MECHANICAL CONTROL OF EASTERN REDCEDAR

(JUNIPERUS VIRGINIANA L.)

By

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PREFACE

The scope of this study is to evaluate the efficacy of four mechanical control methods for controlling eastern redcedar. The primary objective is to determine the most economically viable means of control available to the typical rancher or landowner in Oklahoma. Mathematical models for predicting the clearing costs for each of the methods studied was developed by regression analysis.

The author wishes to express his appreciation to his major advisor, Dr. Jimmy F. Stritzke, for his guidance and assistance throughout this study. Thanks and appreciation is also expressed to Dr. P. Larry Claypool for his invaluable assistance in regard to the statistical analysis and modelling of the experimental data. Appreciation is also expressed to Dr. Robert L. Westerman for his helpful suggestions and recommendations in the preparation of the final manuscript.

Thanks is extended to Fran Holbrook who labored diligently and sacrificially for the excellence of the final copy. Appreciation is also expressed to Margie Garringer for her assistance in the typing of the manuscript.

Special gratitude is expressed to my parents, Jim and Doris, and my sister Anita, for their encouragement, patience and love.

Finally, my utmost appreciation and thanks goes to the Lord Jesus Christ. He has been my sole source of wisdom, strength, and hope since coming into my heart eight years ago.

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CHAPTER I

Introduction

The rapid encroachment of eastern redcedar (*Juniperus virginiana* L.) into pastures and rangelands during the past twenty years has been an area of growing concern for landowners. The large increase in numbers of eastern redcedar may be attributed to the suppression of natural wildfires and increase in seed dispersion by birds. Government programs which have promoted the use of eastern redcedars for shelterbelts and wildlife cover may have also contributed to the problem.

Infestations of eastern redcedar on Oklahoma rangeland poses a threefold problem to the landowner. The forage productive capacity of the land decreases as the density of redcedar stands increase. Secondly, accessibility and maneuverability through the field with farm equipment is hampered. Thirdly, livestock management is impaired as cedar stand densities increase.

The need for efficient and effective measures to control eastern redcedar populations prompted this investigation. Renewed interest on the part of many landowners to explore mechanical control measures provided the impetus to examine avenues economically available. The scope of this research was to examine four mechanical measures as possible control options for eastern redcedar.

CHAPTER II

Review of the Literature

Description and Habitat

The genus Juniperus is a member of Cupressaceae and may be found in the Northern Hemisphere temperature zone from Guatemala to the Artic Circle in the Western Hemisphere, and from the Artic Circle to southern China in the Eastern Hemisphere (Haverbeke et al. 1976). The junipers comprise the third largest genus of Coniferales and contain about 60 species according to Dallimore and Jackson (1966) and Hall and Carr (1964). Endlicher (1847) and Hall (1961) categorized the genus into three sections Caryocedrus, Oxycedus and Sabina. Sabina contains about thirty species which includes virginiana. All indigenous junipers of the United States except Juniperus Communis L. fall in this section. Eastern redcedar is the most widely distributed coniferous tree in the eastern United States. It is indigenous in every state east of the 100th meridian and in the southern portions of Ontario and Quebec (Williamson, 1965) and is quite adaptable to a wide range of climatological, topographic, and edaphic conditions. This is reflected in the extent of its' geographical habitat which ranges from 29° to 45° north latitude and from 69° to 102° west longitude. Climatological extremes tolerated by eastern redcedar in terms of precipitation range from 40.6 cm in the Great Plains to over 152 cm in the Southeast. Acceptable temperature regimes range from -40°C in the Central Plains and Minnesota to 46°C in the Southern and Central Great Plains. The species has been known to tolerate temperatures as low as -47°C (Parker, 1963). Topographical extremes in terms of elevation range from 1524 m in Kansas and Nebraska to sea level. Edaphic extremes relative to soil pH range from 4.7 to 7.8 (Arend, 1948) with indigenous stands favoring soils of limestone and dolomite parent material (Haverbeke, et al. 1976).

Eastern redcedar grows best on moist, deep, well-drained alluvial soils and may attain heights up to 18 meters in 50 years. Maximum heights up to 37 meters have been reported. After attaining a height of around 9 meters the growth rate decreases as its' ability to compete with hardwoods and pines declines. For this reason, eastern redcedar rarely becomes dominant on sites similar to the one previously described (Ferguson et al. 1968). The sites where eastern redcedar is predominant has been found to be dependent upon the specific geologic strata (Beilmann and Brenner 1951a; Read 1952). It was found by Arend and Collins (1949) and Afanasieu (1949) that soil depth and drainage were the most important site factors effecting growth. Perhaps the most common sites of eastern redcedar dominance occur in rocky outcrops of calcareous parent materials, abandoned fields, fence rows and in pastures (Ferguson et al. 1968; Williamson 1965). Stands also appear frequently along the side slopes of ravines and gullies.

