, but they can be visible examples of citizen pride and responsibility for the whole community. TxDOT should publicly praise these individuals for their efforts.

Private Contractors

Private contracting companies are used by TxDOT under Extended Maintenance Items and Post-construction Contracts. Each contract attracts different types of contractors.

Extended Maintenance Contracts

It had been thought that the installation contractors, due to their familiarity of the project and the existing contractual relationship with TxDOT, would most likely perform the best on these projects. In some cases this is true but not in every case. Often, these contractors may be home-based many miles from the project site and are less likely to respond in a timely manner to perform on contract items. Also, the contractor may have placed most of their bid

dollars in the construction phase, thereby reducing the incentive to perform well on the maintenance portion. Since the amount of these contacts may only be in the few thousands of dollars, liquidated damages are often ineffective and not worth the effort. If the contractor defaults, the period of time before a new contract can be let may allow the project to deteriorate to serious levels.

Post-Construction Contracts

These contracts are often let on a local basis which allow local contractors to enter the process. This can greatly improve access to the contractor, and allows the building of better relationships through frequent communications. Also, these types of contractors may have more incentive to perform well due to public visibility of their work. The skill level may range from very high to very low. In some cases, electrical contracting firms win these contracts.

Issues Related to the Use of Private Contractors

In some districts within TxDOT, "landscape work" is often seen as simple, non-exacting, and easily accomplished with low-skilled labor. Consequently, bidder qualifications are lax. It is not uncommon for companies well outside the domain of the landscape industry (ex. electrical contractors) to bid on and win maintenance contracts. Consequently, the skills of contractors winning bids for landscape maintenance contracts is highly variable. Some are quite competent and well-versed in plant care while others know much less.

This variable seems to be reflected in the regional availability of contractors. Large urban areas like Dallas and Houston have a greater number of larger, more knowledgeable contractors while smaller urban centers such as Abilene, Odessa, Amarillo, and Lufkin have fewer. The researchers also found that larger urban areas have more project sites and consequently larger contract prices that may run up to a quarter of a million dollars. This helps keep many small, disreputable firms from bidding on the projects. In the smaller urban centers, the contractors tend to be the "mom and pop" type of company and have fewer

employees. Some firms like this may be highly skilled but are often intimidated by TxDOT's bidding and contracting process.

Another serious problem is that there are few attractive avenues open to project inspectors to enforce performance of the contract. Current options include either imposing liquidated damages or placing the contractor in default. Neither of these options is something that TxDOT would prefer to pursue on such a small contract. This was demonstrated by one comment: "We have been instructed that there will be no liquidated damages!" The researchers also encountered instances where the contractor refused to complete some phase of the contract, yet complained that they should be paid for the work regardless. In at least three of these instances they were paid for work not performed. (These comments came from three different districts.)

In some districts, disreputable contractors are learning how to use this situation to their advantage. They may routinely neglect portions of the contract but still clamor for payment. Even if a contractor is placed in default, they are still allowed to bid on other, similar projects. The effect of this, beyond the waste of money, is to frustrate and demoralize those in charge of enforcing these contracts. One of the side effects of this problem is that these contractors are notoriously low bidders and may keep reputable contractors from attempting to bid on the projects. Several districts commented that many contractors refuse to bid on landscape maintenance projects because they go for such low prices.

Table 2. Summary & Comparison of Contractor Types

Type of Contractor		Advantages	Disadvantages
Private Contractor	**Construction Contractor**	Already on site and knows the project well. Most often is a larger firm with persons skilled in the landscape industry.	Home office may be hundreds of miles away. May not be really interested in maintenance work, and will delay on required activities.
	Post-const. Contractor	More likely to be a local contractor; communication is improved. May be more geared toward landscape maintenance.	Skill levels are highly variable. May or may not have any experience in landscape industry.
State-use Contractor		Quality of work can be high if foreman is skilled in landscape work. Is from the local area. May be highly motivated to do a good job.	Quality of work can be low if foreman is unskilled in landscape work. Usually more expensive than competitive-bid contracts.
City and Civic Agreements		May be highly motivated due to public pressure to keep projects clean. Have vested interest in appearance of project. Skill levels likely to be high. No cost to TxDOT.	If government: budget cuts or shortfalls may prompt them to give the project back to TxDOT. If civic group: resources may be inadequate, expertise may be low, enthusiasm may diminish over time.

Contract Specifications

It was frequently commented that it was not uncommon for contractors bidding on landscape maintenance contracts to be completely unaware, even after being awarded the contract, that the few pages of general notes in the contract were supported by the more comprehensive provisions of the Texas Standard Specifications Manual. This was cited as having led to confrontations.

The specifications of Item 193 - Landscape Maintenance provide an adequate range of maintenance activities but in some cases, if elaboration is not provided, interpretations may vary as to the extent and quality required by the item's provisions. A good example is the provision for pruning. While the number of pruning cycles is limited to one per year, the style or reason for pruning is largely left to the contractor if not described in detail. Shrubs may be pruned to near-topiary and still be within the parameters of this item. The lack of specificity as to the manner and mode of landscape maintenance items may leave too much to the interpretation of the contractor and the inspector.

Contract Enforcement

The researchers found where key provisions of a landscape contract were enforced only minimally or not at all. Exactly why some provisions are not enforced will vary considerably but some reasons are listed below.

- The inspector is not reviewing the project often enough and does not know that something is not being done.
- The inspector does not know that the contractor is responsible for that work.
- The contractor does not know that he is responsible for it and the inspector is reluctant to force the issue.
- The contractor has convinced an inexperienced inspector that he has already done it the way it should be done.
- The contractor refuses to do the work for whatever reason and the inspector has limited support in forcing the completion of the work.
- The contract may be vague as to what constitutes a properly completed activity.
- The inspector may have other, larger projects that require more attention.

Most landscape contract inspectors enjoy working with landscape projects. It offers a change of pace and many like to work with plant material. But even in many of these cases, the inspectors may be unfamiliar with landscape construction, plant material, irrigation systems,

or sound horticultural practices. In such cases the contractor will likely know more about the subject than the inspector and may use this to their advantage.

Most landscape maintenance contracts are written by district vegetation managers and then let to bid through the area offices. In most districts, vegetation managers and landscape architects are heavily relied upon as sources of information for the inspectors of these contracts. Where this support exists and is used, projects are much more successful. The need for expertise by the vegetation manager and landscape architect should not be underestimated. These persons should be experienced, well-trained, and lines of communication between them and inspectors actively encouraged.

Attitudes Towards Landscaping

Roadside landscaping is considered by many in the department to be a low-tech endeavor when compared to the exacting demands of an engineered roadway or bridge structure. Consequently, problems associated with landscapes frequently do not attract attention until they are at a critical stage. (A critical stage may be defined as: "when the public starts complaining".) This same attitude may be the reason that little consideration has been given to the standards and procedures of the landscape industry in general and how they relate to TxDOT's needs. The standards and specifications of TxDOT largely reflect the standards of the engineering profession and the Association of General Contractors. It may be felt by some that the these standards and procedures are good enough for landscaping if they are good enough for highways.

The procedures of the landscape contracting industry do not mesh well with those of the engineering and general contracting industries. This is primarily due to the types of companies in the landscape industry (often small, sole proprietorships), the seasonality of planting, the variability of plants in general and the special skills required to understand plants and plant environments. All these issues are potential problem areas if the contracting system is not designed to take best advantage of them. TxDOT's contracting system is

designed for a different scale of construction and contracting than that required for landscaping and this is a contributing factor to some landscape installation and maintenance problems.

RECOMMENDATIONS

The problems currently experienced in maintaining landscape projects will not be completely solved until fundamental changes are instituted. Three things are required as the foundation of a successful landscape maintenance contract.

1) A bidding and contracting process that increases the chances that the bidder is knowledgeable about the subject and financially able to complete the contract.
   - ♦ A review of current landscape industry standards and procedures should be conducted to identify areas where TxDOT specifications and procedures might be made more reflective of industry practices.
   - ♦ Measures should be enacted to insure bidder competency. There is currently a program called the Texas Landscape Contractors Certification Program which has been established, in part, by the Texas Agricultural Extension Service and The Texas Association of Landscape Contractors. This program is about five years old and might be used as a pre-qualification device to insure a reasonable level of competency.
   - ♦ Inspectors should be encouraged and supported to strictly enforce contract provisions in landscape maintenance contracts. This is the surest way to discourage disreputable contractors from bidding on these contracts.
   - ♦ A provision should be established whereby contractors with a record of defaulting on contracts can be barred from bidding on like contracts for a significant period of time.
2) Specifications should be more detailed and specific regarding maintenance activities.
   - ♦ Contract writers should consider including the entire Item 193 specification in the general notes for landscape maintenance contracts.

- Items included in the specification that could be variously interpreted should be expanded in detail.
- Specifications should be written as much for the inspector as the contractor. This increased specificity will also enable the inspector to better distinguish between proper and improper performance.

3) Inspectors need to be more knowledgeable about landscape maintenance, seek and use all available support, and give the contract serious and close attention. Generally, TxDOT should take landscape maintenance more seriously and provide for more stringent control of all facets of the process. The best tools the department has are the project inspectors.
   - TxDOT has published a Landscape Inspectors Manual but it is rarely used. It should be supplemented with more formal training. This training need not be long. TxDOT already has the personnel best qualified to conduct such training.
   - At present, most projects are inspected by persons from within the area offices. Consideration should be given to using one, district-based person to inspect all landscape projects. This would allow the development of experience in an individual and encourage closer communication with support personnel such as vegetation managers and landscape architects.

PART III - ISSUES AFFECTING WEED CONTROL

THE NATURE OF WEEDS

A weed has been generally defined as a plant that is growing where it is not desired. This means that any plant can be a weed depending on where it is growing. Most weeds in roadside landscape projects will be the grasses of the roadside.

Classification of Weeds

Weeds are divided into three classifications: annuals, biennials and perennials.

- Annuals complete their life cycle in less than one year. They reproduce from seeds and because most annuals produce a tremendous number of seeds, they can be very difficult to control. This group is further divided based on part of the year in which their life cycle occurs: cool season (winter annuals), or warm season (summer annuals).
- Biennials are plants that live for more than one year but not over two years. The first year may be only a rosette stage followed the next year by increased vegetative growth, flowering, fruiting, and death. Only a few weeds fall into this category.
- Perennials live for more than two years and may live almost indefinitely. Most reproduce by seed and many spread vegetatively. Perennials may be warm or cool season species. This group is divided into simple and creeping perennials.
  - Simple perennials spread by seed. They have no natural means of spreading vegetatively but if injured or cut, the cut pieces may produce new plants. The roots are fleshy and may grow very large.
  - Creeping perennials reproduce by creeping roots, creeping aboveground stems, (stolons), or creeping below-ground stems (rhizomes). In addition, they may reproduce by seed. Some may be tuberous such as nutsedges. This group is the most difficult to control.

Implication of Weed Type for Control Method

The plant type determines the method of control and when it is used. The following table outlines the basic control approaches for different weed types.

Table 3. Weed Control Option by Weed Type.

Weed Type	Control Options
Annuals & Biennials	Prevent light from reaching germinating seed. Pre-emergent herbicides applied before season of germination. After germination: Hand-weeding. Post-emergent herbicides. Cultivation (not recommended due to root damage to desirables).
Perennials	Hand-weeding. Post-emergent herbicides.

