Report Title:

PROGRESS REPORT ON RESEARCH TO IDENTIFY EFFECTIVE FOLIAR SPRAY AND MECHANIZED SPRAY DELIVERY SYSTEMS FOR SELECTIVE CONTROL OF MESQUITE ON RIGHTS-OF-WAY

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16. Abstract

High-volume, foliar sprays containing 0.5% clopyralid + 0.5% triclopyr ester applied during October 1995 killed 93% of the mesquite regrowth treated in highway rights-of-way. Apparent mortality of mesquite regrowth treated during the summer of 1996 with the same spray averaged 80% at 1 year after treatment. Mesquite control tended to improve with spray applications delayed until later in the growing season (August or later) compared to earlier applications (June or July). There was no advantage to increasing the concentrations of clopyralid and triclopyr above 0.5%. Commercial surfactants at 0.5% of the spray solution or diesel fuel at 5% performed similarly as adjuvants, and there was no advantage to using vegetable oil or to increasing the concentration of diesel fuel above 5%. Mechanized, automatic delivery systems suited for selective application of foliar sprays to mesquite regrowth include: (1) a Brush Robot which mechanically senses individual mesquite plants; (2) a mesquite-sensing spray boom which detects mesquite with horizontal beams of modulated light; and (3) an automatic sprayer mounted on an all-terrain vehicle which utilizes the human eye to detect mesquite.

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ATV	all-terrain vehicle
C	Centigrade
cm	centimeter
ha	hectare
hr	hour
km	kilometer
kPa	kilopascal
kW	kilowatt
L	liter
LSD	least significant difference
m	meter
min	minute
ml	milliliter
mm	millimeter
o.d.	outside dimension
PTO	power take off
PVC	polyvinyl chloride
r^2	correlation coefficient
ROW	rights-of-way
rpm	revolutions per minute
sec	second
TxDOT	Texas Department of Transportation
YAT	year(s) after treatment
yr	year

INTRODUCTION AND BACKGROUND

The Texas Department of Transportation's (TxDOT) management objective for its highway rights-of-way (ROW) is to create and maintain the native prairie plant community for the region and to minimize mowing on a large proportion of the ROW in rural areas. Honey mesquite (*Prosopis glandulosa* var. *glandulosa*) is a major problem on TxDOT's ROW in the western two-thirds of the State. Mowing, TxDOT's basic ROW maintenance practice, currently costs about $44.50/ha, and only temporarily suppresses mesquite. Mesquite thorns puncture tires of TxDOT vehicles and those of motorists, resulting in considerable expense and a safety hazard. TxDOT manages about 0.57 million ha of highway ROW, hence the expense of mowing is a substantial outlay of tax-payers' dollars which is not considered cost efficient on ROW where mowing is used primarily for mesquite management. The achievement of TxDOT's objective for its ROW hinges upon the development and implementation of effective and cost-efficient technology to control mesquite infestations.

The only herbicide treatment currently recommended for mesquite control by TxDOT's Vegetation Management Staff is the low-volume basal application of Pathfinder II. This ready-to-use formulation of the butoxyethyl ester of triclopyr in a vegetable oil carrier must be applied as an individual-plant treatment by ground crews using pressurized garden sprayers, backpack sprayers, or all-terrain vehicles (ATV) equipped with sprayers. This stem spray method is very labor intensive, especially for control of multiple-stemmed mesquite regrowth growing in association with dense, herbaceous vegetation; therefore, it does not seem to be a feasible mesquite management alternative for the greatest proportion of TxDOT's mesquite-infested ROW.

REVIEW OF PREVIOUS WORK

High-volume foliar sprays (leaf sprays) containing 0.5% triclopyr butoxyethyl ester + 0.5% clopyralid monoethanolamine salt applied in a water carrier containing either 5% diesel fuel or 0.25% non-ionic surfactant have been found highly effective for control of multiple-stemmed mesquite regrowth on Texas rangelands (McGinty and Ueckert 1995). Mesquite mortality following applications of these leaf sprays averaged 80% (range 61 - 93%) in five, large- scale research demonstration plots installed in 1995 on rangelands in west-central Texas (Ueckert et al. 1997). Results from these experiments as well as from our research on TxDOT's highway ROW during 1995 (Ueckert and McGinty 1995) revealed that leaf sprays were much less expensive and labor intensive than stem sprays, especially when the mesquite was of the multiple-stem growth form. Consequently, research to determine the efficacy of foliar sprays containing mixtures of triclopyr ester and clopyralid for control of mesquite on highway ROW appears warranted.

Triclopyr ester (Garlon 4) and clopyralid (Transline) are registered for use on highway ROW. The ester formulation of triclopyr (Garlon 4) is generally more effective for mesquite control than the amine formulation (Garlon 3A) (Jacoby and Meadors 1983, Bovey and Meyer 1987), because of increased penetration of the ester through the leaf surfaces. Clopyralid is the most effective herbicide known for control of mesquite, when applied as a foliar spray (Bovey and Meyer 1985, Jacoby et al. 1981), probably because it is absorbed and translocated downward in greater concentrations than other herbicides (Bovey et al. 1986, Bovey et al. 1988). Adding the butoxyethyl ester of triclopyr to clopyralid (1:1 ratio) in foliar sprays enhanced the deposition of clopyralid upon mesquite leaves, the absorption and downward translocation of clopyralid, and the phytotoxicity to mesquite, compared to clopyralid alone (Bovey et al. 1988, Bovey and Whisenant 1991).

Multiple-stemmed mesquite that have been previously top-killed by mechanical or herbicidal methods or by fire are more resistant to aerial sprays as compared to undisturbed plants with only one to a few stems (Jacoby et al. 1990). When aerial herbicide application to regrowth mesquite is being considered, the general recommendation is to wait 3 or 4 yr to allow the regrowth to grow to about 1.22 m in height (DowElanco 1990) to assure an adequate amount of leaf surface area for absorption of a lethal dose of herbicide. Allowing mesquite in highway ROW to grow for 3 to 4 yr prior to application of leaf sprays is not a viable alternative in many areas because of almost certain negative reactions of landowners, motorists, and taxpayers in general. Consequently, research is needed to determine if increasing the concentration of triclopyr ester and clopyralid in leaf sprays is necessary to achieve effective control of mesquite regrowth that may be only 1 or 2 yr old and which may have a sub-optimal leaf surface area. It also appears warranted to determine if increasing the concentration of oil in oil:water emulsion carriers for these leaf sprays would enhance herbicide penetration through the foliage and young bark sufficiently for absorption and translocation of lethal quantities of triclopyr and clopyralid.

Because of the limited TxDOT labor force and the extent of mesquite-infested ROW, mechanized and automated systems must be identified, or designed and fabricated, which can effectively deliver herbicide treatments for mesquite control on Texas highway ROW. These spraying systems must selectively apply the herbicide treatment to the mesquite plants, with little or no collateral damage to associated grasses and wild flowers and little or no risk of physical drift of herbicide onto susceptible crops or landscape plants on land adjacent to ROW. Automated delivery systems with features applicable for low-impact, selective application of herbicide treatments for mesquite control include the Brush Robot, Scan Ray II, carpeted roller, and the Rotowiper. The Brush Robot was formerly manufactured and distributed by Continental Belton Co. in Belton, Texas, but it is no longer commercially available. The Scan Ray II is manufactured and distributed by the Bowman Manufacturing Co. in Newport, Arkansas. The carpeted roller, has not been commercially fabricated or distributed, but several units have been built in metal shops. The Rotowiper is manufactured by Bisset Engineering International LTD in Ashburton, New Zealand and is distributed in Texas by Greater Southwest Ag in San Antonio.

The Brush Robot attaches to the 3-point hitch of rubber-tired farm tractors and is equipped with "robotic spot guns," which are physically activated as brush plants are traversed. The Scan Ray II sprayer attaches to a front-end loader frame on a farm tractor and is equipped with modulated light beams that optically sense target plants and trigger the release of the herbicidal spray. Wiedemann et al. (1992) recently modified the Scan Ray II sprayer into a "tree-sensing spray boom" that optically sensed mesquite plants and their dimensions, then applied an appropriate dose of the soil-active herbicide hexazinone (Velpar L) to each mesquite plant. The carpeted roller, which also attaches to a front-end loader frame of a farm tractor, utilizes a rotating, carpet-covered cylinder saturated with the herbicide-carrier mixture to treat target plants passing beneath the cylinder as the tractor moves forward (Mayeux and Crane 1985). The Rotowiper is a carpeted roller on wheels which is towed behind an ATV or small tractor.

Research is warranted to evaluate the existing automated herbicide delivery systems for utility in controlling mesquite on highway ROW, modify existing systems as necessary to render them useful for this specific application, and/or design and fabricate new delivery systems which are practical and effective.

STATEMENT OF RESEARCH OBJECTIVES

Objective 2: Determine the minimum concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and the optimal herbicide carrier in high-volume foliar sprays of these herbicides for effective control of mesquite in highway rights-of-way.

Objective 3: Design and fabricate mechanized and automated systems for applications of proven tactical mesquite control techniques, and evaluate the efficiency of these systems for control of mesquite in highway rights-of-way.

RESEARCH APPROACH/PROCEDURES

Objective 2

One small-plot, field experiment was installed in mid October 1995 in Tom Green County and 12 were installed during June, July, and August 1996 (4 each month) in 12 other counties in west-central Texas. Dates and locations for the 13 experiments are shown in Table 1.

Treatments included in the October 1995 experiment included 1:1 ratio mixtures of clopyralid and triclopyr ester at 0.5% + 0.5%, 0.75% + 0.75%, or 1.0% + 1.0% applied as high-volume foliar sprays in water + 0.5% Silwet L-77 surfactant (polyalkyleneoxide modified heptamethyltrisiloxane and allyloxypolyethylene glycol methyl ether), or in oil:water emulsions consisting of water + 5% diesel fuel, 25% diesel fuel, or 5% vegetable oil (Improved JLB Oil Plus). The commercial emulsifier Triton X-100 was used at 8 ml/L of oil to create the oil:water emulsions during agitation in the spray tanks. Treatments applied in the 1996 experiments included 1:1 ratio mixtures of clopyralid and triclopyr ester at 0.5% + 0.5%, 1.0% + 1.0%, or 2.0% + 2.0% applied as foliar sprays in water + 0.5% non-ionic surfactant [25% nonyphenol polyethylene glycol ether (Surf Wet NP)], or in diesel oil:water emulsions containing 5% or 20% diesel fuel. Foliar sprays were applied to individual mesquite plants to the point of runoff with backpack sprayers in the October 1995 experiment and with ATVs equipped with spray tanks, electric pumps, hoses, and spray guns with ConeJet 5500-PPB-X6 adjustable cone nozzles in the 1996 experiments. Experiments were arranged as completely randomized designs with 3 replications of each treatment, except that single plots were treated at the Schleicher County site.