Eastern redcedar is classified as a "pioneer" in vegetative succession (Link et al. 1979). Since 1960, eastern redcedar has appeared in areas previously foreign to their domain (Owensby et al. 1973). Their success may be attributed to a number of factors. Young and Evans (1979) postulated that canopy interception of rainfall and the subsequent competition for soil moisture appeared to be an important cause of the invasion. Beilmann and Brenner (1951b) and Hall (1955) indicated that the control of wildfires promoted the advance of eastern redcedar into many sites within its natural domain. The decline of certain rodents, harmful to juniperus seedlings, may have mitigated the magnitude of their destruction (Ownsby et al. 1973). Van Dersal (1938) reported that 70 species of wildlife use eastern redcedar for food and cover. Government programs which have promoted the use of redcedar for windbreaks, wildlife cover, and erosion control have unwittingly promoted large sources of seed stock.

Mechanical Control

The severing of non-basal sprouting junipers stems at or near ground level with mechanical methods has proven to be very effective for control. Smith et al. (1975) reported 99% control of 1 to 12 years old redberry juniper (Juniperus pinchotii Sud W.) trees that were cut at ground level. He also noted that the maintenance of a good grass cover in conjunction with the top removal of junipers was effective in decreasing their encroachment into grassland.

A wide variety of mechanical methods exists for controlling junipers. Porterfield and Roth (1957) reviewed many of these including chipping, shredding, tree pulling, bulldozing, shearing, broaching, and sawing. Chipping proved to be uneconomical due to the high labor input involved in the process of tree trimming and subsequent hand feeding of limbs into the tractor mounted chipper. Similar problems were encountered with a tractor mounted shredder. In addition to the expense of hand trimming, production rates were sharply curtailed due to the poor portability of the shredder when progressively moving from site to site. Porterfield et al. (1957), in his experiments, selected blackjack oaks (<u>Quercus marilandica</u> Muenchh.) ranging up to 36 cm in diameter as his test species. Although blackjack oaks are hardwoods and eastern redcedars are softwoods, many of the same mechanical control practices and procedures are applicable in eastern redcedar control. Tree pulling using a three man team, a 20.1 kW tractor and a 1.3 cm chain was described as "slow, tedious, and expensive". It was found that bulldozing was effective on trees greater than 8 cm in diameter, but smaller trees only bent and broke rather than being uprooted. A tree shearer was also examined in the study, but a number of problems were encountered including:

1. Excessive positioning time.

2. Insufficient pressure in the hydraulic system of the tractor to operate the shearer.

3. Poor portability.

Porterfield (1970) developed another type of tree shearer but it faced many of the same limitations. Another device examined earlier by Porterfield et al. (1957) was a trapezoidal broach mounted with two sets of converging teeth along the angled opposing walls of the trapezoid. With the broach attached to the drawbar of the tractor, the tree would be broached repeatedly until it was severed. Preliminary investigations found that the broaching tools was not self centering, and that one set of teeth penetrated more readily than the other. Better results were obtained using a single-sided broach; however, due to the poor overall performance of both tools this method was abandoned.

Porterfield et al. (1957) evaluated three methods of sawing which involved a one man chainsaw, a two man chainsaw, and a portable circular saw. The problems encountered with all sawing methods were the pinching of the blade by the weight of the tree, the dulling of the teeth by rocks and stones, and the clearing of the tree canopy near the base to reach the trunk with the saw. Of the various methods of mechanical control studied, sawing appeared to be one of the most promising avenues explored. An efficient means of clearing brush utilizing a tractor mounted saw in conjunction with a small power buckrake was promoted by Cox (1947). He reported the clearing of 8470 brush stems ranging up to 5 cm in diameter and 133 trees ranging from 5 to 20 cm from 0.40 ha in 2 hours and 26 minutes. Mowing, which severs the tree nearly flush with the ground has also proven effective. Buehring (1970) reported 78% control of eastern redcedar trees using a rotary brush cutter on stems ranging from 1.3 to 3.1 cm in diameter.

A hydraulically operated blade was developed by Wiedermann et al. (1977a, 1977b) for the grubbing and removal of resprouting brush species such as mesquite (Prosopis juliflora Swartz). He found that the hydraulic unit increased tree cutting production 33-1/3% over the traditional C-frame tree grubber. The hydraulic grubber was found to be very effective on junipers (Wiedemann and Cross, 1981). Using a John Deere 450-B, turbocharged, shift-on-the-go, 48.5 kW crawler tractor, he found the grubbing rate for a stand density of 80 to 500 trees per hectare to vary between four to five hectares per hour. The costs incurred within these extremes ranged from 6 to 50 dollars per hectare.