The season in which a weed species occurs determines the optimum times of treatment. This is particularly important regarding annuals. Many annuals produce prodigious amounts of seed, not all of which may germinate at the same time. Consequently, one flowering production may cause new plants to pop up all season long, requiring frequent hand-weeding

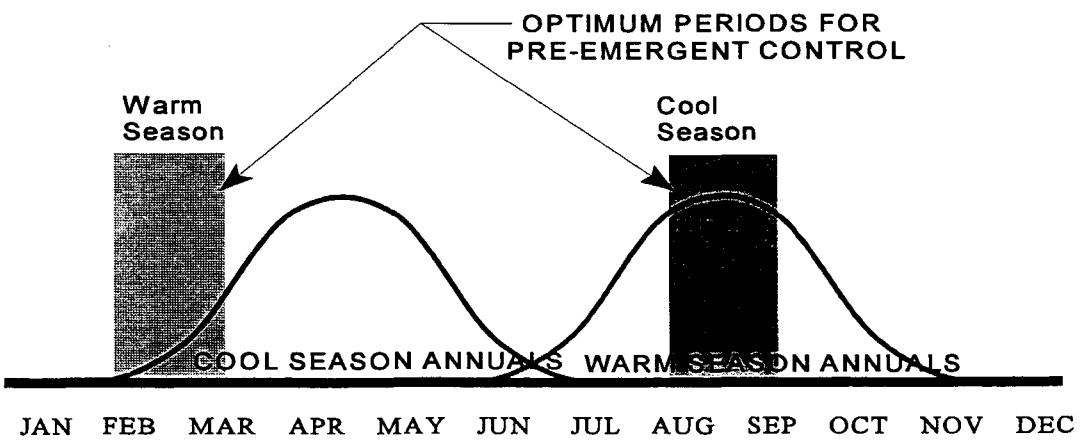

Figure 13. Weed Control Periods for Annual Weeds.

or herbicide application. Depending on the species, pre-emergent applications early in the season can reduce weed problems all season long. Figure 13 shows the optimum time to control annual weeds is just before they germinate. Not only are last year's seed crop prevented from germination, the development of new seed is also curtailed. If pre-emergents are not used, the only other options are hand-weeding and post-emergent herbicides.

Common Roadside Weeds

The following table lists the most common weed types found in roadside landscape projects. Since the most appropriate method of control is dependent on the species being treated, it is important to be able to identify the most common problem plants. Appendix G lists some recommended references that will provide good photographs and descriptions.

Table 4. Common Weed Species in Roadside Landscape Projects.*

Grasses			
Annuals		**Perennials**	
Warm Season	Cool Season	Warm season	Cool Season
Barnyardgrass Junglerice Goosegrass Crabgrass	Rescuegrass Japanese brome Italian ryegrass Annual bluegrass	Bermudagrass Knotroot bristlegrass Johnsongrass Dallisgrass Fall witchgrass Tumble windmillgrass Buffalograss Silver bluestem KR bluestem	Scribner rosettegrass Fescues Little bluestem Texas wintergrass Wildrye
Broadleafs			
Spurges Groundsel Common ragweed Sandbur Goathead Pigweed		Groundsel Thistles Kochia Bindweed Nutsedge	

* Scientific names are provided in Appendix G.

LANDSCAPE DESIGN CONSIDERATIONS

Landscape maintenance should always be considered prior to deciding which type of landscape planting is to occur. Each style of planting will require different levels of maintenance and each of these should be explored thoroughly before selecting a design concept. The following planting approaches cover most landscape types and are historically used on the right-of-way. A project may include more than one type. They are as follows:

- Trees in turf: non-mow areas, routinely mowed areas,
- Shrubs in turf,
- Shrubs in confined beds, and
- Shrubs in raised planters.

Trees in Turf: Non-mow Areas

This approach seeks to establish trees in an area where no routine or long-term maintenance activities are to take place. Such areas are usually termed reforestation, native planting, or re-naturalization. Once the project is established, irrigation, pruning, and insect control could be abandoned as part of a native approach if desired. No long-term maintenance is intended. Plants used in this approach will generally be native species only although some hardy, non-natives will sometimes be suitable. Design considerations include the following:

- Irrigation for establishment,
- Control of weeds in tree-well to reduce weed competition.
- Removal of diseased or dead plant parts during establishment, and
- Control of serious insect pests during establishment.

Trees in Turf: Routinely Mowed Areas

This type of planting is usually required in developed areas where a neater appearance is necessary. This approach requires long-term commitment to most maintenance activities. Because most of these types of plantings are in high-visibility areas, their maintenance levels are higher and plant selection is open to more non-native ornamentals. Maintenance requirements are as follows:

- Irrigation for establishment (long-term optional depending on climate),
- Maintenance of treewells and mulch replacement during establishment,
- Removal of diseased or dead plant parts,
- Control of serious insect pests,
- Removal of weeds from treewell during establishment (hand removal or herbicide), and
- Continued control of tall grass at base of tree (hand-weeding or herbicide).

Shrubs in Turf

Shrubs may also be installed following the two approaches used for trees. Shrubs may be planted as individuals or as groups within the boundaries of natural or non-mow areas. In non-mow areas the demise of one or a few shrubs will generally not show up as serious gap which will enable replacement to be optional instead of required as it may be for trees. Non-mow area maintenance requirements are:

- Irrigation for establishment, and
- Removal of dead plants.

Shrubs may also be planted as individuals or groups in routinely mowed turf areas. Because these plantings are usually in high-visibility areas, maintenance will be more intensive. Plants used in this context are often ornamental, non-native selections, although some natives are frequently suitable. Maintenance requirements are:

- Irrigation for establishment,
- Removal of dead or diseased parts,
- Replacement of dead or damaged plants,
- Fertilization,
- Removal or trimming of grass and weeds until plant is established, and
- Mowing around plant.

Shrubs in Confined Beds

Shrubs may also be planted in areas confined by an edging or pavement. These areas are usually arranged as shrub masses within these confines. These areas may be delineated by paving or by a type of bed edging. The planting may include trees. Maintenance requirements are listed below:

- Irrigation for establishment and for long-term maintenance,
- Removal of dead or diseased parts,
- Replacement of dead or damaged plants,
- Removal of grass and weeds until plant-mass is established (hand removal or herbicide),
- Fertilization,
- Replacement of mulch until plants are established, and
- Trimming of grass at edging (herbicide or string trimmer).

Shrubs in Raised Planters

Shrubs may be planted in raised planters to reduce maintenance. Maintenance requirements for raised planters are usually less than would be encountered in at-grade, confined beds because they are less susceptible to weed or grass seed that may be blown or washed into the planting. Also, invasion of the bed by surface grass runners is much reduced or eliminated in raised planters. Maintenance requirements are:

- Irrigation for establishment and for long-term maintenance,
- Removal of dead or diseased parts.
- Replacement of dead or damaged plants,
- Removal or trimming of grass and weeds until plant-mass is established (hand removal or herbicide),
- Fertilization,
- Replacement of mulch until plants are established, and
- Trimming of grass at edging (herbicide or string trimmer).

Use of Native Plants

A distinction should be noted for the term native planting. A native planting is one in which elements of the surrounding environment are used to recreate, to a degree, the natural occurring landscape character of the area and in which no routine, long-term maintenance activities are intended. Once established, plants are expected to develop, die, or mature as would be expected of the natively growing plant communities of the area.

In many cases, native plants are used in a cultivated and maintained context and are simply the substitution of assumed hardier plants for those of non-native origin. Regardless of where the plants are native to, they must adhere to the criteria for establishing plantings to meet the goal of a maintainable landscape planting. These requirements again are: longevity, dense foliage, evergreen, non-invasive growth, and responsiveness to fertilization. Most native Texas plants will fall short of meeting these requirements. Most are deciduous in nature or have the habit of defoliating during times of high stress such as summer drought. Most are also slow to put on foliage in the spring and many have sparse foliage and open character, which allows the germination of many grasses and forbs.

The use of grasses (natives or otherwise) in ornamental situations should be considered carefully. Their herbaceous character severely limits herbicide usage around them. Also, the removal of last year's growth can be labor intensive.

The majority of native plants should be reserved for use in plantings of a restoration type, where neat, well-defined edges are not an aesthetic requirement. The use of native plants is encouraged but a full description of the requirements of this approach is not within the scope of this study. The needs and the techniques of native plantings are significantly different from that of ornamental plants. This is an area where more study is needed.

Landscape Design Goals for Weed Control

The goal of design for weed control should be to quickly establish a dense cover of desirable vegetation so that weeds are not able to effectively compete. Plantings should be designed so that at the end of two complete growing seasons, the planting shall form a complete canopy. This goal is the foundation of much of the recommendations to follow in this report. Therefore, issues affecting healthy, rapid, plant establishment are also weed control issues.

PLANT SELECTION

Weed control in the early life of a planting is principally determined by the types of shrubs installed. While trees eventually do create canopies that are effective at shading out weeds, this only occurs in later stages of the planting. For that reason, this section deals only with shrub selections.

Desirable Shrub Traits

The goal of complete vegetative cover at the end of two growing seasons places strict requirements on the selection of plants for landscape projects. The requirements for shrubs or ground covers are:

- The plant holds its foliage all year (evergreen),
- The plant foliage is dense enough to completely shade ground surface,
- The plant is reasonably long-lived (10 + years),
- The plant has a spreading growth habit rather than upright, and
- The plant foliage is at least 200 mm deep.

Selecting Shrub Species

Table 5 is a list of shrub or ground cover species that have been or are commonly used in right-of-way plantings throughout most of the state as taken from bid tabulation sheets for the last five years. Those that are expected to meet the performance requirements listed above are marked with an asterisk. More of these plant species have been observed doing well in mature plantings than most other species. The performance of any plant is variable

depending on the part of the state in which it is growing and the overall condition of its growing environment. Some plants not marked may do well in specific applications.

Table 5. Shrubs Commonly Used on the Right-of-way.

Groundcovers	Low shrubs (76 mm or less)		Tall shrubs (more than 76 mm)	
Asian jasmine	Autumn sage	Pavonia	Abelia*	Oleander*
Bedding plants[1]	Barberry	Rabbitbush	Althea	Pampasgrass*[2]
Honeysuckle	Cotoneaster	Rose	Crapemyrtle	Philodrendron
Trumpet creeper	Daniantia	Sotol	Elaeagnus*	Photina
Virginia creeper	Dwarf yaupon*		Forsythia	Santolina
	India hawthorne*		Fountaingrass	Spirea
	Junipers*		Four-wing	Sumac
	Lantana		Saltbush	Texas Sage
	Lilac		Juniper*	Waxmyrtle
	Nandina		Muhleygrass	Wisteria
			Nandina	

[1] Annual plants that are used to provide seasonal color.

[2] While not an evergreen, the density and accumulation of old foliage have essentially the same effect as an evergreen plant.

As can be seen, the number of plants meeting the requirements is not large. The decision to use any plant is dependant on many factors, not the least of which is the designer's preference for specific aesthetic effects. The list presented is offered as a guide to accomplishing the specific goal of the fastest evergreen bed cover possible.

Shrub Size and Spacing

The most appropriate container size for a plant varies with each plant species. A good knowledge of species growth rates for an area is indispensable in plant selection. Mature spacing, as given in most references, is usually for plants growing under optimum conditions. In most roadside situations, heat, wind, and pollution modify stated growth rates considerably. In most cases, plants may need to be spaced closer or larger sizes installed.