Table 1. Dates and locations of small-plot field experiments installed to identify the optimal concentration of clopyralid (Transline) and triclopyr ester (Garlon 4) in leaf sprays and the optimal adjuvant for these sprays to achieve acceptable control of frequently mowed mesquite on highway rights-of-way in west-central Texas.

Date	County	Location
Oct. 16-17, 1995	Tom Green	East Loop 306 between FM 765 and US 87
June 18, 1996	Schleicher	US 190 between reference markers 358 & 360
June 19, 1996	Reagan	US 67 between reference markers 754 & 756
June 20, 1996	Menard	FM 2092 between reference markers 420 & 422
June 21, 1996	Runnels	FM 2333 between reference markers 344 & 346
July 22, 1996	Edwards	FM 2630 between reference markers 452 & 454
July 23, 1996	Concho	FM 2134 between reference markers 364 & 366
July 24, 1996	Coke	FM 2742 from FM 2059 west 3.2 km
July 24, 1996	Sterling	SH 163 between reference markers 450 & 452
Aug. 19, 1996	Crockett	FM 1964 from 3.2 km W. of SH 137, then 3.2 k W.
Aug. 19, 1996	Irion	SH 163 between reference markers 484 & 486
Aug. 20, 1996	Glasscock	FM 1357 between reference markers 340 & 342
Aug. 20, 1996	Nolan	FM 1170 between reference markers 385 & 387

Plot sizes varied depending upon the density of the mesquite. Plots extended from fence lines to the edge of the strip-mowed swaths adjacent to the pavements (i.e., mesquite that had been strip mowed during the season of treatment were not sprayed). Mesquite in the ROW plots in Tom Green and Coke Counties had not been mowed for approximately 3 yr and that at the study sites in Menard, Edwards, and Sterling had not been mowed for about 2 yr at time of treatment. At all other study sites the mesquite had been mowed during the autumn preceding the 1996 treatments.

Each plot was evaluated by a team of three workers at approximately 1 yr post-treatment and the plots treated during mid October 1995 were evaluated again at 2 yr post-treatment. Each worker carefully examined all mesquite in a belt transect approximately 2 m wide and parallel with the long axis of each plot. Mesquite plants with live tissue were recorded as live and those with no live tissue were recorded as "apparently dead." The percentage of apparently dead plants in each plot was calculated. The data were subjected to analyses of variance and means were separated by least significant difference (LSD) at the 0.05 probability level, where appropriate.

Objective 3

It is critically important to apply stem sprays (e.g. Pathfinder II) completely around the circumference of all stems on a mesquite plant to achieve an acceptable level of mortality (McGinty and Ueckert 1995). Because of this, and the fact that mesquite plants that have been repeatedly mowed have many basal stems and that the basal stems are often difficult to spray because of the presence of dense, herbaceous vegetation, the probability of success in designing effective automated delivery systems for stem sprays was judged to be too low to justify the effort. Consequently, efforts were concentrated on automated delivery systems for leaf sprays in Objective 3.

Included in the first phase of this effort was the design, fabrication, and testing of a personnel carrier and the field testing of mechanized, selective herbicide delivery systems that were currently available relative to their utility and efficiency for selectively applying foliar-active herbicides to regrowth mesquite in highway ROW. A Brush Robot with an 2.44-m boom and a carpeted roller were acquired from the Texas Agricultural Extension Service at Corpus Christi and College Station, Texas, respectively. A Rotowiper was acquired on loan from Greater Southwest Ag in San Antonio, Texas. We contracted the design and fabrication of a 3.66-m mesquite-sensing spray boom to Professor Harold T. Wiedemann, P.E. (Texas Agricultural Experiment Station - Vernon, Texas). Selected components of the Scan Ray II sprayer were purchased from Bowman Manufacturing Co. in Newport, Arkansas for fabricating this sprayer. The first prototype of the mesquite-sensing spray boom was completed in October 1997. We also designed, fabricated, and field tested the first prototype of an automatic spraying system that was transported by an all-terrain vehicle (ATV). This system utilizes the human eye to sense mesquite and manually controlled electric switches to selectively spray mesquite as they pass beneath the 1.83-m front-mounted spray boom.

Personnel Carrier

A personnel carrier was designed and fabricated to be mounted onto the front-end loader frame of a farm tractor to transport a crew of 3 workers while they manually and selectively sprayed mesquite regrowth as the tractor traversed the mesquite-infested ROW (Fig. 1). The center section of the personnel carrier tool bar was constructed from a 1.83-m long piece of 7.62-cm X 7.62-cm X 0.32-cm square tubing. Brackets were attached to the center section with bolts which facilitated attaching it to the lift arms of a John Deere 145 front-end loader (bucket removed) mounted on a 29.8-kW farm tractor. Three-meter lengths of 6.35-cm X 6.35-cm X 0.95-cm square tubing were telescoped 1.22 m into each end of the center section of the tool bar and held in place by set screws, resulting in a total tool bar width of 6.1 m. Heavy-duty plastic seats, equipped with a seat belt and foot rest, were bolted on at the center of the tool bar and at 30.5 cm from each end to allow a crew of 3 workers to spray a 7.3-m swath. A 95-L spray tank, equipped with a 5.3 L/min, 12-volt electric pump was attached to the 3-point hitch of the tractor in a bracket.

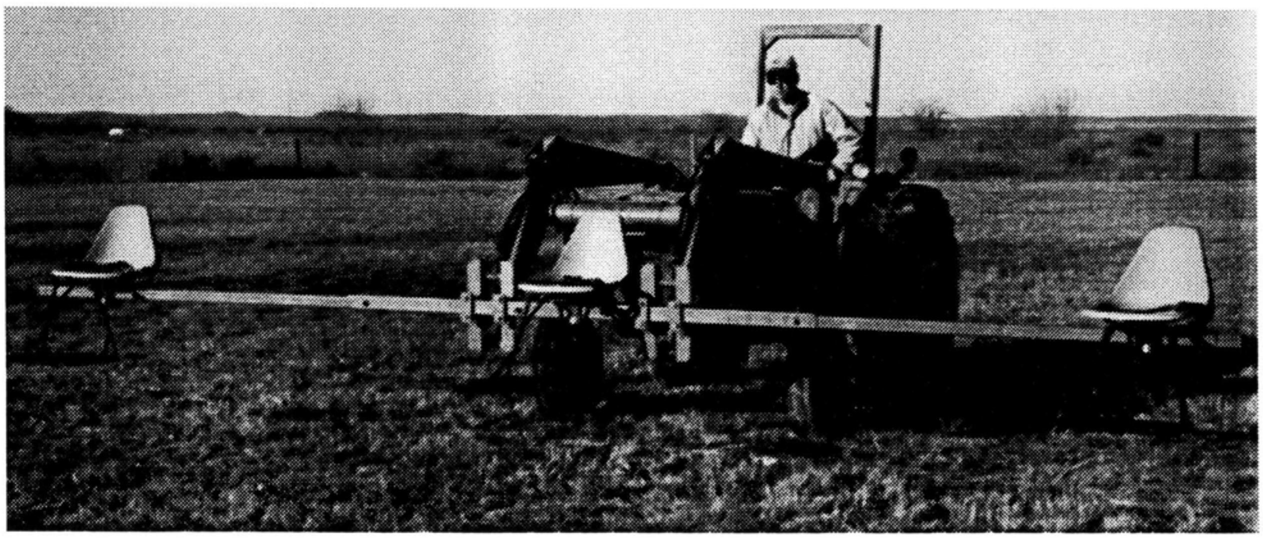

Figure 1. First prototype of 6.1-m-wide personnel carrier designed to allow three workers to selectively apply leaf sprays to mesquite in highway rights-of-way.

The personnel carrier was evaluated for efficiency within 4 plots approximately 0.4-hectare (ha) in size on August 23, 1996. The leaf spray contained 0.5% clopyralid + 0.5% triclopyr ester and was applied in a water carrier containing 0.25% non-ionic surfactant and 0.25% Hi-Light spray marking dye with TriggerJet spray guns equipped with ConeJet 5500 PPB X-8 adjustable cone nozzles. The tool bar was carried at 0.9 m above the soil surface at a ground speed of 1.6 km/hr. Time required to treat each plot was recorded as was the volume of spray used. Workers counted the numbers of mesquite sprayed in each plot with hand tally counters. To estimate cost/ha for operating the personnel carrier, the tractor + personnel carrier was valued at $16/hr, labor for the tractor driver and 3 workers was valued at $12.05/man-hr, and the spray was valued at $0.48/L. The actual costs for the tractor + personnel carrier and labor was adjusted to 80% efficiency, to adjust for inefficiencies associated with traveling to-and-from work sites, a.m. and p.m. rest breaks for the workers, and equipment breakdowns. The data were subjected to regression analysis to quantify the relationship between cost/ha and mesquite density (no./ha), and a graph of the relationship was prepared.

2.44-m Brush Robot

The first Brush Robot tested (Fig. 2), with an effective swath width of only 2.13 m because of missing robotic spot guns on each end of the boom, was evaluated within four 0.4-ha plots on July 26, 1996. The robotic spot guns were equipped with 7.6-L/min flat fan nozzles (Spraco 76402004). The Brush Robot was attached to the 3-point hitch of the 29.8-kW tractor and the implement was raised or lowered so that the sensors on the robotic spot guns would encounter the lower 1/3 of the mesquite canopies. The robotic spot guns were on 15.2-cm centers on the spray boom, and the spray was supplied to the nozzles from a 473-L tank via a high-volume, PTO-powered, rotary pump at 120 kPa pressure. The spray mixture was the same as discussed above for the personnel carrier, except that 5% diesel fuel was used as the adjuvant, rather than the surfactant. A flow meter was installed between the pump and the spray boom to measure the volume of spray applied in each plot, and a worker walking behind the sprayer counted the number of mesquite plants treated. The tractor was operated at 2.8 km/hr and meandered around plots with low densities of mesquite to minimize the traversing of areas obviously devoid of mesquite. Time required to treat each plot was recorded and costs were calculated with the tractor + Brush Robot valued at $19/hr, labor for the tractor operator at $12.05/hr, and spray at $0.48/L. Costs for labor and machine time were adjusted for 80% efficiency as discussed above and the data were analyzed and graphed as discussed above.

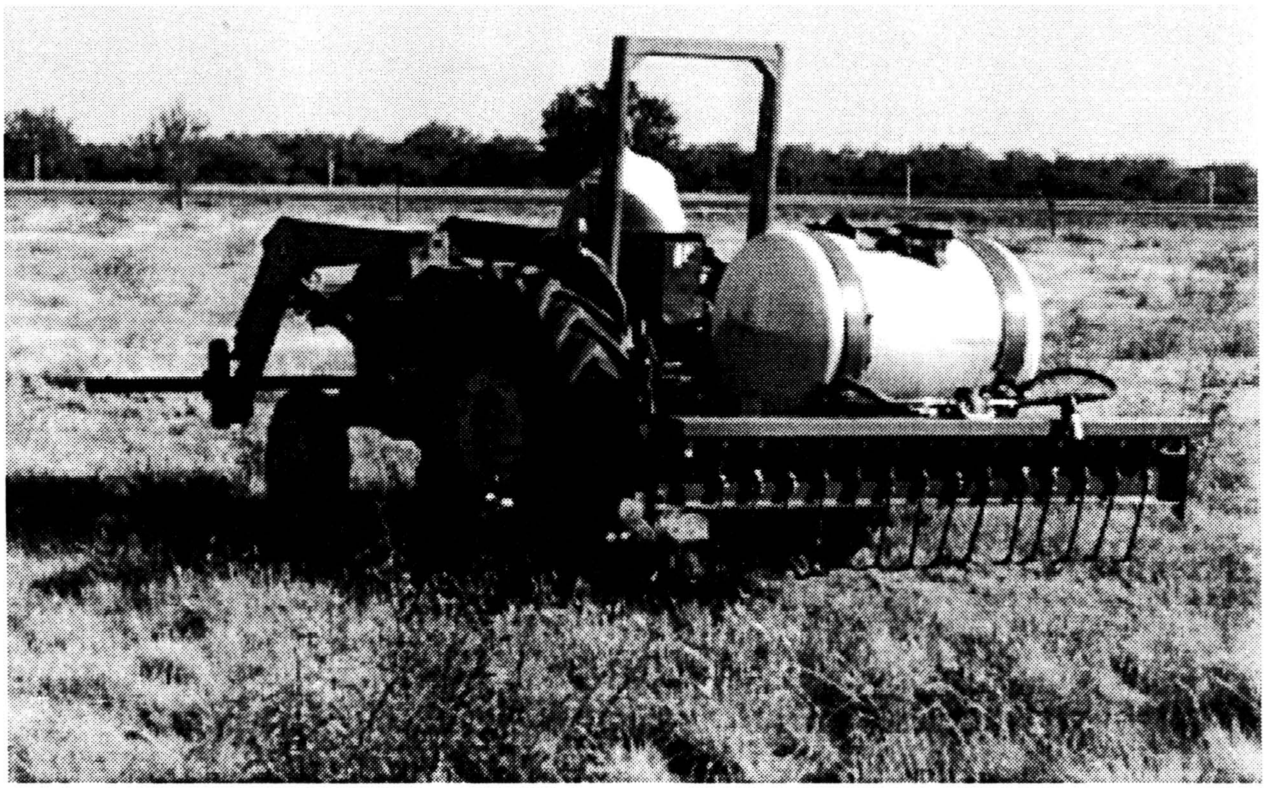

Figure 2. Brush Robot with 2.44-m boom (2.13-m effective swath width).

4.88-m Brush Robot

The original Brush Robot was modified during summer 1997 by adding two additional robotic spot guns to the existing spray boom and attaching a flexible, 1.22-m extension onto each end of the original boom, resulting in an effective swath width of 4.88 m (Fig. 3). The 1.22-m extensions were hinged to the ends of the original 2.44-m boom so they could be rotated forward when the implement was not in use, or transported on an equipment trailer. The robotic spot guns were fabricated in the shop from 2.54-cm X 2.54-cm X 5.08-cm blocks of polyvinyl chloride (PVC) and 0.6-cm, schedule 80 (7935 kPa) PVC pipe (Boedeker Plastics, Inc.; Shiner, TX) and "Handee-Bend" water nozzles (Milton Industries, Inc.; Chicago, IL). The serrated, rubber flanges that attach at the lower ends of the spot guns were cut from truck mud flaps. All robotic spot guns were placed on 15.2-cm centers. During field testing of the original Brush Robot, we observed that the volume of spray applied by the 7.6-L/min nozzles spaced 15.2 cm apart was excessive, thus the second prototype was equipped with 3.8-L/min nozzles (VeeJet 95-10). This implement was evaluated within 13 plots, approximately 0.4 ha in size, during August 6, 26, and 27, 1997. The methods were identical to those used for the original implement, except that 2 workers walking behind the implement counted the mesquite plants sprayed in plots where the mesquite density was relatively low, and the numbers of mesquite treated in high-density plots was estimated immediately after treatment by 4 workers who counted the treated mesquite within 1-m-wide belt transects parallel with the long axis of each plot.

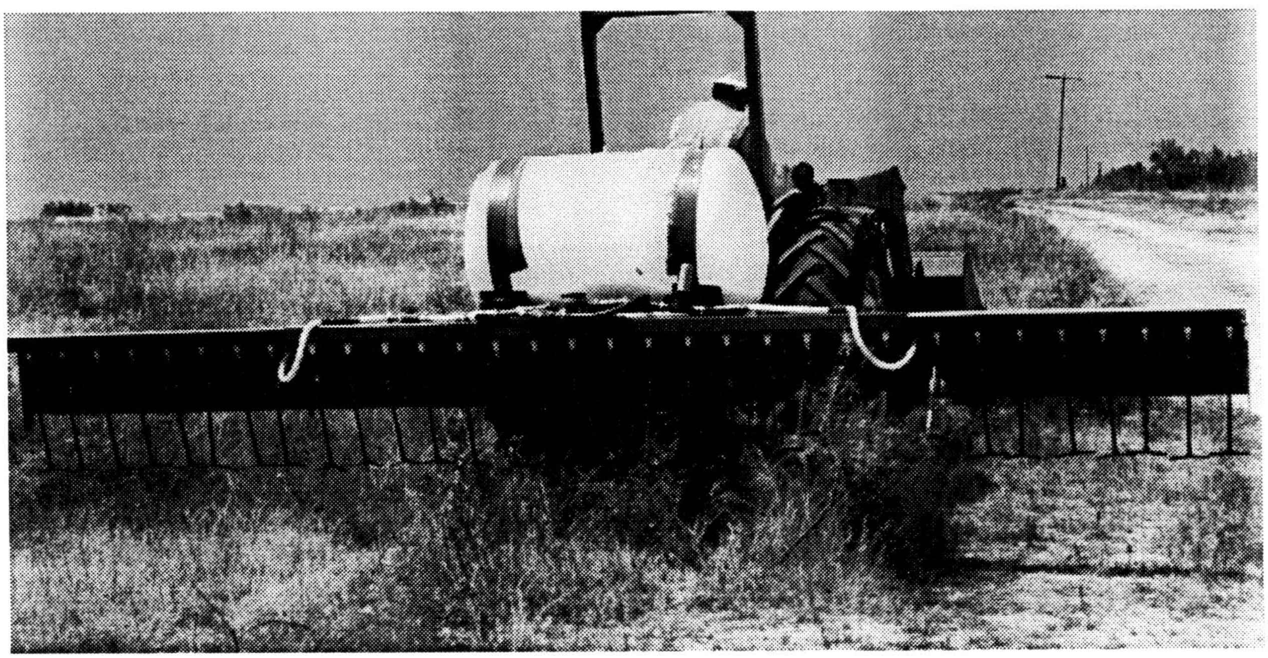

Figure 3. Second prototype of Brush Robot with 4.88-m boom.

Carpeted Roller

The shop-built carpeted roller had an effective swath width of 1.98 m (Fig.4). The rotating cylinder, made of 26.7-cm (o.d.) diameter PVC pipe covered with common household carpet with medium-length dense shag was continuously rotated at 40 rpm with a hydraulic motor. The direction of rotation of the bottom edge of the cylinder was opposite to the direction of travel to maximize the amount of herbicide applied. The implement was attached to the lift arms of the front-end loader mounted on the 29.8 kW tractor, allowing the driver to adjust the bottom edge of the roller to the proper height for the mesquite encountered. The herbicide mixture, applied in a water carrier with 1% non-ionic surfactant and 0.25% Hi-Light dye, included 4.54% clopyralid (Transline) and 4.54% triclopyr ester (Garlon 4). This 1:10 herbicide-water mixture was applied by gravity flow from a reservoir mounted above the roller through a horizontal, 1.3-cm diameter PVC pipe with 1.6-mm diameter holes drilled on 1.3-cm centers mounted above the roller. The tractor driver wet the carpet and released additional fluid as necessary during operation by an electric, push-button switch which controlled a solenoid valve beneath the spray tank.

The efficiency of this implement was evaluated on August 23, 1996 within 4 plots, approximately 0.4 ha in size. The tractor was operated at 3.7 km/hr and meandered so as to treat all the visible mesquite in each plot without traversing areas devoid of mesquite. A worker following the implement counted all the mesquite treated in each plot. Costs were estimated with the tractor + carpeted roller valued at $19/hr, labor valued at $12.05/hr, and the herbicide spray valued at $4.29/L. Costs for labor and machine time were adjusted and the data were analyzed and graphed as discussed above.

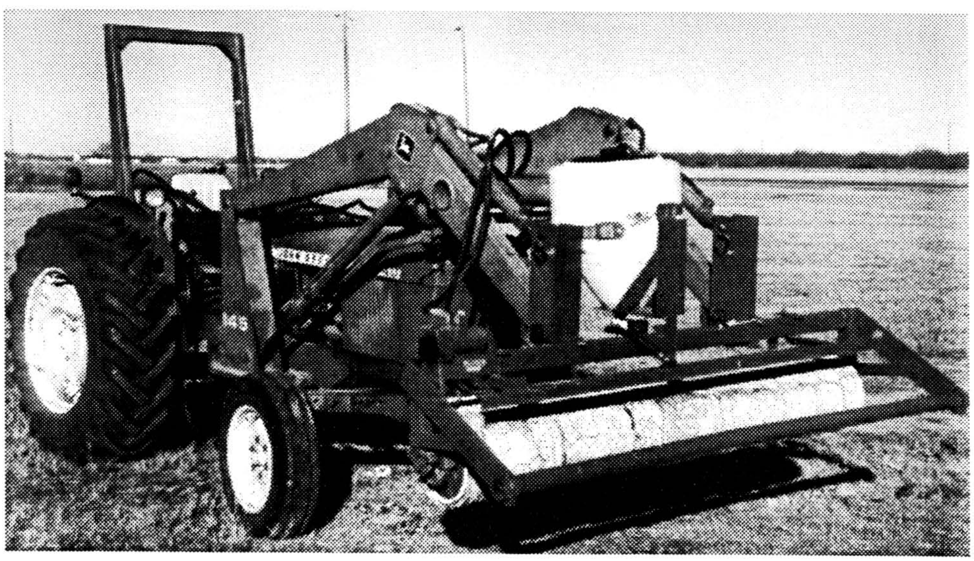

Figure 4. Carpeted roller with 1.98-m wide, carpet-covered, rotating cylinder for selective application of herbicide solution to mesquite in highway rights-of-way.