This will increase the cost of the installation but these costs should be considered in light of anticipated reductions in long-term maintenance costs and improved aesthetic quality. If the closer spacing increases costs excessively, consideration should be given to reducing the bed size rather than using the wider spacings.

Table 6 is a comparison of some typical plant spacing alternatives and their comparative installation costs. The chart shows how much a plant must be expected to grow in a twelve month period in order to reach the complete-coverage goal. As can also be seen by the chart, the spread of the plant at time of planting has considerable impact. This is an excellent example of the importance of good inspection in insuring that plants less than specified are not installed. The shaded areas indicate those spacings that should be considered *maximum* for most plants. Some fast-growing shrubs such as pampasgrass and elaeagnus may exceed these rates in some places.

Table 6. Comparison of Rate of Growth at Different Plant Spacings.

1-Gallon plant @ $5.00 ea. 250 mm foliage spread					
Plant spacing (mm)	Cost per sq.meter	Distance between foliage at planting. (mm)		Increase in spread required per yr to cover bed. (mm)	Avg. % increase per yr to cover bed in two years.
300	$31.12	50		25	9%
450	$27.56	200		100	34%
600	$15.60	350		175	56%
910	$6.89	660		330	94%

5-Gallon plant @ $20.00 ea. 380 & 450 mm foliage spread							
Plant spacing (mm)	Cost per sq. meter	Distance between foliage of different plant spreads. (mm)		Increase in spread required per yr to cover bed. (mm)		Avg. % increase per yr to cover bed in two years.	
		380 sprd	450 sprd	380 sprd	450 sprd	380 sprd	450 sprd
600	$62.21	228	150	114	76	27%	17%
760	$39.72	380	300	190	150	42%	29%
910	$27.66	533	450	267	228	56%	42%
1220	$15.50	830	760	419	380	71%	64%
1520	$9.90	1143	1065	711	533	120%	70%

The shaded areas are recommended maximums because higher rates of growth would likely occur only under optimal conditions. Therefore, these are considered a compromise between coverage and cost.

BED PREPARATION

The preparation of the area in which the bed is to be installed is a critical component of controlling weed problems later. It must be assumed that whatever is growing there now may be a problem later if not thoroughly removed. The goal of this phase is to remove as much *perennial* vegetation as possible. Perennials, particularly perennial grasses, have extensive root systems allowing them to survive tough growing conditions for a long time. Removing perennials after plants are installed is the costliest type of weed control.

The type of bed preparation procedures used will vary with the area of the state, but in most situations the following procedures should be considered the minimums. These measures assume a planting of shrubs that are to be kept in a weed-free condition usually in a high-visibility area. The alternatives available in preparing an area to be planted are:

- Sod removal;
- Soil removal, replacement, or addition;
- Herbicides:
  - soil sterilization,
  - pre-emergents, and
  - post-emergents; and
- Non-herbicide alternatives:
  - repeat-till (see 10/10 Method).

Sod Removal

The goal of this phase is to remove existing root systems and dormant seeds from the top few inches of the soil. Obviously, the deeper the excavation, the more effective the results. To be effective, the process should remove the soil to a minimum depth of 50 mm below the *soil line*. The preferred depth is 76 mm. The distinction about soil line is important because matted grasses, thatch, and an uneven ground surface can reduce the depth to much less. To insure that the proper depth is attained, require the area be mowed to a height of 25 mm prior to sod removal.

The proper method of removing sod for anything but small areas is the use of a mechanical sod-cutter. These machines can be set to varying depths of cut and are quite efficient. The use of larger equipment such as bobcats and front-end loaders is much less precise and if the ground is soft, they may press surface layers (with their seeds and roots) deeper into the soil. The use of shovels is acceptable for small areas but close inspection is required during the operation to insure that the laborers are excavating to the desired depth.

Soil Removal, Replacement or Addition

In some cases, the existing soil may be unfavorable for planting due to extensive perennial rhizomes or other contaminants such as herbicide residue. Other instances include those designs where raised planters or retaining walls are included in the project. In such cases it is necessary to import new topsoil into an area to be planted. The most significant danger of imported soil is that it may contain weed seeds or rhizomes. If this occurs, the cost of weed control will rise dramatically.

The term topsoil implies that the soil comes from the top few inches of the soil surface. While this zone is often the most fertile and the most conducive to plant growth, it is the worst possible soil for bed planting due to the potential weed hazard involved. For this reason it is best to never use the term "topsoil" when specifying backfill for planting areas. Instead it is best to describe the soil in terms of its lack of any vegetative parts, and its drainage. The fertility can be added later with fertilizers. To distinguish a clean soil from a contaminated one may not be easy. A soil that appears clean may have thousands of near microscopic seeds throughout. Three options are available to deal with this problem.

- Require that a soil sample be sent to a soils testing laboratory to be analyzed for the presence of seeds or other plant parts. This method may cost in the area of $100.00 to $200.00.
- Visit the source of the soil to see exactly what strata is being excavated and see what type of vegetation is growing in the area of the pit. Samples of the approved soil should be taken to compare with future material delivered to the site to

confirm that the source has not changed during construction.

- Specify a special mix that does not include any soil. These mixes are similar to those used by nursery growers for container-grown plants. They are widely available and are more expensive than soil backfill by 50-100% depending on the type of materials used. Materials used for special mixes are similar or identical to the soil amendments discussed in the following section. The major differences will be particle size (many fines less than 10 mm), and the degree to which the material has been composted. These materials are usually mixed with clean masonry sand at rates of 85-90% organic material to 10-15% sand. This provides a very well-drained mix that works well where excellent drainage is required.

Regardless of which technique is used, the importance of providing a clean planting medium cannot be stressed too strongly.

Bed Preparation with Herbicides

Herbicides have been used to control weeds in landscape plantings for many years. Today, improved herbicides are available that are more effective, easier to use, and safer. The decision to use herbicides will involve a number of issues and these are discussed in the section Herbicides in Ornamental Plantings.

- Contact herbicide applied to existing vegetation,
- Mow dead vegetation to 25 mm height, remove clippings,
- Remove sod to 76 mm depth,
- Roto-till amendments into soil (optional, see the section Soil Amendments),
- Rake the area to finish grade,
- Apply pre-emergent herbicide to soil (see the section Herbicides in Ornamental Plantings), and
- Install vegetation barrier (optional, see the section Landscape Mulches and Fabrics).

Non-Herbicide Alternatives

In some cases, the decision may be made to avoid the use of herbicides completely. In these instances, the complete removal of existing vegetation is even more critical. The process includes:

- Mow existing vegetation to 25 mm height, remove clippings,
- Remove sod to 75 mm depth,
- Roto-till amendments into soil (optional, see the section Soil Amendments),
- Rake the area to finish grade, and
- Install vegetation barrier (optional, see section on Landscape Mulches and Weed Fabrics).

The 10/10 Method (Repeat-till)

In most instances, upper soil contains dormant seeds of potential weeds which may quickly germinate after the sod is removed and the soil tilled. An old technique is to allow time after the initial tilling for the seeds to germinate. After they have germinated, uproot them by another tilling operation. The disadvantage of this method is the length of time the soil is exposed to erosion and other seed invasion. This method is not as effective against perennial weeds since they are generally slower to germinate. The 10/10 method includes the following instructions:

- Mow existing vegetation to 25 mm height, remove clippings,
- Remove sod to 75 mm depth,
- Roto-till soil to min. 100 mm, allow to rest for 10 days,
- Roto-till soil to min. 100 mm, allow to rest for 10 days,
- Roto-till amendments into soil (optional, see the section Soil Amendments),
- Rake the area to finish grade, and
- Install vegetation barrier (optional, see section Landscape Mulches and Weed Fabrics).

SOIL AMENDMENTS

Soil amendments are materials incorporated into the soil and are intended to improve its ability to support plant growth. A soil amendment may be one of two general types:

- Organics, or
- Superabsorbants.

Organic Soil Amendments

Most organic soil amendments used today are barks, tree trimmings, cottonseed burrs, or other plant parts that have been composted to some degree. It is important that soil amendments have undergone a composting process of at least a few months. There is no simple test to confirm the extent of decomposition and different materials decompose at different rates. Generally, composted materials will be darker in color but this is not always a reliable indicator. The best method of assuring the quality of a proposed soil amendment is to visit the supplier to see exactly what they intend to ship.

Recent Research in the Use of Soil Amendments

Over the past few years there have been a number of studies which have shown that the inclusion of soil amendments does not provide any benefit to plants and in many cases, has a detrimental effect. The reason for this is attributed to the fact that in an unsaturated soil, water will only move from a coarse-textured soil to a fine-textured soil. This is a matter of soil physics. Studies have shown that when a nursery plant is placed in an amended soil, the coarse texture of the rootball of the plant will quickly give up moisture to the finer-textured soil around it. This amended soil in turn gives up its moisture to the finer soils surrounding it. This leads to difficult establishment due to water stress and a generally stunted plant (Whitcomb 1975) (Schulte and Whitcomb 1975).

The use of soil amendments in poorly drained clays for tree plantings has been shown to be particularly undesirable since the increased pore space is more likely to hold water and create a deoxygenated sump (Carnell and Anderson 1986). Other studies have found that organic

matter can also contribute to local soil deoxygenation by virtue of the oxygen consumed by decomposer micro-organisms (Kopinga 1985).

Soil amendments have shown some value, however, in areas where the entire rooting area of the plant is amended, such as in the case of a bed planting. In these cases, there is no water movement out of the soil except at the edges of the planting (Whitcomb 1987).

The decision of whether or not to use soil amendments must consider the character of the existing soil. For tree planting, there is sufficient evidence that the practice provides no significant benefit to the plant and the money could be better spent elsewhere, such as in mulches and weed control. Where shrubs are being planted as part of a large bed and where the entire area is being treated, soil amendments are not as detrimental and can improve drainage. However, in these cases, careful irrigation is required and surface mulch layers must be maintained.

Superabsorbants

Superabsorbants are also known as hydrogels. They are starch derivatives and have appeared in greater varieties in the landscape trade over the last few years. Some of the trade names include: Stasorb, Aqua-Terre, Permasorb, Super Slurper, and Terra-Sorb. The granules may expand up to 200 times in weight when wetted and some may hold the water for months.

Studies have yielded conflicting results on the use of these materials. Some research has indicated significant positive effects (Callahan, Lindley et al. 1989)(Ingram and Burbage 1985) while others have shown none at all (Appleton and Whitcomb 1982)(Tomlinson and Bilderback 1985)(Taylor and Halfacre 1986)(Hummel and Johnson 1985)(Mayens and Paps 1986). Studies dealing specifically with landscape rather than container trials generally concur with those that found no significant effects (Hitchmough 1994). Until further research reveals information to the contrary, these amendments do not appear to offer any benefit to landscape plantings.

FERTILIZERS

Fertilizers are important to the establishment of newly planted trees and shrubs. In some instances, the existing soil may contain enough of the nutrients the plant needs, but in most situations this is not the case. The amount of fertilizer needed depends on factors such as nutrients already present, soil, type of plant, amount of water available, temperature, and season.