Rotowiper

The 1.80-m wide X 15.2-cm diameter, steel cylinder on the Rotowiper (Fig. 5) was covered with a carpet-like material with very short fibers. The cylinder was rotated by a belt attached to a pulley on the right wheel. The belt was twisted so that the direction of rotation of the lower edge of the cylinder was opposite the direction of travel. Height of the cylinder was adjustable by screw-type top links between the implement frame and the hinged wheel-support brackets. The herbicide spray was applied to the carpeted roller from a reservoir via a 5.3 L/min, 12-volt pump and small, plastic fan-type nozzles, positioned on 12.7-cm centers, inserted into a 1.3-cm diameter black poly pipe mounted above the cylinder. The pump could be activated as necessary by the driver with a hand-held, push-button electric switch. During operation, the Rotowiper periodically applied streaks of soap suds to mark the swath treated along the left-hand side of the carpeted roller from a 9.5-L reservoir containing a soap-water solution. A diaphragm air pump powered by a cam and lever device on the axle of the left wheel pumped air into the reservoir to generate the foam.

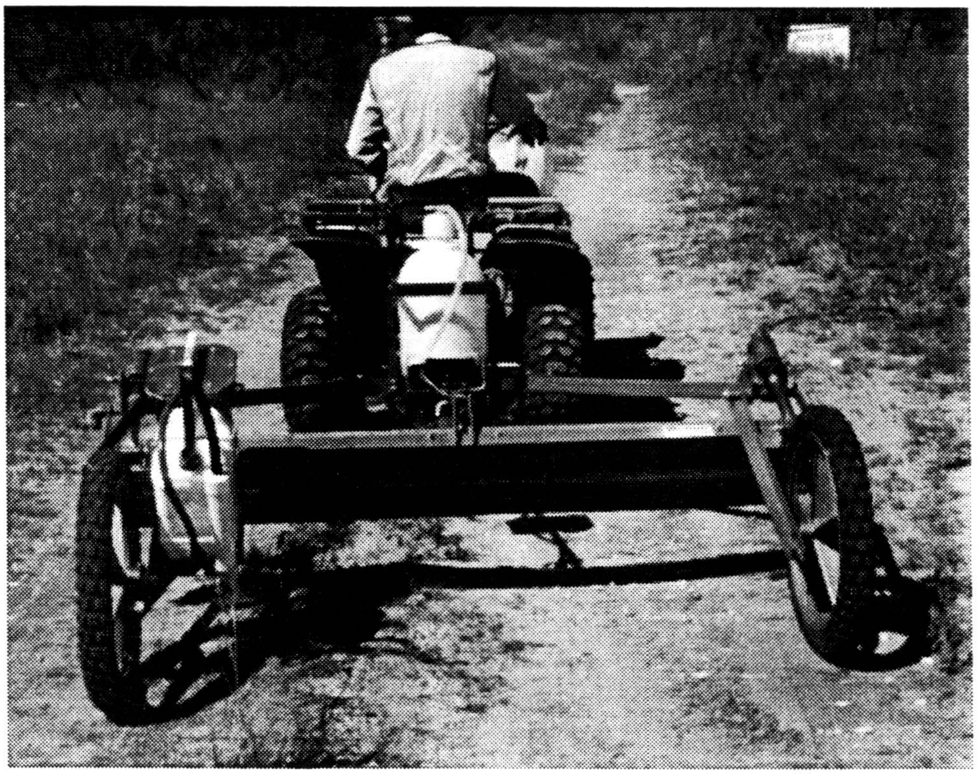

Figure 5. The Rotowiper was towed by a Polaris 250 all-terrain vehicle while selectively applying herbicide solution to mesquite in highway rights-of-way.

The Rotowiper was towed behind a Polaris 250 2X4 ATV, operated at 5-8 km/hr, during evaluation of the implement on September 11, 1996 within 2 plots approximately 0.4 ha in size. The spray mixture was the same 1:10 herbicide-water mixture described above for the carpeted roller and all methods were the same as for the carpeted roller, except that the ATV driver counted the mesquite as they were treated. Costs were estimated with the ATV + Rotowiper valued at $4.00/hr, labor at $12.05/hr, and the herbicide solution at $4.29/L. Costs for labor and machine time were adjusted for 80% efficiency. The data were graphed but not subjected to regression analysis because of inadequate sample size.

Automatic ATV Sprayer

The first prototype of the ATV-mounted, selective spraying implement was constructed from 2.54-cm X 2.54-cm X 0.32-cm square tubing. The 0.86-m-wide frame was attached to the [illegible] of the front rack of the ATV with U bolts, and diagonal support braces from the front of the frame bolted to the lower frame of the ATV. The 1.83-m spray boom was attached above the frame with a parallel linkage, allowing the boom to be raised and lowered with a lever by the ATV operator to the appropriate height above the target plants. Three nozzles, each capable of applying spray over a 0.91-m-wide swath, were attached to the boom on 0.86-m spacings, resulting in a total effective swath width of 2.74 m. A horizontal bending/retaining bar was attached to the frame 20.3 cm in front of the nozzles to bend taller mesquite over to the appropriate distance from the nozzles as they were traversed.

A solenoid valve was attached by each nozzle on the spray boom so the nozzles could be operated independently for selective application of herbicide to mesquite plants as they were traversed by the spray boom. A push-button electric switch was attached adjacent to the driver's left foot, left thumb, and right foot that controlled the left, center, and right solenoid/nozzle units of the spray boom, respectively. Spray was supplied from a 95-L spray tank and 11.4 L/min, 12-volt electric pump attached to the rear rack of the ATV. The sprayer allowed the operator to selectively apply the herbicide spray to mesquite plants as they were encountered on the left or right sides or at the center of the ATV (Fig. 6). Operators mastered the eye-hand and eye-foot coordination within 30 min.

The automatic ATV sprayer was evaluated within 6 plots using 3.8 L/min nozzles and within 12 plots using 7.6-L/min nozzles during August 1997, using spray containing 0.5% clopyralid + 0.5% triclopyr ester as described above. Costs were estimated with the ATV + sprayer valued at $4/hr, labor at $12.05/hr, and the spray at $0.48/L. Methods for adjusting machine and labor costs for 80% efficiency and for analyzing the data were the same as described above.

Figure 6. First prototype of an automatic ATV sprayer with 3 nozzles for selective application of leaf sprays to mesquite across a 2.74-m-wide swath.

Mesquite-Sensing Spray Boom

The mesquite-sensing spray boom (Fig. 7) was designed and fabricated under a sub-contract by Professor Harold Wiedemann, P.E. and Gerral Schulz, Texas Agricultural Experiment Station - Vernon, from 10.2-cm X 10.2-cm X 0.95-cm square tubing. The 1.83-m long center section was attached to the front-end loader frame on the 29.8 kW tractor. A 0.91-m section, hinged on each end of the center section, flexes upward to the vertical position when not in use or when the implement is being transported. The boom has four 0.91-m-wide sections, each equipped with a 7.6-L/min flat fan nozzle, solenoid valve, a modulated light sender and receiver, a time-delay relay, and a counter. When a mesquite twig or leaves break the light beam on any section of the boom, an electrical impulse is sent through the time-delay relay to the solenoid, which supplies the herbicide spray to the nozzle as the mesquite passes beneath the boom. The counters in the electrical circuits keep a tally of the number of times each light beam is broken, which approximates the number of mesquite plants sprayed. A 189-L spray tank with its frame is attached to the 3-point hitch of the tractor, and the spray is supplied to the nozzles by a PTO-powered rotary pump. A flow meter between the pump and the spray boom measures the spray applied during any time period or upon any target area. A brush guard on the center section of the boom protects the electrical components and flow meter.

This implement was subjected to a preliminary field test in a heavily grazed field of WW Spar bluestem infested with mesquite seedlings and saplings near Vernon on October 17, 1997.

The primary objective of this test was to determine the appropriate tractor speed, nozzle size, time-delay relays and to determine if other modifications were needed.

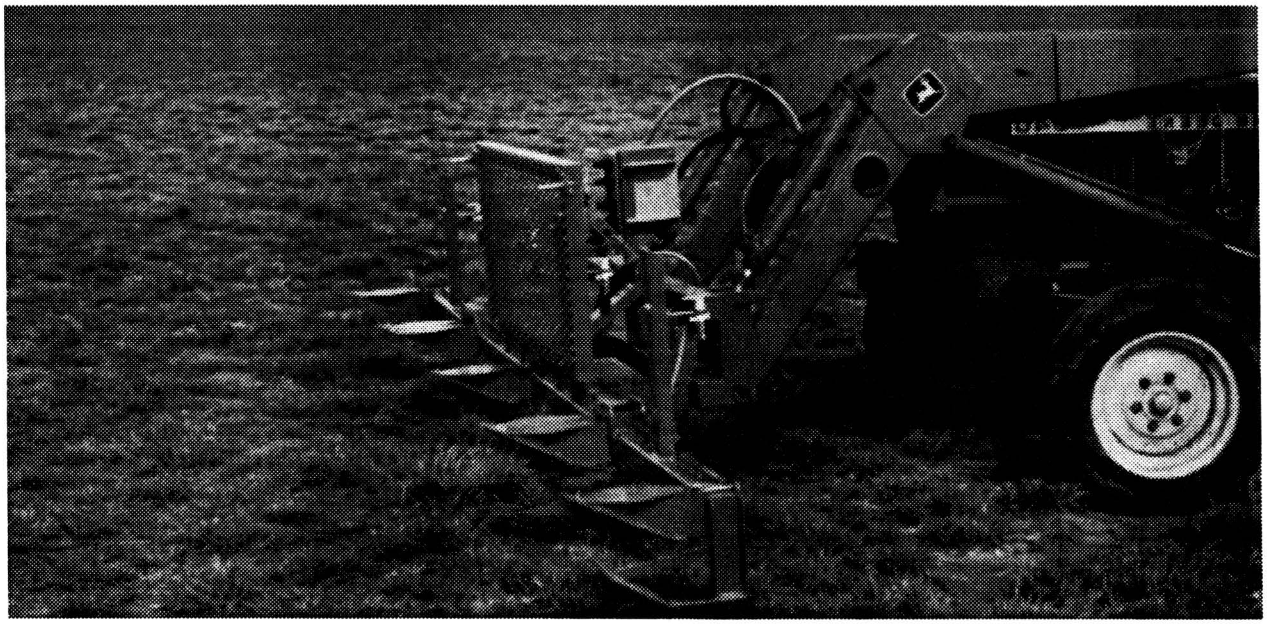

Figure 7. First prototype of the 3.66-m mesquite-sensing spray boom, which automatically and selectively applies leaf sprays to mesquite after their leaves or stems break horizontal beams of modulated light.

FINDINGS/DISCUSSION

Objective 2

1995 Experiment

Mesquite control was highly satisfactory (>86% mortality) at 2 years after treatment (YAT) for all treatments applied October 16-17, 1995 in Tom Green County to mesquite regrowth which had not been mowed for about 3 yr (Table 2). Mesquite mortality at 2 YAT averaged 100% for foliar sprays containing 0.75% clopyralid + 0.75% triclopyr ester with 5% diesel fuel as the adjuvant, but this level of mortality was not significantly different from that achieved with foliar sprays containing 0.5% clopyralid + 0.5% triclopyr ester applied with 5% or 25% diesel fuel as adjuvants. Mesquite mortality achieved with 0.5% clopyralid + 0.5% triclopyr with 5% diesel fuel as the adjuvant (98%) was similar to that achieved by the same herbicide concentrations with 0.5% Silwet L-77 as the adjuvant (90%), but significantly greater than that achieved by the same herbicide concentrations with 5% vegetable oil as the adjuvant (86%) (Table 2). The data indicated that, in general, there was no advantage to increasing the concentrations of clopyralid and triclopyr ester above 0.5% in mesquite leaf sprays, and that the choice of adjuvants had little impact.