The information most helpful in arriving at a proper fertilizer type, amount, and rate is gained from a soil test. The test should identify the levels of the macro and micronutrients present as well as the soil pH. In an optimal situation, the amounts of nutrients provided would be carefully synchronized between plant species, environment, season, and water. If soil amendments are used, the nitrogen amounts will need to be adjusted upward since the organic materials will use available nitrogen as part of the decomposition process. Consequently, there is no one schedule for fertilization that can be recommended for all situations. The guidelines in Table 7 should be used as a beginning point in specifying fertilizer use in landscape plantings. Subsequent applications should be based on observed plant condition, soil type, and environmental conditions.

Fertilization Rates

Whitcomb (1987) provides a list of the ranges that should be used as a guide in determining the amounts of nutrients to add to a planting based on the findings of a soil analysis. The list is provided in Table 7. These amounts roughly parallel figures compiled from other studies (Hitchmough 1994).

Table 7. Fertilizer Ranges for Landscape Plantings.

Soil test values should be adjusted to the following general ranges.		
Item	**Values**	**Other Remarks**
pH	4.5 to 6.5	Depending on species to be grown and the geographic area.
Nitrogen	5.6 to 56 kg/ha	Depending on species involved, type of fertilizer used, desired growth rate of the plant, and time of the year.
Phosphorus	67 to 120 kg/ha	Levels above 68 kg may suppress growth of some species.
Potassium	168 to 336 kg/ha	
Calcium	673 to 2242 kg/ha	
Magnesium	224 to 1121 kg/ha	
Iron	40 to 50 mg per l.	
Manganese	15 to 40 mg. per l.	
Sulfur	45 kg/ha or more	
Copper	3 to 8 mg. per l.	
Boron	0.4 to 0.8 mg. per l.	
Zinc	2 to 4 mg. per l.	

Application Methods

Fertilizers may be applied in one of three ways: granular, water soluble, and time-released. These may be used in conjunction with one another. The choice of which to use is not as important as when and where they are applied. For new tree and shrub plantings where phosphorus is included in the mix, the fertilizer may be incorporated into the top few inches of the backfill or applied to the surface. For established trees and shrubs, there is no advantage to applying fertilizer other than on the surface of the soil (Whitcomb 1987) (Neely, Himelick et al. 1970) (Smith 1981). Slow release types such as Osmocote are industry favorites and have proven effective in many applications.

Many roadside plantings installed in the past have included fertilizer tablets placed approximately midway between the top and bottom of the planting pit. Based on the studies

cited above, this practice does not accomplish as much as could be with surface applications of either granular or time-released varieties. This could be largely due to the fact that the most rapid rate of root growth occurs nearer the top of the soil where moisture and oxygen are most readily available.

Timing of Application

The best time to fertilize is in the fall (Whitcomb 1978) (Whitcomb 1988). This is contrary to the widely accepted practice of fertilizing in the spring which may have originated in turf fertilization programs. The rationale for fall fertilization is that in the fall, while the soil is warm and greater energy is present in the stems and roots, roots absorb nutrients much quicker. In the spring, however, since most plant activity is concentrated in the leaves, root activity is greatly reduced (Whitcomb 1987).

LANDSCAPE MULCHES AND WEED BARRIER FABRICS

Mulches

Research studies have proven that mulches benefit the soil and growing plants. Their inclusion in roadside landscape projects is common state wide. Research has shown that the use of a mulch over landscape plants greatly influences their survival and growth rates.

Mulches can be almost any material, either organic or inorganic. Organic mulches include straw, bark chips, sawdust, grass clippings, corn cobs, pine needles, and others. Inorganic mulches are sand, pea gravel, crushed brick, stones, and gravels. In the drier, western part of the state, aggregate type mulches are more prevalent but bark type mulches are the most widely used organic mulch.

Bark Mulches

Bark mulches are generally classified as either coniferous or pine and hardwood. Each has distinctive characteristics which can be used to determine their best application. The most important of these characteristics is particle size and shape.

Particle Size

Finer-grained mulches:

- Absorb and hold water that could go to the soil,
- Provide a better environment for annual weed seed germination,
- May slow oxygen exchange with the soil, and
- Will add more organic material to the soil.

Coarser-grained mulches:

- Allow water to get to the soil surface quicker,
- Are better at preventing annual seed germination,
- Allow freer oxygen exchange into the soil, and
- Take longer to decompose which adds less organic material to the soil.

At the extremes of each scale a very fine mulch may crust over and dry to the point that it will repel water while a very coarse mulch will provide too much open pore space for light to reach the soil surface.

Particle Shape

- Pine bark tends to fracture into discrete particles and so is more susceptible to floating away in rains.
- Hardwood barks are generally highly fibrous and so tend to intertwine making them less susceptible to washing.

Specifying Bark Mulches

It is very difficult to specify bark mulches because the methods used to classify materials vary with the supplier. In the past, a specification relying on percent-passing-sieve has been used but this is no longer recommended. Processors do not use this method to classify their mulch. A more appropriate approach is to specify the size and shape of the particles and the type of bark. Avoid relying on descriptive supplier names unless you are sure that other suppliers know what the name means. Terms such as composted, humus, yard-waste, and even the term "mulch" may represent different products to different suppliers.

Pine barks will perform best when specified for generally level surfaces since they tend to be easily floated away in runoff. Hardwood mulches will perform better on slopes particularly on top of weed fabrics which may have a somewhat slick surface due to their fibrous nature which tends to interlock and resist movement by water. Pine barks that are in the size range of greater than 10 mm will be more effective at weed control since this size provides less opportunity for annual seed to germinate (Billeaud 1988). Hardwood mulches, being more fibrous, will be more easily invaded by annuals.

Tree or Brush Trimmings

These materials are sometimes available from tree companies or from municipalities and can provide a good mulch. Since the shredding process is not as thorough as in the large mulch companies, particle size is more variable as is the source of the material. As stated above, a period of composting is required. Inspection before acceptance is more important with this material to avoid getting noxious weeds or trash in the mix.

Inorganic Mulches

The most commonly used inorganic mulch is aggregate ranging from pea-size gravel (+/- 10 mm), to stone sized (to 100 mm). These types of mulches are most often used in the dry, western portion of the state but may have applications elsewhere. Their chief advantage is that they are very long lasting, are not easily moved by water or wind, and are often attainable in colors. Their chief disadvantage is that the larger sizes may allow too much light to reach the soil surface and they may generate more heat than organic mulches. Larger aggregate sizes also tend to trap a lot of litter that is hard to collect. Smaller sized aggregates seem to perform better and are easier to repair in case of disturbance than large aggregate. As with the organic mulches, depth is important. The layer must prevent light from reaching the soil surface and be of sufficient depth to prevent newly-germinated seeds from reaching the surface of the soil.

Mulch depth

In research studies, 85% of weed control was achieved over a three year period with a depth of 750 mm (Greenly and Rakow 1995) (Robinson 1988). Depths over 100 mm have shown minimal improvements and in some cases may contribute to reduced plant vigor (Billeaud 1988). Shallower mulch layers may allow weeds to penetrate the layer too easily while very deep layers may slow soil-oxygen exchange and reduce the levels of water reaching the soil. The size of

the particle will have a bearing on the depth of the mulch. The larger the particles, the greater the depth required to keep light from reaching the soil surface.

Weed Fabrics

Weed barriers are geo-textile fabrics now widely used in commercial and residential gardening and landscaping. (Polyethylene plastic sheeting is now recognized as being generally detrimental to plant growth.) These fabrics are commonly woven, geo-textile fabrics that vary in thickness, density, and color.

When used alone, weed barriers will reduce weed invasions, however, seams, tears, and cut-outs for plants are highly susceptible to weed invasion. While there are some differences between fabrics, when used with a mulch, these differences may have little importance. In a study comparing five fabrics (DeWitt, Exxon, Duon, Typar, and Visqueen), it was found that when used alone there is a significant difference in their effect on soil temperatures and soil moisture. However, there were no significant differences between the fabrics when used with a mulch covering. (Appleton, Derr et al. 1990) Exxon and Typar allowed more weeds to come through because they allowed enough light to penetrate bare soil conditions.

Landscape fabrics as weed barriers are often included on many roadside landscape projects. In some cases they have been used alone on large pampasgrass plantings on slopes. These have generally proven successful though some of the darker fabrics can significantly raise soil temperatures which may slow the development of plant roots near the soil surface. The effect of this higher heat has not been determined but does not seem to be serious if irrigation is present. In most cases, weed fabrics are used in conjunction with organic mulches. This combination provides the benefits of an organic mulch, (reduced soil temperature, soil moisture conservation, water infiltration, and aesthetic appearance), with the weed-inhibiting attributes of fabrics (Billeaud 1988) (Watson and Kupkowski 1991).

As noted in the survey, results have been mixed around the state as to the effectiveness of weed fabrics. The lack of effectiveness may be due to other circumstances such as improper or non existent bed preparation or wrong type or inadequate mulch layers. In most applications, however, weed fabrics should improve weed control.

HERBICIDES IN ORNAMENTAL PLANTINGS

Herbicide usage on ornamental roadside plantings today is largely limited to the use of glyphosate-type (post-emergents) chemicals. While TxDOT does not currently limit herbicides to this type, neither does TxDOT encourage the use of other types specifically designed for ornamental landscapes, in particular, pre-emergents.

Many of the problem weeds observed involved summer annuals. A post-emergent is only effective on these species if applications are repeated on an almost weekly basis during the growing season. The seeds of most annuals germinate very quickly and easily and are easily spread by lawnmowers, birds, and winds.

Post-emergents such as Roundup have no effect on a seed prior to its germination and are primarily effective for the control of all vegetation while pre-emergents are designed to control germinating weeds. In most situations, landscape maintenance programs in TxDOT have specifically addressed only the established weeds. The use of pre-emergent herbicides offers a cost-effective alternative to solving many of the weed problems associated with the typical roadside planting.

The following information regrading herbicides is basic information to serve as a backdrop for discussion of their use in roadside maintenance planning. While some herbicide formulations are recommended, each landscape site should be considered unique and selections made based on specific site conditions such as weed type, desirables present, season, soil type, and bed construction. The Vegetation Management Staff of TxDOT's

Construction & Maintenance Division has specific information regarding handling safety, formulations, and application.

Classification of Herbicides

There are three main categories of herbicides: soil sterilents, pre-emergents, and post-emergents.

Soil Sterilents

Soil sterilents do just that; sterilize the soil. Most are applied as fumigants and will kill virtually any living thing in the soil including fungi, nematodes, earthworms, roots, and seeds. These chemicals are some of the most dangerous since they are very toxic. Their use on the roadside is not recommended since most applications of these materials require a period of time where the soil is covered with plastic sheeting. Pedestrians or vehicle accidents could be in serious danger if these areas were disturbed prematurely.

Pre-emergent Herbicides

These herbicides do not kill established weeds. Most prevent the germination of seeds or root growth. Pre-emergent herbicides attach to soil particles in the top 50 mm of soil where most of the seed germination takes place and kill weed seeds as they germinate.

Post-emergent herbicides

These herbicides control weeds that are actively growing and have produced above-ground growth. These are further classified, based on their mobility, as *contact* or *systemic*.

- Contact herbicides kill living cells on contact. This rapid process usually takes place within minutes or hours after contact.
- Systemic herbicides are translocated into the root system by water. This slow acting process occurs only after the absorption of the herbicide by the plant. Systemic herbicides are most effective if applied when the weed is actively

growing. An example of a nonselective, post-emergent, systemic herbicide is Glyphosate (Roundup).

Herbicides are also classified on the range of plants they affect.