It should be pointed out that the treatments applied October 16-17, 1995 were later into the autumn than is normally recommended for leaf sprays (September 30) (McGinty and Ueckert 1995). However, air temperatures during treatment applications ranged from 27 to 32° C, soil temperatures at 30 cm were 21 to 23° C, and the mesquite foliage was in good condition with no new growth on the stem tips. Relative humidity was low (range: 12 to 38%) during treatment applications. It was unusual that the mortality values for 10 of the 12 treatments increased during the time interval between 1 and 2 YAT (Table 2). Mesquite mortality values usually decrease slightly to substantially from 1 to 2 YAT following application of foliar herbicides to mesquite because some plants which have no green tissues during the first growing season after treatment usually produce basal sprouts during the second growing season post treatment.

1996 Experiments

When the data collected at 1 YAT for each experiment were analyzed independently, there were significant differences among treatments within only four of the 12 experiments (Appendices A, B, and C) and there was no consistent pattern or trend among the four experiments relative to these differences. Data from the individual experiments do, however, show the range in efficacy observed within each treatment. For example, within the four experiments installed in June 1996 the apparent mortality for leaf sprays containing 0.5% clopyralid + 0.5% triclopyr ester with the 5% diesel fuel adjuvant ranged from 63 to 81% among the four locations (Appendix A). Similarly, apparent mortality achieved with leaf sprays containing 2% clopyralid + 2% triclopyr ester with the 20% diesel fuel adjuvant ranged from 41 to 86%.

Table 2. Mean percent (%) apparent mortality (AM) of mesquite along Loop 306 East in Tom Green County at 1 year after treatment (YAT) and mean percent mortality at 2 YAT with leaf sprays containing various concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and various adjuvants on October 16-17, 1995.

Treatment			
Herbicide			Mortality @
Transline + Garlon 4	Adjuvant	AM @ 1 YAT[1]	2 YAT
(%)		------------(%)	-----------
.5 + .5	.5% Silwet L-77	80 d	90 cd
.75 + .75	.5% Silwet L-77	84 cd	90 bcd
1 + 1	.5% Silwet L-77	89 bcd	93 a-d
.5 + .5	5% Diesel	98 ab	98 abc
.75 + .75	5% Diesel	99 a	100 a
1 + 1	5% Diesel	80 d	90 bcd
.5 + .5	25% Diesel	95 ab	98 ab
.75 + .75	25% Diesel	93 abc	95 abc
1 + 1	25% Diesel	94 ab	96 abc
.5 + .5	5% JLB oil	92 abc	86 d
.75 + .75	5% JLB oil	90 abc	93 a-d
1 + 1	5% JLB oil	93 abc	98 abc

[1] Means within a column followed by a similar lower case letter are not significantly different according to $LSD_{0.05}$.

When the data from the four experiments were pooled within each month of treatment and subjected to analysis of variance, there were no significant treatment effects within June, July, or August dates of application (Table 3). Similarly, when data from all 12 experiments were pooled and subjected to analysis of variance there were no significant treatment effects (Table 3, last column). Apparent mortality of mesquite at 1 YAT, averaged over all treatments in June, July, and August application dates, averaged about 82%. Results at 1 YAT indicate that there is no advantage to increasing the concentration of clopyralid or triclopyr ester above 0.5% in leaf sprays used for mesquite control on highway ROW. Similarly, these results suggest that 0.5% surfactant, 5% diesel fuel and 20% diesel fuel performed similarly as adjuvants in mesquite leaf sprays.

Results from the 12 experiments installed in 1996 were in general agreement with those from the October 1995 experiment. The high mesquite mortalities achieved in the October 1995 experiment in Tom Green County (Table 2) were probably due to the fact that the mesquite regrowth was at least 3 yr old at time of treatment. High apparent mortality values for mesquite regrowth that was about 3 yr old in Coke County (Appendix B) support this hypothesis, although August treatments of regrowth <1 yr old also resulted in high levels of apparent mortality at 1 YAT (Appendix C).

Averaged over all treatments, apparent mesquite mortality was not significantly different among the June, July, and August treatment dates, but there was a trend toward increasing efficacy with each month delay in treatment time (i.e. June<July<August) (Table 3). Apparent mortality averaged 74, 83, and 90% for June, July, and August treatments, respectively. This trend could be due to increasing soil temperatures as the summer progressed, increasing herbicide absorption and translocation as the mesquite leaf surface area increased over the 3-month period, increasing downward translocation of absorbed herbicide as the production of new growth at the stem tips ceased in response to decreasing availability of soil moisture as summer progressed, or to a combination or interaction of all three of these factors.

Table 3. Mean percent (%) apparent mortality of mesquite in highway rights-of-way at one year after treatment (YAT) with leaf sprays containing various concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and various adjuvants during June, July, or August 1996 at 12 locations.

Treatment		Apparent mortality @ 1 YAT[1]			
Herbicide		Month treated			
Transline + Garlon 4	Adjuvant	June[2]	July[3]	August[4]	Mean
(%)		-(%)-			
.5 + .5	.5% Surfactant	81	91	87	87
1 + 1	.5% Surfactant	72	90	94	85
2 + 2	.5% Surfactant	82	83	92	85
.5 + .5	5% Diesel	71	74	92	79
1 + 1	5% Diesel	71	82	92	82
2 + 2	5% Diesel	81	82	87	83
.5 + .5	20% Diesel	70	65	84	73
1 + 1	20% Diesel	68	87	93	83
2 + 2	20% Diesel	70	88	92	84
	Avg.[5] =	74	83	90	82

[1]Means within a column were not significantly different according to analysis of variance at the 5% probability level ($P \leq 0.05$).
[2]Average for experiments in Schleicher, Reagan, Menard, and Runnels Counties.
[3]Average for experiments in Edwards, Concho, Coke, and Sterling Counties.
[4]Average for experiments in Crockett, Irion, Glasscock, and Nolan Counties.
[5]Means within the Avg. row were not significantly different according to analysis of variance at the 5% probability level ($P \leq 0.05$).

Objective 3

The goal of field work during 1996 - 1997 was to screen an array of experimental and currently available automated delivery systems for utility in selective application of leaf sprays to mesquite in highway ROW. The evaluations were not designed to facilitate a statistically valid comparison among the systems. The work was carried out over about a 1-yr period at various locations, and the size and density of mesquite varied considerably among plots upon which the various implements were evaluated.

Personnel Carrier

The personnel carrier functioned well and the 5.3-L/min electric pump had ample capacity to supply the 3 spray guns. The implement was particularly appealing to the workers, who were accustomed to walking while applying mesquite leaf sprays. Mesquite plant density on the 4 plots treated averaged 1391/ha and efficiency of the personnel carrier averaged 1.3 ha/hr (range: 1.1 ha/hr @ 2081 mesquite/ha to 1.4 ha/hr @ 1213 mesquite/ha. Cost for operating the personnel carrier with the tractor operator and 3 workers spraying mesquite was estimated at $60.45/ha plus $0.03 for every mesquite plant sprayed ($Y = 60.45 + 0.03X$) within the range of mesquite densities encountered in the test plots (Fig. 8). The high value for the constant (60.45) reflected the high fixed cost of the tractor and 4 workers, whereas the low coefficient (0.03) indicated that cost for the spray for treating each plant was very low. Mesquite density was associated with 83% of the variability in cost/ha ($r^2 = 0.83$). Costs could be reduced considerably by using self-propelled personnel carriers that are commercially available because one less worker would be needed and because the per-hr cost for operating the machine would be about 40 to 50% of that for operating the farm tractor. The major disadvantage of the personnel carrier for applying leaf sprays to mesquite was that the maximum speed of travel possible to allow ample time for workers to achieve adequate spray coverage on the mesquite plants encountered was about 1.6 km/hr. The implement occasionally had to be stopped momentarily where mesquite densities were high. Shortage of labor may render the personnel carrier concept of little utility in most TxDOT county maintenance departments.

Brush Robot

The Brush Robot with a 2.13-m effective swath width, equipped with 7.6-L/min nozzles performed quite well, even on mesquite with <1 full growing season's growth. Efficiency averaged 0.90 ha/hr on the 4 plots where mesquite density averaged 677 plants/ha (range: 0.76 ha/hr @ 825 mesquite/ha to 1.16 ha/hr @ 405 mesquite/ha). Cost for operating the 2.13-m Brush Robot was estimated at $1.93/ha plus $0.18 for each mesquite plant treated ($Y = 1.93 + 0.18X$; $r^2 = 0.96$) within the range of mesquite densities encountered in the plots (Fig. 9). The high cost/plant treated was a function of the high volume of spray applied to each plant. It was common for a single mesquite plant to activate 2 or 3 of the 7.6-L/min nozzles. Bunch grasses that were of the same (or greater) height as the mesquite also frequently activated the nozzles, resulting in wastage of the spray. The amount of spray applied to each mesquite plant with the 7.6-L/min nozzles appeared excessive.