- Nonselective herbicides will affect any plant that is green and growing to which it is applied but not in every case. (Read the label.)
- Selective herbicides will affect only certain types or species of plants.

Herbicide Toxicity

Herbicide toxicity is expressed with an LD rating. LD means lethal dose and LD50 means the dose will kill 50% of a population of test animals, usually rats. This value is expressed in terms of milligrams of the substance per kilogram of body weight of the test animal. The higher the LD number, the less toxic the herbicide. The LD rating for Roundup is greater than 5,000. For comparison, the LD rating for aspirin is 1,240 and 3,320 for table salt.

Herbicide Application

Herbicides may be obtained as water-soluble, oil-soluble, liquid, wettable powder, granules, and pellets. Each of these formulations have their advantages. Some herbicides are available in more than one formulation.

- Pre-emergents are applied to the soil surface and remain viable for 1 to 12 months. They are usually broken down by soil micro-organisms. To maximize effectiveness and minimize loss through volatilization and photo-degradation, pre-emergent herbicides must be watered-in either through irrigation or rainfall, to wet the upper one to two inches of soil. (Note: drip irrigation will not water-in herbicides applied to a mulch layer.)

  Pre-emergents applied during construction can be a granular type incorporated into the top layer of soil. Subsequent applications may require water-soluble types to reach the soil below mulch layers.

- Post-emergents are foliar applied and adsorbed into plant tissues. They are usually applied by sprays and may be wettable powders or liquids. Some, but not all, degrade quite rapidly either due to becoming gaseous and escaping into the air, photo degradation, or by soil micro-organisms.

Herbicide Brands

The trade names of herbicides can be misleading. The important consideration in selecting a product is to identify its active ingredient. This information is given on the container label. Also given on the container is a list of weeds that the chemical will control and *usually* a list of plants that the chemical will not affect *at the recommended application rates.* Table 8 lists some of the more common herbicides either currently being used on the roadside (the post-emergents) or that should be considered for use in ornamental landscapes (the pre-emergents).

Table 8. Herbicides for Ornamental Plantings

Trade name	Common name	Type	LD-50 (mg/kg)	Effective control on:
Roundup*	Glyphosate	post-emergent	>5,000	Nonselective on most all vegetation
Oust*	Sulfometuron methyl	both	>5,000	Many annual and perenial grasses and broadleaf weeds
Escort*	Metsulfuron methyl	post-emergent	>5,000	Selective broadleaf control
Transline*	Clopyralid	post-emergent	>5,000	Certain broadleaf weeds
Princep	Simazine	pre-emergent	>5,000†	Most annual broadleaf and grass weeds
Ronstar	Oxadiazon	pre-emergent	>8,000†	Most annual broadleaf and grass weeds
Dual	Metolachlor	pre-emergent	2,534†	Most annual broadleaf and grass weeds
Surflan	Oryzalin	pre-emergent	>10,000†	Most annual broadleaf and grass weeds
Treflan	Trifluralin	pre-emergent	3700†	Most annual broadleaf and grass weeds

* From TxDOT Herbicide Operations Manual, Sept., 1996.

† From Nursery and Landscape Weed Control Manual, (Rice, 1992)

Pre-emergent Herbicide Usage

Pre-emergents have been widely studied for applications in the nursery industry particularly in container and field-grown situations (Ruff and Talbert 1989) (Kuhns and Haramaki 1980) (Neal and Senesac 1991) (Walker 1983).

Each type of chemical is variable in which species it will control and which it will not harm. In some cases where wider species control is desired, chemicals are combined. Oryzalin, simazine, and metolachlor have been tested in various combinations with each other with the oryzalin and simazine showing better control of annual grasses than metolachlor when used separately (Wehtje, Gillman et al. 1986).

The rates at which chemicals are applied are also important. Simazine and oryzalin showed no injury to selected groundcovers at normal rates but when rates are doubled, significant injury resulted to *vinca minor* and *pachysandra terminalis* (Ahrens 1979). Haramaki and Kuhns (1979) found that oryzalin and oxidiazon caused little or no injury to common boxwood and glossy abelia while simazine injured both at higher rates.

While all of the above pre-emergents have given consistent weed control, application method and species should be considered. Oxidiazon was found to cause unacceptable foliage damage to liriope where granules were trapped in plant crowns but returned to acceptable levels as new foliage was produced (Wells and Constantin 1990). Oxadiazon, oryzalin, and trifluralin all showed serious damage to pansy and coleus (Bing and Macksel 1984). Trifluralin also gave undesirable results on impatiens and begonias (Senesac, Neal et al. 1990) and Ronstar was shown to cause unacceptable damage to petunia, coleus, and portulaca (Bracy, Wells et al. 1987). It appears that extra precaution should be taken when annual bedding plants are to be used in the planting.

These studies demonstrate the importance of knowing the target weed species and carefully matching the chemical to the desirable vegetation. The list of plants that each of these

chemicals can be used with is too long to be included in this report but good descriptions can be found in Nursery and Landscape Weed Control Manual (Rice 1992).

IRRIGATION SYSTEMS

Rapid plant establishment is essential to a weed-free landscape planting. To accomplish this, all landscape plantings will require some degree of supplemental irrigation.

Truck Irrigation

Truck irrigation, also referred to as sprinkle irrigation, is commonly used where the numbers of plants are small, water lines are remote or too difficult to access, or where the plants are to be watered for only a short period. This technique is best used with hardy, native plants that require little water once established. It is best for use with small numbers of trees and/or shrubs but is not recommended for most ornamental shrub plantings in beds.

Truck irrigation is sometimes difficult to control. Its effectiveness is determined in large part by the person who is actually holding the hose. Also, truck entry into the site can be very disruptive, destroying turf and creating an obvious and unattractive road through the site.

In-ground Irrigation System

In-ground irrigation systems have been used on the roadside in some form for many years. Early uses were turf irrigation. These old systems used a cumbersome, high-maintenance technology that caused many problems. These systems have been abandoned. Irrigation technology today is vastly different and has demonstrated its usefulness on the right-of-way in non-turf situations.

Most roadside plantings should include an irrigation system for the following three reasons:

- The plantings are usually in a high-visibility area and are required to look good and last for a long time,

- The amount of water delivered is easier to control and more dependable than sprinkle irrigation, and
- The delivery of water to the plant has the capability of being more precise and this prevents wasted water.

The systems that are proving to be the highest maintenance are those that:

- Have many moving parts,
- Have large numbers of above-ground parts, and
- Apply water to an area rather than to a plant.

Today most landscape plantings can, through design and current technology, avoid each of the conditions. There are many variations on the design of irrigation systems and the best option will be determined by the specifics of a particular planting. Drip systems are proving to be the most reliable method of delivering water to plants on the roadside. Their advantages include the following:

- Components that are relatively simple and inexpensive,
- Parts that are easy to replace,
- Few moving parts,
- A system that can be entirely below ground or mulch layers,
- Application rates to plants that can be very closely controlled, and
- Less danger of over-spray on pavements or cars.

Systems other than drip can be successful but will generally require more maintenance. Also, higher water delivery rates of bubbler and spray systems can make them attractive to indigent persons who use them for washing and drinking. Water delivery by spray can be disrupted by high winds. Also, much of the water from spray systems will evaporate from leaf and mulch surfaces. In addition, water applied to plant leaves offers more opportunity for the spread of plant diseases. Some "micro-irrigation" products are also available. These involve tiny above ground sprays for small areas. These are not recommended for the same reasons listed above.

OTHER LANDSCAPE MATERIALS

Bed Edging

In plantings located in high-visibility sites, such as at a signal-controlled intersection, keeping weeds and grass out of the beds is critical. The best edgings are those that:

- Have no seams that a plant root might follow to the bed,
- Are at least 300 mm wide with 600 mm being a preferred width,
- Extend at least 76 mm below grade, and
- Extend at least 50 mm above the finished grade.

The depth of the edging will help prevent weeds from entering the bed below grade. Edgings placed on top of the ground will not be effective against underground rhizomes. The greater width allows more time between mowing and manual edging to keep runners from crossing the bed edge. The height above grade helps prevent water entering the bed and perhaps bringing in weed and grass seed. This is especially important where the bed is located at the bottom of a slope.

Landscape Pavers

Landscape pavers are being used on the roadside in increasing quantities. As noted in the survey, weeds can become a problem in pavers. The most serious problems occur where the pavers are near areas containing grass or weeds. An edging as recommended above should be used to help control vegetative invasion. Seeds blown or washed into the pavers will often germinate in the fine silt and dust that over time, settles into the paver joints.

Controlling weeds in pavers can be accomplished by:

- Applying pre-emergent herbicides before paver installation,
- Applying pre-emergent herbicides after paver installation,
- Applying post-emergent herbicides to weeds present, and
- Hand-pulling.

Pre-emergent Herbicide Usage in Pavers

As noted above in the discussion of herbicides, pre-emergents can be applied in granular or soluble form. Both methods may have benefit for use in pavers. Longer acting granules may be best for new installations while soluble forms will be best for seasonal, post-construction applications.

Another form of pre-emergent is found in the recent introduction of herbicide-impregnated geo-textile fabrics. These fabrics are intended for installation underground or under mulch. They may be effective as a strip (300-600 mm) under the outside edge of pavers. The fabrics use some of the same chemicals as found in granular and soluble forms.

The life of pre-emergents varies from one chemical to another. Some are only effective for a few months. Pre-emergents will be most effective against annual weeds and grasses. If sprayed at the proper time, two application per season may be sufficient. Very little study has been done in this regard but it could easily be tested by an individual district.

Post-emergent Herbicides in Pavers

Perennial weeds and grasses such as bermudagrass and johnsongrass are best controlled with glyphosate type herbicides. Because these are contact types of herbicides they are only effective on the weeds present at the time of application. Weeds from unaffected root systems will likely appear later. This is why it is necessary to use repeated applications over a period of time. Once all root systems are destroyed, control is needed less frequently. Control of weeds in pavers with herbicides should be a very effective tool since it is easier to treat weeds in pavers without worrying damaging dersirable plants.

CONSTRUCTION DOCUMENTS

While it may have been assumed that only qualified persons bid on landscape projects and therefore knowledgeability regarding landscapes is a given, experience has shown this is not the case. Where the contract amounts are low and virtually anyone has access to the system, it must be assumed that skill levels will be low. The first place to deal with this reality is in the documents associated with both new construction and maintenance contracts.

To install a project that has as one of its central goals its manageable upkeep and healthy, rapid maturity, the goal must be fully understood by each participant in the process. This understanding can be stressed through the construction documents. Some of the issues involved in a successful project are very specific and must be carried out precisely. Failure to communicate just one or two important concepts can initiate a series of connected events that could result in more costly maintenance in the future.

General Notes in a Maintenance Contract

As noted in earlier discussions regarding contractor types and landscape maintenance contracts, problems have occurred when the contractor did not fully understand the full scope of their responsibility because they were not aware of the full text of the Standard Specifications. Extra effort should be made bring this fact to the attention of bidders before they sublet their bids.

Increasing Detail in Item Provisions

The researchers recommend that the wording of an item be expanded in detail whenever possible so that not only the method is clarified but also the intent of the method. For example, under 193.2.2, *in addition* to the description, the following might be added:

> 'Mulch material shall be pine bark only. Particle size shall generally range from 10 mm to 40 mm. The mulch shall be installed at a depth of 700 mm. The mulch shall not have excessive fines such that free air exchange with the soil is prevented or that suitable fines

for weed seed germination is provided. The mulch shall not have an excessive proportion of large particles such that light may penetrate gaps between particles and reach the soil surface.'