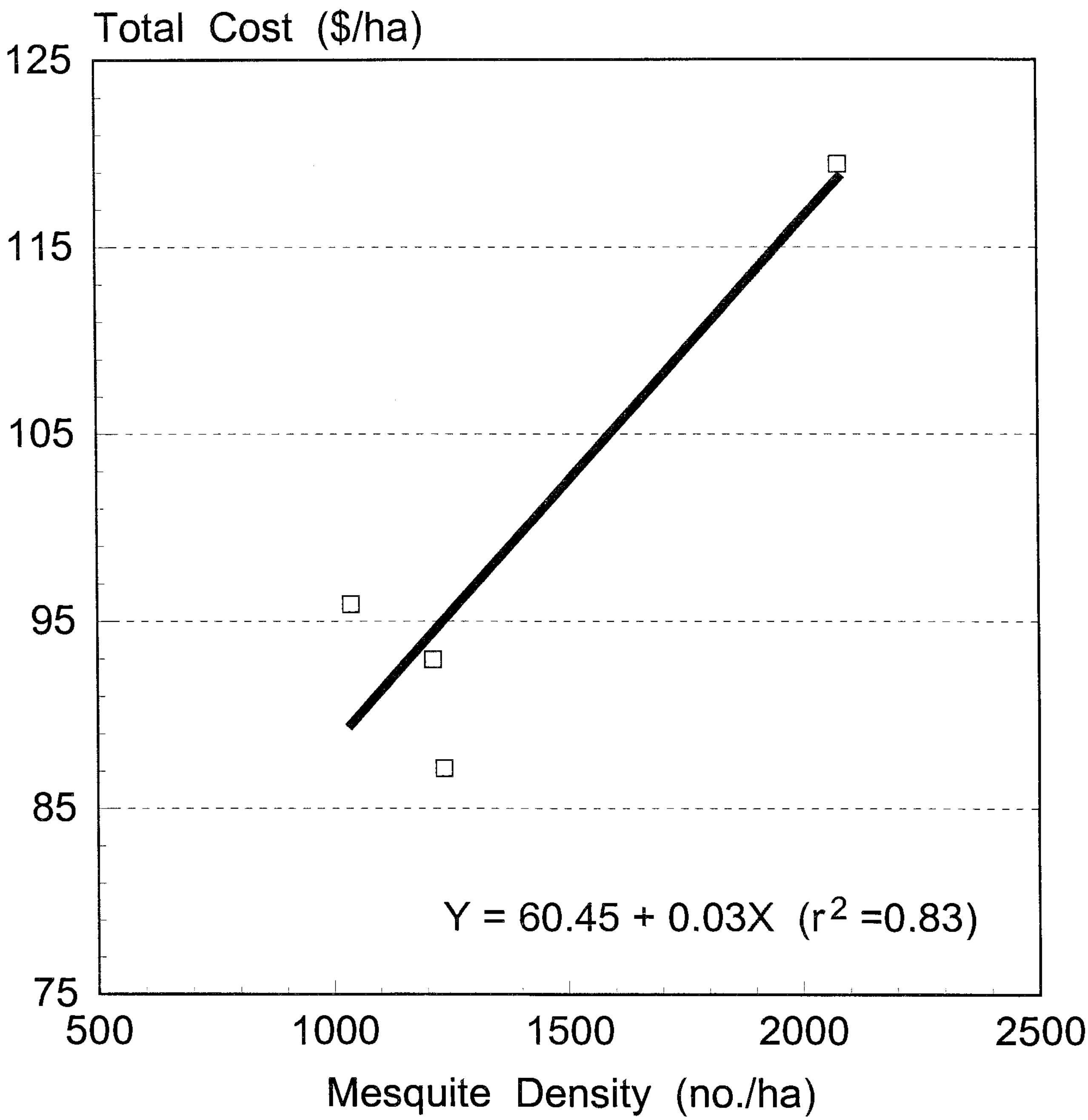

Figure 8. Relationship between cost ($/ha) and mesquite density (no./ha) for selective application of leaf sprays containing 0.5% clopyralid + 0.5% triclopyr ester to mesquite in highway rights-of-way with an experimental personnel carrier.

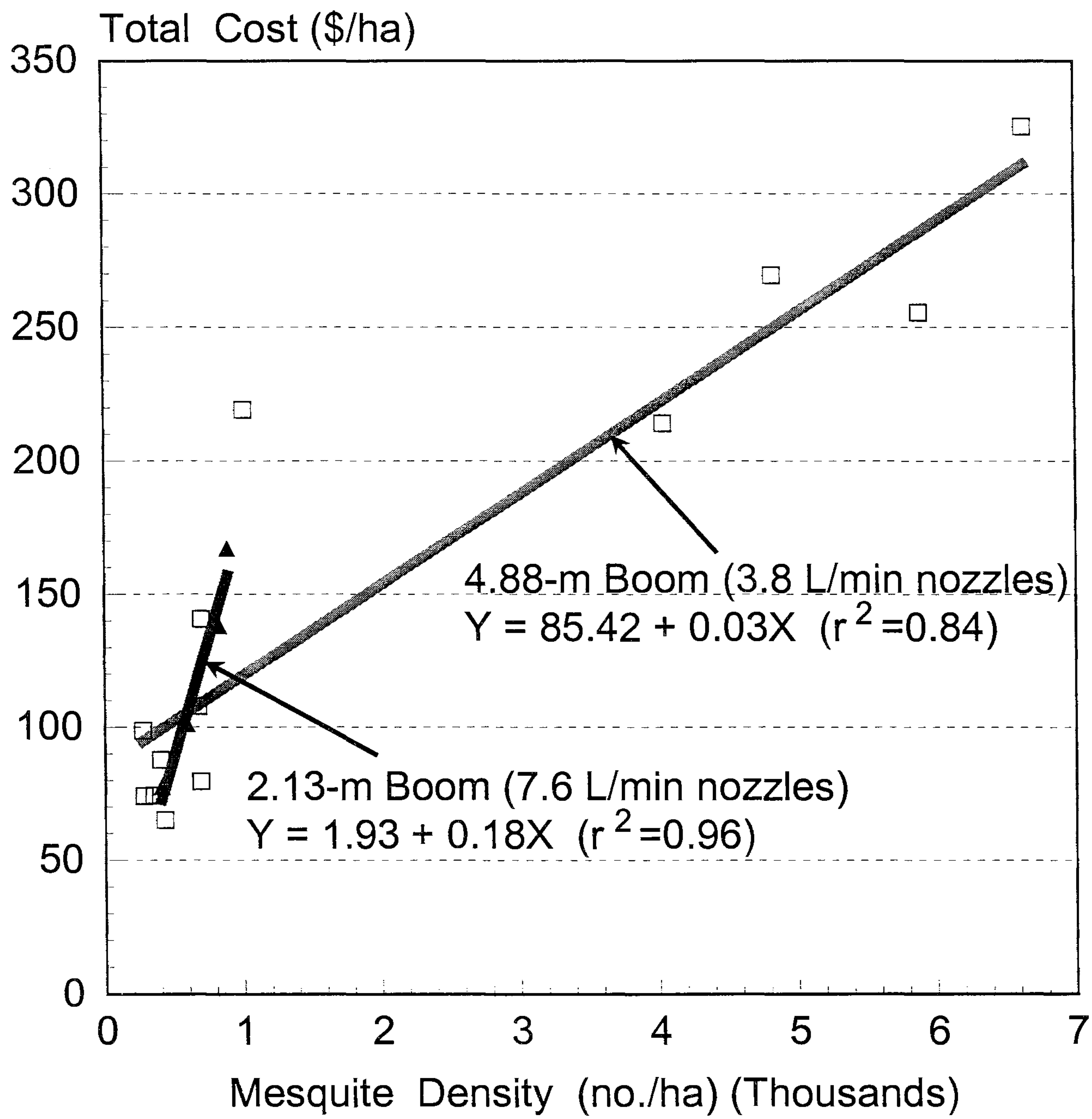

Figure 9. Relationship between cost ($/ha) and mesquite density (no./ha) for selective application of a leaf sprays containing 0.5% clopyralid + 0.5% triclopyr ester to mesquite in highway rights-of-way with 2.13-m and 4.88-m Brush Robots.

The Brush Robot with a 4.88-m effective swath width was capable of treating 1.31 ha/hr on the 13 plots where mesquite density averaged 2014 plants/ha (range: 1.22 ha/hr @ 6632/ha to 1.45 ha/hr @ 1006/ha). Cost for operating the 4.88-m Brush Robot with 32, 3.8-L/min nozzles was $85.42/ha plus $0.03 for each mesquite plant treated ($Y = 85.42 + 0.03X$; $r^2 = 0.84$) within the range of mesquite densities encountered (Fig. 9). The basic per ha cost for the 4.88-m prototype was greater than that for the 2.13-m unit because the mesquite was much larger and tall grass was more abundant in the plots where the 4.88-m unit was tested. Spray coverage on the mesquite plants encountered appeared quite adequate using the 3.8-L/min nozzles. The advantage of the 4.88-m boom was that the implement should theoretically cover >2X more acreage per unit of time compared to the 2.13-m boom. However, a substantial percentage of mesquite plants were missed when the rigid, 4.88-m boom was operated within the swale in ROW. Another serious limitation of the Brush Robot, regardless of boom width, was that the tractor driver must look backward very frequently to assure that the boom was positioned at the proper height for the mesquite being encountered. This problem could be alleviated by designing a Brush Robot suitable for attachment to a front-end loader frame.

Carpeted Roller

The carpeted roller was capable of treating 1.66 ha/hr in the 4 plots where mesquite density averaged 949 plants/ha (range: 0.90 ha/hr @ 1401/ha to 2.53 ha/hr @ 961/ha. Operating the carpeted roller cost $19.89/ha plus $0.04/mesquite plant treated ($Y = 19.89 + 0.04X$; $r^2 = 0.81$) within the range of mesquite densities encountered (Fig. 10). The carpeted roller also wasted considerable spray when grasses and weeds were as tall as the mesquite. However, the primary problem with this implement was that the amount of herbicide deposited upon the regrowth mesquite simply was not adequate, based upon our experience in controlling mesquite with the herbicides being used. Another problem was that the water-herbicide mixture gravitated to the down-slope end of the carpeted roller when working on slopes, resulting in non-uniform herbicide application rates over the boom width.

Rotowiper

Only 2 plots were treated with the Rotowiper because of the obvious deficiency in herbicide deposition upon the mesquite leaves and stems. Within these plots, however, the efficiency averaged 1.68 ha/hr and the mesquite density averaged 709 plants/ha (range: 1.60 ha/hr @ 941/ha to 1.75 ha/hr @ 474/ha). Cost was about $52/ha at both densities (Fig. 11), probably because of greater abundance of tall grass in the plot with low mesquite density, which resulted in a disproportionally high deposition of herbicide. Regression analysis of the data were not possible because of insufficient data. The advantages of the Rotowiper are that it would use little herbicide and that it could be towed with an ATV. However, the necessity to dismount the ATV and manually adjust the height of the carpeted roller as heights of mesquite and grasses vary within any segment of highway ROW does not seem feasible. The Rotowiper was not given further consideration because of these problems.