The above description goes beyond the specifying of a material. It provides both the inspector and the contractor with guidelines in determining 1) how to identify an acceptable mulch, and 2) why those specifications are important. The extra time spent to expand the general notes may seem time-consuming but most of these notes will only be written one time. Once written however, the notes then provide not only a set of specifications but also an educational tool and a clearer platform for agreement and decision-making.

Increasing Detail in Plans

The character of maintenance contracts varies from district to district. In some instances, the set is comprised of only a few sheets of typed specifications and administrative requirements. Better contract sets include plans and details graphically showing how things should be placed or installed in the project. This is by far the best approach for the same reasons discussed above. And as noted above, these details should also be enhanced by the inclusion of the same type of descriptive language that will explain the intent of the detail.

MAINTENANCE OF PLANTINGS

Weed Control Options

Herbicides

When selected carefully and used properly, herbicides offer the most cost-effective means of bringing plantings to a relatively weed-free condition. With proper plant selection, and care which maximizes growth, the need for herbicide usage might be concentrated in the first two years. After this time, a regular program of herbicide control will keep weeds from over-running a planting.

Biological Controls

Biological controls are those controls which rely on a plant's natural predators (mostly insects), to maintain a weed population at a tolerable level. This approach has principally been used in agricultural settings where there is a single crop and a single weed species to be dealt with. The applicability of this approach to roadside landscape is remote. Most measures target only one weed species and frequently rely on imported insects. The introduction of non-native insect species is an exacting process and fraught with potentially dangerous side effects (Rosenthal, Maddox et al. 1984) (Shroeder 1983). Since most roadside landscape weed problems are comprised of multiple species, the management of such a maintenance approach would not be feasible or practical.

Organic Control Methods

Control methods not involving chemicals have generally been referred to as an "organic approach". In most cases, this term is applied to vegetable gardening where specific insect pests or companion planting schemes are used to repel unwanted insect pests. The most viable organic control in the context of ornamental weed control involves the use of thorough bed preparation before planting, the use of a maintained mulch layer, and hand-weeding. Each control is already practiced to some degree in TxDOT programs.

Mulching

Mulching is an important activity and will greatly determine the success of weed control efforts. Item 193 of the Standard Specifications specifies a minimum depth of 50 mm for mulch layers. As noted earlier, studies indicate that this depth may be too low and should be keyed to the type of mulch and particle size. For most weed control applications, a depth of 75 mm is recommended for pine barks with a particle size of 10 mm to 40 mm.

Fertilizers

As noted earlier, fertilizer rates should be based on the findings of a soil test. This should be a requirement for each new maintenance contract. The cost of these tests will generally range

from $10 to $20. Since most landscape maintenance contracts are for two years, this is not a prohibitive cost. Multiple soil samples should be taken and the fertilizer makeup and rates should be based on the deficiency of specific nutrients.

When to Remove Staking

The staking of plants at the time of installation has been widely practiced. Research suggests that this practice may not be as beneficial as once thought. Studies have shown that plants that have spent much of their early life in stakes show a reduction in caliper size and root development when compared to plants that have not been staked (Whitcomb 1987). Research also suggests that where staking is required due to height or winds, the stakes should be very low on the trunk so as to allow for the movement of the trunk above the stakes. This movement is what triggers the action of plant processes that encourage trunk girth development.

The reason for early staking is directly related to root system development. As a newly planted tree begins to develop a root system, the first roots are very thin and fragile as they extend into the backfilled soil. If the soil around the rootball is not yet settled, a rocking motion of the rootball may break these roots and delay establishment. In windy conditions (common on the roadside), tall, newly planted trees will require some support. The length of time may vary but six months should be adequate in most cases (Whitcomb 1987). By that time, a properly watered and fertilized tree will have anchored itself to its new home.

Frequency of Watering

The watering of plants can be an exacting science. Weather, soil and surface drainage, and the depth and type of mulch or shrub canopy, all play a role in determining how much and how often an area should be irrigated. Due to these factors, specifying a given amount for a planting is often nothing more than a wild guess. Because these factors are variable from site to site and season to season, the best way to correctly determine the amount of water to be provided is to conduct a field infiltration test. The following specification is provided as a

recommended specification for a test to be done at the beginning of a contract either for construction or maintenance.

Establishing Infiltration Rate of Soil

The contractor shall, under supervision of the engineer, conduct water infiltration test in at least four (4) locations selected by the engineer. The contractor shall dig the test holes to a depth of 450 mm with a diameter of 200 to 300 mm. The holes may be dug with auger or post-hole digger but the sides of hole shall be scarified with a knife or other sharp-pointed instrument in order to remove any smeared soil surfaces and to provide a natural soil interface into which water may percolate.

The hole shall then be filled with water to a minimum depth of 300 mm. It may be necessary to refill the hole in order to keep water in the hole until saturation occurs (approximately 24 hrs). Determine the percolation rate 24 hours after water is first added to the hole. After the overnight saturation period, adjust the water depth to 300 mm from the bottom and from a fixed reference point, measure the drop in water level over a 30 minute period. This procedure is to establish the rate at which water will be removed from the basin by the surrounding soil.

The procedure for determining the infiltration rate in liters-per-hour shall be as follows: (All measurements shall be in centimeters.)

1. 3.14 x (radius of hole)^2 = surface area of hole
2. (surface area of hole x water drop in 30 min.) x .001 = liters of water drop in 30 min.
3. Liters of water drop in 30 min, x 2 = infiltration rate in liters per hour.

If a test is not conducted, the only other alternative is frequent monitoring. This includes an inspection of the plants themselves for signs of wilting and judging the moisture in the soil below the mulch by touch.

For new plantings, the water requirements will be higher than normal. This is not because they need more water but is due to the fact that they have not yet developed sufficient root-tips for water-gathering. As more roots develop farther into the planting medium, the area of moisture available to the plant is larger and less water needs to be applied. As a planting becomes established and root systems expand, less water will be needed because the plants are more efficient.

The danger in watering is often that the plants will receive too much rather than not enough. It may be to the contractor's advantage to over-water since they may be held accountable for losses if the plants are not sufficiently watered. However, it is not likely that they will have to replace plants lost due to over-watering since the symptoms are harder to diagnose.

Plant soil should be moist but not wet. Wet or saturated soil is soil in which the oxygen has been driven from the pores of the soil. In this condition, the plants suffocate and die. Additionally, soil-borne fungi and some plant diseases thrive in warm, wet soil conditions. In some cases, the demise of a plant in overly moist rather than saturated soils may be due to the presence of pathogens rather than due to oxygen deprivation. For this reason, it is advisable in established plantings to allow the soil to stay on the dry side of moist than on the wet side. This condition will allow better oxygen exchange between the soil and the atmosphere.

Mowing

Mowing near bed areas can be a source of seed invasion if the clippings are thrown toward the bed. The notes should specify that the direction of mowing shall be such that no clippings will be thrown toward a bed area.

PART IV - AN OUTLINE FOR AN INTEGRATED WEED MANAGEMENT PROGRAM

An integrated program uses a range of appropriate tools to accomplish a stated goal. The suitability of a specific tool will depend upon a number of issues such as site, community, budgets, skill levels, district commitment, and overall project goals. The diverse nature of the landscapes that are found throughout Texas make a single approach impossible. Each district should design a program suited to not only their landscapes, but also to their unique goals and resources.

The researchers recommended the following outline stating measures or approaches that affect weed control and weed maintenance for the most common landscape design types. Some measures focus on quickly establishing the planting while others address specific weed control methods. Not all measures will be applicable to all situations and should be modified for local conditions.

We recommend that this outline be used as a beginning for the development of a more detailed and formal program of integrated weed management specifically designed for landscape plantings. Such a program will include alterations to the bidding, letting, and inspection procedures, refinement of herbicide options and alternatives, training for TxDOT personnel in weed maintenance, and plant identification.

I. NEW TREE PLANTINGS

Weeds associated with tree plantings have two impacts. Firstly, weeds inhibit the development of the tree's root system and slow overall growth. It is for this reason that weed control is important in all tree planting situations, not just those that are located in frequently mowed, high-visibility areas. Secondly, weeds at the base of trees are unsightly and give the appearance of shoddy maintenance.

A. Soil Amendments
    1. New installation
        a. Use of amended soils for backfill is not recommended
B. Fertilizers
    1. New installation
        a. Use soil test to determine existing nutrient levels and set rates
        b. Use soil drench once every 30 days for 90 day warranty period
        c. Application
            i. Truck irrigation
                a) Apply fertilizer to surface of the soil
            ii. Drip irrigation
                a) Incorporate fertilizer into top 50 to 70 mm of soil
C. Weed Control
    1. New installations
        a. For control of annual weeds
            i. Herbicides
                a) Apply granular pre-emergent to soil surface of planting pit prior to mulch installation
            ii. Non-herbicide alternative
                a) Weeding by hand
        b. For control of perennial weeds
            i. Herbicides
                a) Apply liquid post-emergent as spot treatment as needed
                    1) Specify hand removal of weed residue
            ii. Non-herbicides alternative
                a) Weeding by hand
    2. Post-construction or existing planting
        a. For control of annual weeds
            i. Herbicides

a) Apply post-emergents (Round-up) to existing weeds if present.

b) Apply water soluble or granular pre-emergents to surface of mulch layers

ii. Non-herbicide alternative

a) Weeding by hand

b. For control of perennial weeds

i. Herbicides

a) Apply liquid post-emergent as spot treatment as needed then apply pre-emergent.

ii. Non-herbicide alternative

a) Weeding by hand

3. Follow-up with hand removal of weed residue

D. Mulch

1. Slopes 4:1 or less steep

a. Pine bark

i. Particle size: 10 to 50 mm

ii. Install at 70 to 80 mm, no more than 100 mm

iii. Require samples at pre-construction conference

2. Slopes steeper than 4:1

a. Hardwood mulches

i. Particle size: "longest piece shall not be longer than 150 mm"

ii. Install at 70 to 80 mm, no more than 100 mm

iii. Require samples at pre-construction conference

E. Irrigation

1. Truck irrigation

a. Include wetting agent in water

b. Conduct on-site field test to determine infiltration rate to set minimum application per plant

2. Automatic irrigation systems

a. Conduct on-site field test to determine infiltration rate to set application rates

II. NEW SHRUB PLANTINGS

Cost-effective, long-term weed control in shrub plantings is predicted by the rapid development of healthy plants. Therefore, intensive and timely procedures are concentrated in the early stages of the project, particularly the 90-day establishment period.

A. Bed preparation.
   1. Remove existing vegetation.
      a. Herbicide application.
         i. Use nonselective post-emergent to kill all vegetation.
   2. Sod removal.
      a. Mow existing turf to 30 mm, remove clippings.
      b. Use sod-cutter only.
      c. Remove sod to 70 mm depth.
   3. Non-herbicide alternatives.
      a. Repeat-till method.
   4. Soil replacement.
      a. Specify pH of soil.
      b. Inspect source of new soil.
      c. Require soil test and seed count of proposed soil.

B. Edgings.
   1. Types
      a. Concrete
         i. Width of edging 300 mm minimum, 600 mm preferred.
         ii. Top of edging minimum 50 mm above finished grade of bed.
         iii. Bottom of edging minimum 50 mm below finished grade.
      b. Pavers
         i. Width of edging 300 mm minimum, 600 mm preferred.
         ii. Use with 200 mm wide concrete border on all sides.
         iii. Steel and plastic borders not recommended.

iv. Install herbicide-impregnated geo-textile below sand leveling course.

c. Stone

i. Width of edging 300 mm minimum, 600 mm preferred (depending on type of stone).

ii. Bottom of stone minimum 50 mm below finished grade.

iii. Mortar all stone joints.

d. Steel edgings.

i. Not recommended.

C. Soil amendments

1. Organics are recommended for most bed plantings.

a. Specify minimum length of time of composting.

b. Mushroom compost is not recommended.

c. Require samples at pre-construction conference.

2. Inorganics

a. Absorbent gel-type polymers are not recommended.

D. Fertilizers

1. Require soil test to determine application rates.

2. Incorporate fertilizer into top 50 to 70 mm of soil.

E. Mulch

1. Slopes 4:1 or less steep.

a. Pine bark

i. Particle size: 10 to 50 mm.

ii. Install at 70 to 80 mm depth, no more than 100 mm.

iii. Require samples at pre-construction conference.

2. Slopes steeper than 4:1.

a. Hardwood mulches

i. Particle size

a) Specify maximum length of any one piece, ie: "longest piece shall not be longer than 150 mm".

ii. Install at 70 to 80 mm depth, no more than 100 mm.

iii. Require samples at pre-construction conference.

F. Weed barriers.

1. Recommended in most bed plantings.

a. Color is not important when used with mulch.

G. Weed control.

1. For control of *annual* weeds during 90-day establishment period.

a. Herbicides.

i. Apply granular pre- and post-emergents to soil surface of planting pit prior to mulch installation.

b. Non-herbicide alternative.

i. Weeding by hand.

2. For control of *perennial* weeds during 90-day establishment period.

a. Herbicides.

i. Apply liquid post-emergent spot treatment as needed and pre-emergent.

a) Follow-up with repeat application.

b) Specify follow-up with hand removal of weed residue.

b. Non-herbicide alternative.

i. Weeding by hand.

H. Irrigation

1. Drip irrigate all bed plantings.

2. Drip irrigation recommended on tree plantings.

3. Set watering rates based on site conditions.

a. Conduct on-site field test to determine infiltration rate to set application rates.

III. WEED CONTROL IN ESTABLISHED TREE AND SHRUB PLANTINGS

A. Fertilizers

1. Require soil test at beginning of each new contract or every two years to set application rate.

2. When to apply.
    a. Fertilize in spring and fall for shrub plantings.
    b. Fertilize trees only in fall.
3. Do not incorporate fertilizer into soil of bed or planting pit - broadcast only.

B. Weed Control.
1. For control of *annual* weeds.
    a. Herbicides.
        i. Pre-emergents should be applied before weeds germinate but may be applied at any time of season.
        ii. Apply water soluble pre-emergents to surface of mulch.
        iii. Apply granular pre-emergents and water-in.
    b. Non-herbicide alternative.
        i. Weeding by hand.
2. For control of *perennial* weeds.
    a. Herbicides.
        i. Post emergents may be applied any time growth is active.
            a) Apply liquid post-emergent as spot treatment as needed.
            b) Apply follow-up application within three weeks and as needed.
            c) Follow-up with hand removal of weed residue.
    b. Non-herbicide alternative.
        i. Weeding by hand.

C. Mulch
1. Slopes 4:1 or less steep.
    a. Maintain pine bark mulch layer
        i. Particle size: 10 to 50 mm.
        ii. Maintain 70 to 80 mm depth, never less than 50 mm, nor more than 100 mm.
2. Slopes steeper than 4:1.
    a. Maintain hardwood mulches

i. Particle size: longest piece shall not be longer than 150 mm.

ii. Maintain at 70 to 80 mm depth, never less than 50 mm, nor more than 100 mm.

D. Mowing

1. Avoid the spreading of weed and grass seed.

a. Specify that the direction of mowing shall be such that no clippings will be thrown toward a bed area.

IV. WEED CONTROL FOR PAVER CONSTRUCTION

A. Excavate minimum 80 mm below grade to remove existing grasses.

B. Weed Control (Refer to Part III, Section B, Weed Control.)

1. During construction.

a. Herbicides.

i. Add pre-emergents to sand leveling course prior to paver installation.

a) Install herbicide-impregnated geotextile below sand leveling course.

b) Apply granular pre-emergents to surface of sand course.

2. Post-installation maintenance.

a. Herbicides.

i. Apply spray pre-emergents to pavers to control annual weeds.

ii. Apply water-soluble post-emergents to control perennials.

a) Follow-up application within three weeks as needed.

b) Follow-up with hand or weed-eater removal of weed residue.

b. Non-herbicide alternative.

i. Weeding by hand.

CONCLUSION

Landscape construction on Texas roadsides has reached a significant level of infrastructure cost and public involvement. In many cities, the public is demanding more attractive highway landscapes and in most cases this means landscape plantings in addition to other aesthetic treatments. As more projects are installed, the cumulative maintenance costs may become excessive to the point of precluding further development or cutbacks in existing maintenance programs.

As shown in this study, weed control is related to many factors, many of them far removed from the actual project site. In many cases, weeds are only one problem of many but it one that is very visible. An integrated program which is designed to identify and attain specific maintenance goals is the most viable alternative in solving many of the common problems associated with roadside landscape maintenance today. In addition to the outline provided, TxDOT should consider the following initiatives as foundations for an effective landscape maintenance program:

1. Review the contracting system regarding landscape construction and maintenance contracts with the intention of developing alternatives (compatible with state statutes) that will tighten bidder qualification standards in order to get the best qualified contractors,

2. Review the skill levels required at all phases of landscape development and provide for additional training where appropriate,

3. Consider ways to expand support and training in the use of herbicides in ornamental applications, and

4. Investigate ways to adapt some of the more successful partnerships with communities in order to spread both responsibility and costs.

APPENDIX A - SURVEY FORM

LANDSCAPE SITUATION [1]	PROBLEM LEVEL	TYPICAL WEED SPECIES	INVASION MECHANISM[2]	CONTROL METHOD	EFFECTIVENESS
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective
	❑ Short-term, does not recur. ❑ Recurs occasionally. ❑ Is a continuous problem.				❑ Very effective ❑ Moderately effective ❑ Minimally effective

1 Repeat the situation on the next line if you use more than one control method.

2 ex.: surface runners, seed deposited after installation by wind, underground rhizomes from surrounding vegetation, rhizomes existing in soil

APPENDIX A Cont.

2. If you were to establish an approximate cost/benefit ranking, how would you rank the methods you use in terms of most effective for the cost?

   Most cost effective: _____

   _____

   _____

   _____

   Least cost effective: _____

3. **Respondent profile.**
   Please describe your professional position within TxDOT:

   - ❑ Landscape Designer
   - ❑ Vegetation Manager
   - ❑ Maintenance Supervisor
   - ❑ Maintenance Engineer
   - ❑ Area Maintenance Engineer
   - ❑ Other (describe):_____

   Number of years in this capacity: _____

   How would you rate your knowledge of weeds, grasses, vegetation management and control?

   - ❑ Thoroughly experienced in all phases of vegetation management
   - ❑ Somewhat experienced
   - ❑ Basic level of experience

   - ❑ I know most weeds and grasses in my area by name
   - ❑ I can identify a few weed and grass species in my area
   - ❑ I am relatively unfamiliar with grass and weed species in my area

   What types of publications or resources do you use to broaden your knowledge of vegetation management and weed control issues?

   _____

   _____

   _____

APPENDIX A Cont.

Is there any information that you think might benefit you in the area of weed control? Please describe._____

_____

_____

_____

_____

Comments:_____

_____

_____

_____

_____

In the event we might want to follow up on your survey, please give your name and phone number where you may be reached. Thanks.

Name: _____

Phone: _____

Please return the survey to:

Jim Schutt
Texas Transportation Institute
707 Texas Ave. Suite 100-E
College Station, Texas 77843

APPENDIX B - SUMMARY OF RESPONSES

Types of Weed Problems

LANDSCAPE SITUATION	*	TYPICAL SPECIES	MECHANISM	CONTROL METHOD	**	DIST.†
PAVERS	2	BERMUDA	SEED	ROUNDUP	2	21
	2	VARIES	SEED	PRE- & POST -EMERGENT	2	8
	3	WEEDS, J.G.	RHIZOMEDS	ROUNDUP, HAND PULL	2	14
	3	JG, THISTLE, BG, GROUNDSEL	SEED, SURFACE	ROUNDUP, HANDTOOLS	2	17
	3	BERMUDA, ALL OTHERS	-	HERBICIDES	3	18
	3	SPURGE	SEED	POST-EMERGENT	1	15
	3	NUTSEDGE, CRABG, BLUESTEM, BURS, CABBAGE	SEEDED BY MOWERS & WIND	HAND PULL	1	9
	3	NUTSEDGE, CRABG, BLUESTEM, BURS, CABBAGE	SEEDED BY MOWERS & WIND	ROUNDUP	2	9
	3	NUTSEDGE, CRABG, BLUESTEM, BURS, CABBAGE	SEEDED BY MOWERS & WIND	RODEO	1	9
	3	BG	RUNNNERS	HERBICIDES	1	9
PLANTING BEDS	3	WEEDS	SEED	ORNAMEC	2	21
& PLANTERS	3	BERMUDA	RUNNERS	CONC. MOW STRIP	1	22
	3	BROADLEAFS	WINDBLOWN SEED	MECHANICAL	2	22
	3	BROADLEAFS	WINDBLOWN SEED	HERBICIDE	2	22
	3	J.G., RYEGRASS, BERMUDA	SEED & RUNNERS	PRE- & POST-EMERGENT	3	8
	3	J.G., RYEGRASS, BERMUDA	SEED & RUNNERS	WEED BARRIER	3	8
	3	J.G., RYEGRASS, BERMUDA	SEED & RUNNERS	MANUAL	2	8
	3	BERMUDA, BURS, J.G.	SEED, RHIZ.	HAND PULLING	3	14
	3	BERMUDA, GROUNDSEL	SURFACE, SEED	ROUNDUP, MULCH	2	17
	3	JG	-	HAND PULL, HERBICIDE	3	18
	3	JG	SEED, RHIZ	HERBICIDE, & HAND PULL	2	18
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	WEED BARRIER	2	15
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	POST EMERGENT	1	15
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	HAND PULLING	3	15
	3	JG	-	ROUNDUP	2	9
	3	JG	RHIZ	HANDPULL	1	9
	2	-	RHIZ	WEED BARRIER	2	23
	3	NUTSEDGE, BG	SEED RHIX	HAND PULL	3	9
	3	CRABGRASS	SEED	ROUNDUP	1	11
	3	NUTSEDGE	RHIZ	ROUNDUP	2	11
	3	BG	RHIZ, SEED	ROUNDUP	1	11
	3	CRABGRASS	SEED	ROUNDUP	1	11
	3	NUTSEDGE	RHIZ	ROUNDUP	2	11
	3	BG	RHIZ, SEED	ROUNDUP	1	11
	3	J.G, CRABGRASS	SEED, RHIZ	HERBICIDE, PLASTIC BARRIER	2	1
TREE WELLS	2	BUFFEL/BERMUDA	SEED	ROUNDUP/OUST	2	21
	3	BERMUDA, THISTLE, GROUNDSEL	SEED, BIRDS	HAND TOOLS, MULCH	3	17
	3	JG, DALLIS, BG	SURF, SEED, RHIZ	SPOT SPRAY, WEED-EAT	3	18
	3	BINDWEED	WINDBORNE SEED	ROUNDUP	3	5
SHRUB PLANTINGS		BROADLEAFS & GRASSES	EX. SEED & RHIZ.	TIGHT PLANTING	1	22
	3	J.G., WEEDS, RATAMA	SEED, RHIZ.	HAND TRIM, WEED-EAT, HAND PULL	3	14