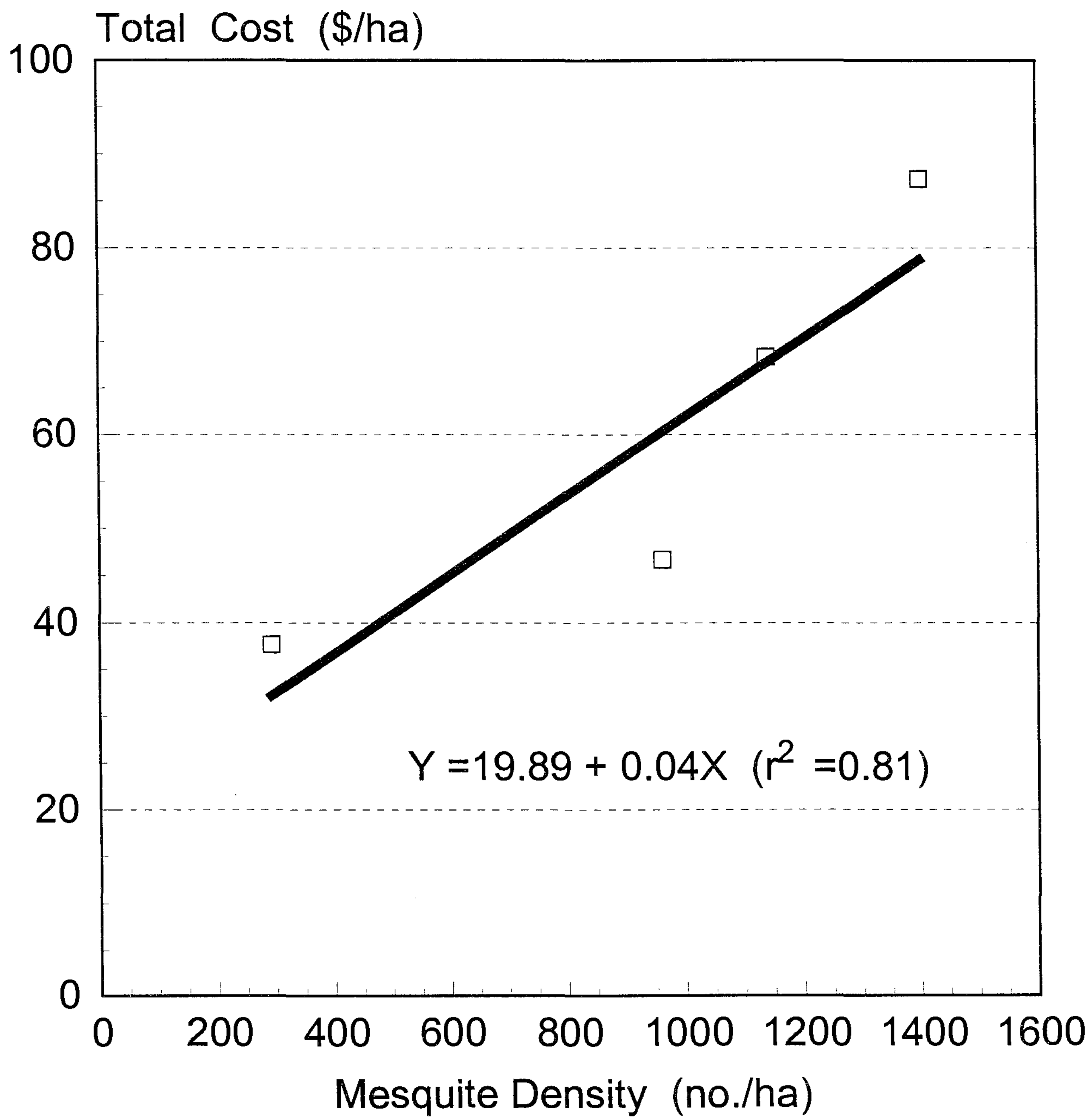

Figure 10. Relationship between cost ($/ha) and mesquite density (no./ha) for selective application of a herbicide mixture containing 4.54% clopyralid + 4.54% triclopyr ester to mesquite in highway rights-of-way with a carpeted roller.

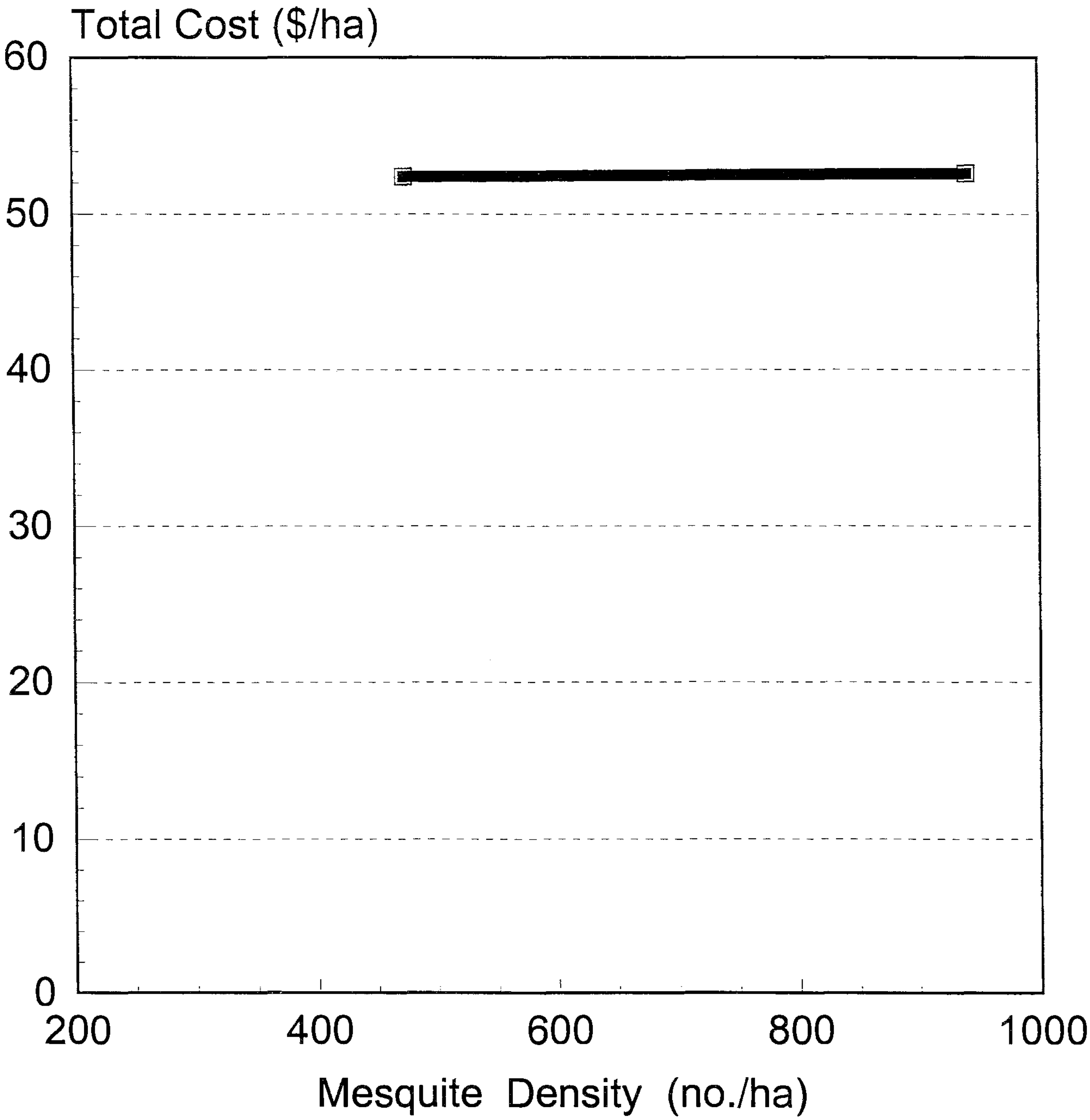

Figure 11. Relationship between cost ($/ha) and mesquite density (no./ha) for selective application of a herbicide mixture containing 4.54% clopyralid + 4.54% triclopyr ester to mesquite in highway rights-of-way with a Rotowiper.

Automatic ATV Sprayer

Operators acquired sufficient eye-hand and eye-foot coordination to efficiently operate the automatic ATV sprayer following about 30 min practice. Efficiency of the ATV sprayer averaged 1.07 ha/hr on the 19 plots on which it was evaluated and where mesquite density averaged 783 plants/ha (range: 0.68 ha/hr @ 2224/ha to 2.70 ha/hr @ 64/ha). Equipped with 7.6-L/min nozzles, the cost was estimated by regression to be \$23.34/ha plus \$0.06/mesquite plant treated ($Y = 23.34 + 0.06X$; $r^2 = 0.95$) within the range of mesquite densities encountered (Fig. 12). Cost when the sprayer was equipped with 3.8-L/min nozzles was \$17.96/ha plus \$0.04/mesquite plant sprayed ($Y = 17.96 + 0.04X$; $r^2 = 0.99$) (Fig. 12). Cost per ha was more highly correlated with mesquite density for the automatic ATV sprayer (r^2 values 0.95 to 0.99) than for the other delivery systems evaluated because tall grasses did not cause spray nozzles to be activated. The advantages of this sprayer, compared to the other delivery systems evaluated, were that the cost/hr for equipment was low and herbicide usage was low. The automatic ATV sprayer would be ideal for low-density mesquite infestations (<1000/ha), but its efficiency decreases substantially at higher mesquite densities. Also, operator fatigue would be a problem during operation of the ATV sprayer in high-density mesquite infestations for prolonged periods.

One problem observed with this delivery system was that the horizontal bending/retaining bar that was designed to bend mesquite plants over to the appropriate distance from the spray nozzle was positioned too far forward, thus allowing many plants to spring upright just as they were approaching the spray pattern. This resulted in inadequate herbicide coverage on some plants. This problem can be alleviated by positioning the bending/retaining bar rearward, closer to the spray pattern, and by adding a second retaining bar to assure the mesquite remains at the proper distance from the nozzles.

Mesquite-Sensing Spray Boom

The mesquite-sensing spray boom functioned well during the preliminary field test on October 17, 1998. At reasonable operating speeds, the 0.05- and 0.1-second (sec) time-delay relays discontinued the release of spray too quickly. The 0.15-sec relays necessitated a travel speed of about 6 km/hr for proper synchronization of spray release over the mesquite being traversed. This operating speed could be excessive on many highway ROW. At an operating speed of 6 km/hr, spray deposition on the mesquite foliage and stems from 7.6-L/min nozzles was slightly below optimal, thus slightly slower operating speeds appear necessary. Additional relays which provide time delays of 0.2, 0.3, and 0.4 sec have been acquired and will be tested during 1998, as will 3.8- and 5.7-L/min nozzles.

The automatic counters did not accurately count the number of mesquite plants because a mesquite plant with multiple stems interrupted the light beam >1 time as it was traversed. There is probably no way to correct this deficiency, but a counter would have little value during commercial use of the sprayer for mesquite control on highway ROW.

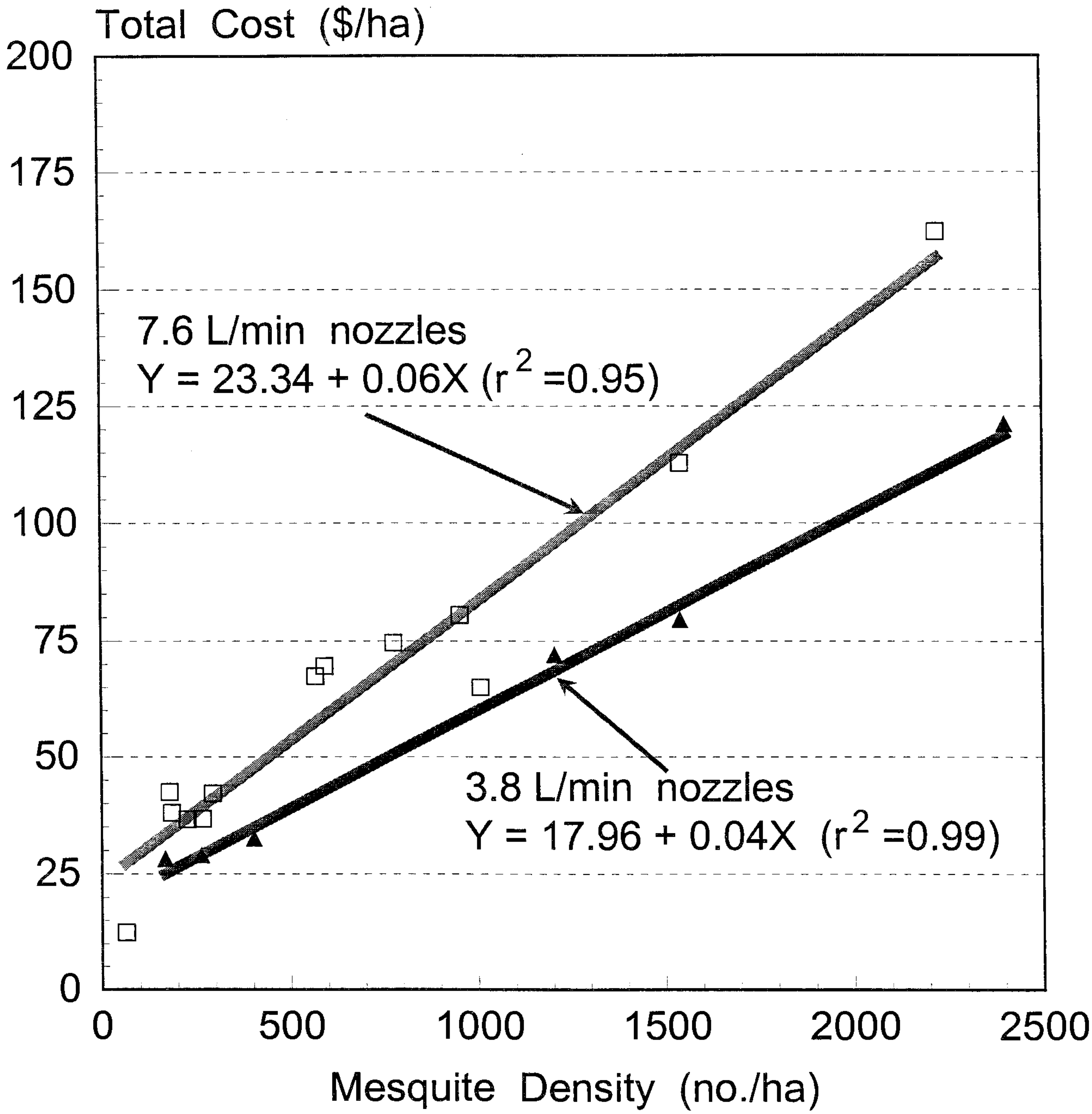

Figure 12. Relationship between cost ($/ha) and mesquite density (no./ha) for selective application of leaf sprays containing 0.5% clopyralid + 0.5% triclopyr ester to mesquite in highway rights-of-way with an experimental ATV sprayer equipped with either 3.8- or 7.6-L/min nozzles.

The horizontal mesquite-sensing lights could be easily adjusted to the proper height with the hydraulic controls of the front-end loader to detect a high percentage of the mesquite, even at a speed of 6 km/hr. This front-mount feature is a major advantage of the mesquite-sensing spray boom over the 3-point-hitch-mounted Brush Robot.

One problem detected in the preliminary field test of the mesquite-sensing spray boom was that the taller mesquite plants generally sprung upright too quickly when traversed by the 10.2-cm X 10.2-cm square boom to receive the full dose of leaf spray. Two horizontal rods, behind and parallel with the lower edge of the boom have subsequently been added to the boom to alleviate this problem. Shields have also been fabricated from sheet metal and attached to the spray boom to minimize the potential for lateral displacement (drift) of herbicide droplets off the target area.

We have calculated that the mesquite-sensing spray boom should be able to treat about 1.78 ha/hr at a speed of 4.8 km/hr. The actual efficiency of this delivery system will be determined during the summer of 1998 and further refinements in the design will be made as necessary. At this time, we feel that the advantages of this delivery system are that there are few mechanical parts, operator fatigue will be minimized because the implement is mounted in front of the tractor, and the faster operational speeds possible. Also, this implement could probably be commercially available within a relatively short time, if there was a demand. The disadvantages are that we know little about the durability and expected life of the electronic components.

CONCLUSIONS

The data presented on apparent mesquite mortality at 1 YAT and mortality at 2 YAT in this report are firmly believed to be conservative estimates of the efficacy of treatments evaluated because many small mesquite plants killed by these treatments break down rapidly and cannot be found at 1 or 2 YAT. Furthermore, mesquite plants with green tissues are much easier to see at 1 or 2 YAT than are dead plants. Even though the data presented may underestimate the efficacy of our treatments, these preliminary data strongly suggest that mesquite in highway ROW can be effectively controlled with selective leaf sprays containing 0.5% clopyralid + 0.5% triclopyr ester with either 0.5% surfactant or as little as 5% diesel fuel as the adjuvant. The data indicated no advantage to increasing the herbicide concentrations or the concentration of diesel fuel in the spray mixture. Spraying mesquite foliage to the point of runoff with the 0.5% + 0.5% concentrations of clopyralid and triclopyr apparently saturates the capacity of regrowth mesquite in highway ROW to absorb and translocate these herbicides.

There was a distinct trend toward increased efficacy of leaf sprays with 1-month delays in application dates during the growing season. This phenomenon has also been observed following aerial application of herbicides for mesquite control on rangelands, and it may be related to increased soil temperatures, greater downward translocation of photosynthates, or increased leaf surface area for herbicide absorption as the growing season progresses. Final conclusions relative to treatment efficacies should not be drawn until all experiments have been evaluated at 2 YAT.

Preliminary data collected during 1996 and 1997 indicate a very high probability of identifying two or more automated delivery systems that are well-suited for low-impact, selective control of mesquite in highway ROW. Systems which appear best suited to TxDOT's needs include the Brush Robot, mesquite-sensing spray boom, and automatic ATV sprayer. The Brush Robot would have greater utility if the boom were re-designed to mount on a front-end loader frame, to reduce operator stress in the necessary frequent adjustments in boom height. Also, the Brush Robot boom should be re-designed to a 3.66-m length to spray mesquite more effectively over the variable relief in highway ROW. The automatic ATV sprayer can be improved by modifying the bending/retaining bar so that the twigs and leaves of taller mesquite are held at the optimum distance from the spray nozzles as they are traversed. There is also the possibility that modulated light sensors of the Scan Ray II sprayer can be integrated into the automatic ATV spraying system. This feature would greatly reduce operator stress associated with sensing individual mesquite plants with the human eye and the manual release of leaf spray with electric switches. The one-day preliminary test with the mesquite-sensing spray boom suggested that, following some minor modifications, this delivery system will be effective and very well suited for TxDOT's mesquite management problem. We envision no problem in selecting the appropriate time-delay relays and nozzles that will allow efficient operation of this selective leaf spray delivery system at appropriate speeds for use on highway ROW.

RECOMMENDATIONS FOR IMPLEMENTATION

The results presented herein are very positive, but preliminary in nature. The research that is planned for 1998 and 1999 must be completed before there will be recommendations for implementation of the technology addressed in this project.

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APPENDIX A

Mean percent (%) apparent mortality of mesquite in highway rights-of-way at 1 year after treatment (YAT) with leaf sprays containing various concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and various adjuvants during June 1996 in four counties.

Treatment		Apparent mortality @ 1 YAT[1]				
Herbicide		Replications (sites)[2]				
Transline + Garlon 4	Adjuvant	1[3]	2	3	4	Mean
(%)		--------------(%)--------------				
.5 + .5	.5% Surfactant	86	82 ab	85 ab	72 ab	81
1 + 1	.5% Surfactant	78	76 abc	62 bc	72 ab	72
2 + 2	.5% Surfactant	86	90 a	74 abc	78 a	82
.5 + .5	5% Diesel	68	63 bc	71 abc	81 a	71
1 + 1	5% Diesel	91	83 a	77 ab	32 cd	71
2 + 2	5% Diesel	100	87 a	52 c	84 a	81
.5 + .5	20% Diesel	93	57 c	92 a	39 bc	70
1 + 1	20% Diesel	77	72 abc	89 a	35 cd	68
2 + 2	20% Diesel	86	86 a	68 abc	41 bc	70

[1] Means within a column followed by a similar lower case letter are not significantly different according to $LSD_{0.05}$. Absence of lower case letters in mean column indicates no significant differences among treatments.
[2] Sites: 1= Schleicher County; 2 = Reagan County; 3 = Menard County; and 4 = Runnels County
[3] The experiment at Site 1 was not replicated, thus the data were not subjected to statistical analysis.

APPENDIX B

Mean percent (%) apparent mortality of mesquite in highway rights-of-way at 1 year after treatment (YAT) with leaf sprays containing various concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and various adjuvants during July 1996 in four counties.

Treatment		Apparent mortality @ 1 YAT[1]				
Herbicide		Replications (sites)[2]				
Transline + Garlon 4	Adjuvant	1	2	3	4	Mean
(%)		-(%)-				
.5 + .5	.5% Surfactant	92	79	99	96 a	91
1 + 1	.5% Surfactant	94	75	95	96 a	90
2 + 2	.5% Surfactant	73	72	97	88 ab	83
.5 + .5	5% Diesel	88	34	91	85 ab	74
1 + 1	5% Diesel	100	67	86	76 b	82
2 + 2	5% Diesel	74	82	91	83 ab	82
.5 + .5	20% Diesel	71	42	90	57 c	65
1 + 1	20% Diesel	94	67	92	97 a	87
2 + 2	20% Diesel	96	76	98	84 ab	88

[1] Means within a column followed by a similar lower case letter are not significantly different according to $LSD_{0.05}$. Absence of lower case letters within a column indicates no significant differences among treatments.

[2] Sites: 1= Edwards County; 2 = Concho County; 3 = Coke County; and 4 = Sterling County

APPENDIX C

Mean percent (%) apparent mortality of mesquite in highway rights-of-way at 1 year after treatment (YAT) with leaf sprays containing various concentrations of clopyralid (Transline) and triclopyr ester (Garlon 4) and various adjuvants during August 1996 in four counties.

Treatment		Apparent mortality @ 1 YAT[1]				
Herbicide		Replications (sites)[2]				
Transline + Garlon 4	Adjuvant	1	2	3	4	Mean
(%)		----------------(%)----------------				
.5 + .5	.5% Surfactant	85	98	73	94	87
1 + 1	.5% Surfactant	86	94	98	96	94
2 + 2	.5% Surfactant	86	91	97	92	92
.5 + .5	5% Diesel	91	88	91	96	92
1 + 1	5% Diesel	93	94	89	94	92
2 + 2	5% Diesel	75	91	95	85	87
.5 + .5	20% Diesel	82	94	74	84	84
1 + 1	20% Diesel	90	88	98	97	93
2 + 2	20% Diesel	80	93	95	99	92

[1] Absence of lower case letters within a column indicates no significant differences among treatments according to analysis of variance at the 5% probability level ($P \leq 0.05$).
[2] Sites: 1= Crockett County; 2 = Irion County; 3 = Glasscock County; and 4 = Nolan County