	3	BG	SURF, SEED, RHIZ	SPOT SPRAY, WEED-EAT	3	18
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	WEED BARRIER	2	15
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	POST EMERGENT	1	15
	3	BG, JG, SPURGE	SURF, SEED, RHIZ	HAND PULLING	3	15
	3	NUTSEDGE, BG, PIGWEED	SURF, SEED, RHIZ	HANDWORK, HERBICIDES	2	9
	2	JG, BG	RHIZ, SEED	HAND REMOVAL	2	3
	3	JG, WOODY PLANTS	WIND, BIRDS, NATURE	ROPE WICK BY HAND, HAND PULL	2	1
	2	JG, CRABGRASS	RHIZ, SEED	HERBICIDES	2	
WEEDS	2	TUMBLEWEEDS	CLUMPS	ROUNDUP/OUST	1	24
GRASS	2	BERMUDA	SURFACE RUNNERS	ROUNDUP	1	24
VEGETATIVE ISLANDS	3	J.G., SUNFLOWER, THISTLE	RHIZOMES, SEED	ROUNDUP, WEED-EAT, HANDTRIM	2	14
RAILROAD TRACKS W/GR'S	3	J.G., BERMUDA, GEORGIA CANE	RHIZ, SEED,SURFACE	WEEDING, ROUNDUP	2	14
DRAINAGE DITCHES	3	GEO.CANE, CATTAIL, J.G.	RIHZ., SEED	RODEO, MECH.	2	14
TURF AREAS	2	JG, THISTLE, GROUNDSEL, RAGWEED	SEED, RHIZ	MOWING, ROUNDUP,TRANSLINE	1	17
	3	DALLISGRASS & OTHERS		??	-	18
PAVEMENT JOINTS (CRACK GRASS)	3	ALL	-	HERBICIDE	3	18
FLOWER BED	3	NUTSEDGE	SEED	IMAGE, MANAGE	2	5
	3	BG	SEED, RHIZ	SPOT ROUNDUP	2	3
	3	BROADLEAF WEEDS	SEED	SPOT ROUNDUP	1	3
	2	GRASSES	SEED, ETC.	SMALL BEDS, THICK PLANTING	1	3
DISTURBED & OPEN AREAS	3	GOATHEADS, KOCHIA, PIGWEED	WINDBORNE SEED	INCREASE CANOPY	2	5
	2	JG	RHIZ	ROUNDUP	1	5
MULCH OVER WEED BARRIER	3	NONE	WIND & RAIN	LEAVE MULCH OFF SLOPE	1	1

* 1=Short-term, does not recur
2=Recurs occasionally
3=Is a continuous problem

** 1=Very effective
2=Moderately effective
3=Minimally effective

† 1=Paris 3=Wichita Falls
5=Lubbock 8=Abilene
9=Waco 11=Lufkin
14=Austin 15=San Antonio
17=Bryan 18=Dallas
21=Pharr 22=Laredo
23=Brownwood 24=El Paso

APPENDIX C - COMMENTS

DI = Desired information
C = Comments

DIST	DESIRED INFORMATION AND COMMENTS
22	DI: I need more experience in herbicide application.
8	DI: Any information concerning pre-emergent herbicide. Also any info on "over the top" application over shrub cover to control grass or herbaceous species. Also any effective structural control besides weed barrier.
21	C: I have quit using weed barriers. They do not work.
24	DI: Only manufacturers data with directions on how and where to use their products. C: El Paso district is located in a desert environment. Annual avg. precipitation is +/- 7 inches. Our weed problem is limited and solved through herbicide applications.
14	DI: Information on a chemical that is effective in weed control but does not harm desirable plants in planting beds. Information on weed control, plant identification, pre planning on projects to be installed, pre-emergent treatment. C: Information and effective tools are needed to deal with existing problems and head off existing problems.
18	DI: Any information, publications, or manuals would be helpful.
18	DI: Information on what pre-emergent herbicides might be effective in landscape situations.
5	DI: More information that is very easy to understand regarding germination - especially in regards to light and canopy cover.
6	C: Use patterned, colored, concrete instead of pavers.
23	C: Routine maintenance is required on any project if you want it to stay neat and attractive. Application by the contractor, of any weed control, is critical to how effective this control is. Weed barriers in planting beds and surfaces are a good deterrent to hand weeding.
9	DI: Always looking for better ways of weed control. Landscaped areas with ornamental plants.
11	DI: More training on weed and grass identification.
11	DI: More training on weed and grass identification.
3	C: All of median plantings within the District are adopted or maintained by others. TxDot will work with various communities or service clubs desiring to plant maintain a beautiful median area. Some of work is done jointly, as with the city of Wichita Falls, while other work is done by TxDOT then adopted by others. Total maintenance is the responsibility of others. On median plantings, the District places our "trademark" on a 16"-18" concrete border behind the curb on all medians. This gives a clean appearance and allows mechanical edging of roadway. Most areas have sodded grass, trees, and shrubs with a very small amount of seasonal flowers. We recommend these potted flowers be planted as close together as possible to inhibit contamination of weeds grasses spread by seed.
1	DI: Interested in all information in the area of weed control. A guide to what will work best to control weeds in various types of plantings and the best pesticide for the particular situation. C: Weed control in plant beds is a very costly maintenance problem. With fewer FTEs we must look at new and better pesticides that will provide a long-term effect. Also, that is friendly to the environment.

APPENDIX D - RESPONDENT PROFILE

L. Desnr.	Veg. mgr.	M. Supr.	M. Eng.	AM Eng.	Other	Yrs.	T. Exp.[1]	S. Exp.[2]	B. Exp.[3]	Most	A Few	None
*	*					1.5		*			*	
*						7	*			*		
*	*					9		*		*		
			*			15		*			*	
	*					12	*				*	
	*					13		*			*	
				*		2			*		*	
*	*					5	*			*		
					M. Insp.	3		*		*		
	*					2	*			*		
*						0.5			*		*	
			*			6			*		*	
	*					9		*		*		
	*					10		*			*	
					L. Maint.	15			*		*	
	*					10		*		*		
	*					14	*			*		
		*				2			*			*
	*					11			*		*	
		*				12		*			*	
5	11	2	2	1	2	7.95	5	9	6	8	10	1

[1] Thoroughly experienced.
[2] Somewhat experienced.
[3] Basic level of experience.

APPENDIX E - EFFECTIVENESS OF CONTROLS

DIST	MOST COST EFFECTIVE EFFECTIVE				LEAST
22	TIGHT SPACING, MOW STRIPS	HERBICIDES	HEAVY MULCH		HAND PULL/MECH.
8	POST- & PRE-EMERGENT HERB.	POST-EMERGENT ONLY			MANUAL LABOR
21	ROUNDUP, ORNAMEC, "HERCULES"	WEED FABRIC/HAND WORK			
24	SPRAYING HERBICIDES	MANUAL LABOR			
14	ROUNDUP/RODEO	WEEDEATING	MECHANICAL		HAND PULLING
17	HERCULES	MOWING			HAND TOOLS
18	USE OF NATIVE GRASSES/XERISCAPE TECHS.	ALL METHODS IN USE NOT COST EFFECTIVE			
18	HERBICIDE SPOT SPRAYING	HAND REMOVAL OF WEEDS			WEEDEATING
5	RAISING MOWING HEIGHT/REDUCE MOWING	ROUNDUP ON BINDWEED			
15	POST-EMERGENT HERBICIDE	WEED BARRIER			HAND PULLING
9	ROUNDUP IN PAVERS	HAND PULLING			RODEO
23	WEED BARRIERS				
9	HERBICIDES	HAND WORK			
11	HERBICIDES	HAND WEEDING			
11	HERBICIDES	HAND WEEDING			
3	THICK PLANTINGS	SPOT ROUNDUP			HAND REMOVAL
1	HERBICIDES, PRE- AND POST-EMERGENT	WEED BARRIERS	HAND ROPE WICK	HAND LABOR	MECHANICAL
1	HERBICIDES, PRE- AND POST-EMERGENT	WEED BARRIERS			

APPENDIX F - SOURCES OF INFORMATION USED

District	None	Mags & Books	Exten. Serv.	Chemical Companies	TxDot Div. Personnel	TxDot Manual	TxDot Training	Exper.	Educ. Classes	Conf.	Word of Mouth
22		*									
8		*	*	*							
21				*	*	*					
24				*		*					
14						*	*	*			
17					*	*					
18	*										
18		*					*		*	*	
5		*		*					*		
15							*				*
9		*					*				
23	*										
9		*		*	*						
11							*				
11							*				
3				*		*					
1		*	*			*					
22						*					
22						*					

APPENDIX G - LIST OF WEED NAMES* AND REFERENCES

Annual Grasses

Warm Season

Barnyardgrass	*Echinochloa crusgalli*
Goosegrass	*Eleusine indica*
Junglerice	*Eleusine colona*
Crabgrass	*Digitaria sanguinalis*

Cool Season

Rescuegrass	*Bromus unioloides*
Japanese brome	*Bromus japonicus*
Italian ryegrass	*Lolium perenne*
Annual bluegrass	*Poa annua*

Perennials

Warm season

Bermudagrass	*Cynodon dactylon*
Knotroot bristlegrass	*Setaria geniculata*
Johnsongrass	*Sorghum hapalense*
Dallisgrass	*Papalum dilatatum*
Fall witchgrass	*Digitaria cognata*
Tumble windmillgrass	*Chloris verticillata*
Buffalograss	*Buchloe dactyloides*
Silver bluestem	*Bothriochloa saccharoides*
KR bluestem	*Bothriochloa ishmaemum*
Yellow Nutsedge	*Cyperus esculentus*
Purple Nutsedge	*Cyperus rotundus*
Witchgrass	*Panicum capillare*

Cool Season

Scribner rosettegrass	*Dichanthelium oligosanthes*
Fescues	*Festuca sp.*
Little bluestem	*Schizachyrium scoparium*
Texas wintergrass	*Stipa leucotricha*
Wildrye	*Elymus canadensis & elymus virginicus*

Broadleafs

Annuals

Spurges

Ridgeseed spurge	*Euphorbia glyptosperma*
Toothed spurge	*Euphorbia dentata*
Leafy spurge	*Euphorbia esula*

Groundsel	*Senecio sp.*
Common ragweed	*Ambrosia artemisiifolia*
Sandbur	*Cenhrus longispinus*
Goathead	*Tribulus terrestris*
Pigweed	*Amaranthus sp.*

Perennials

Groundsel	*Senecio sp.*
Thistles	*Cirsium sp.*
Kochia	*Kochia scoparia*
Bindweed	*Convolvulus arvensis*

* From Texas Range Plants, (Hatch and Pluhar 1993) and Weeds of the West, (Whitson 1996).

Recommended references for identifying weeds and grasses. (See References for complete citation.)

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