Weidermann (1981) later modified the hydraulic grubber to mount onto a 44.8 kW John Deere 2440 rubber tire tractor. The tractor was also outfitted with specially recapped airplane tires to circumvent the possibility of tire puncture. A study was then conducted on a group of junipers which ranged up to 3 meters in height and a stand density ranging from 120 to 1200 stems per hectare. The results indicated a 72% reduction in energy costs with no sacrifice in productivity. In addition, the capital investment for the unit adapted for the John Deere 2440 was approximately half that of the one adapted for the 450-B.

CHAPTER III

Methods and Materials

Mechanical Control

The site selected for the Mechanical Control study was located approximately ten miles southwest of Stillwater, Oklahoma. The soil type was a vernon clay-loam, fine, mixed, thermic typic ustochvetts with slopes ranging from 0 to 5°. The vegetation consisted mainly of native grasses.

The mechanical control experiment was conducted as a randomized complete block design with nine replications blocked according to the indigenous number of large stems (greater than 5 cm in diameter). Plots were 50 by 100 meters, and all plots contained at least ten large stems.

Control Methods

The four methods of mechanical control evaluated in this study were:

1. Use of the rotary saw for the removal of large stems (greater than 5 cm in diameter) and a long handled axe to remove the smaller stems.

2. Use of the rotary saw for large stems and a tractor mounted mower to remove the smaller stems.

3. Use of the rotary saw for large trees and long handled pruners to remove the small stems.

4. The removal of all stems using a mobile rotary saw.

Machine cutting with the rotary saw was performed in February of 1982. The machine was a modified self-propelled windrower, powered by a 250 cc Chevrolet engine. A series of hydraulic cylinders served to manipulate a mechanical arm which was attached to a large circular saw. The arm consisted of a drive shaft centrally mounted in a steel framework attached to a differential. The drive shaft was engaged and disengaged via a V-belt drive system located in the cab of the machine. The drive shaft was connected to the differential of the arm with a universal joint. To the sawed-off axle of the differential was bolted a 0.6 x 45 cm circular low carbon steel plate. The plate had been notched in several places around the periphery, and Adam hard surface rod welded to the tips of the notches. The tips were then ground to form the cutting teeth of the saw.

Once the drive shaft of the arm was engaged, the spinning blade was manipulated, via the hydraulic servo-system, to sever through the base of the target tree. Once cut, the blade was disengaged and the machine driven to the next tree and the process repeated. This cycle was repeated in each plot until all target trees had been cut.

Before severing small stems in plots with the mower, all large trees that had been cut by the rotary saw were manually removed from the field. After removal, small stems were cut with a 1.8 m wide three-point hitch "Sidewinder" mower and powered by a Ford 3600 tractor. The entire plot was mowed lengthwise and a running tally of cut cedars was kept by the driver. A tractor speed of 8 km per hour and a PTO speed of 1000 revolutions per minute was maintained throughout the cutting of the plot.

The cutting time required to clear stems in an experimental plot was determined by calculating the difference between the entry and exit time a machine or man spent in each plot. Cutting time for those plots receiving the axe treatment consisted of the machine time required to remove large stems (greater than 5 cm in diameter) with the rotary saw, and the manual time required for two men to cut the smaller stems with long handled axes. In the mower plots, cutting time included the removal of large stems with the rotary saw, and the time required to remove small stems with a tractor mounted mower. The procedure involved in estimating the cutting time for the pruner treatment was the same as that described for the axe. The only exception was that long handled pruners, rather than axes, were used to cut small stems. In the rotary saw treatments, cutting time consisted of the total time required to remove all stems with the machine.

Analysis of Stem Counts and Cutting Times

Experimental plots were blocked according to the number of large stems within each half hectare plot. Beginning with the four plots which contained the greatest number of large stems, down to the four containing the lowest number. The four treatments were randomly assigned to the four plots in a block or replication. Plots which did not contain stem densities comparable to that of other plots in a replication were eliminated from the study.

Initially, ANOVA procedures were performed on large and small stem counts in plots to determine if significant differences in means could be detected due to replications or due to treatments. Similar analyses were performed on the small and large stem cutting times. To mitigate the inherent variability associated with stem counts between plots, a Rank Transformation (Conover and Iman, 1981) procedure was performed on the raw data and subsequent statistical analysis performed on the ranked data.

Analysis of Production Variable Data

Three production variables were derived from the cutting time parameter associated with the number of stems severed per plot. Those parameters were defined and analyzed as: the number of hectares cleared per hour, the number of stems cut per minute, and the total cost per hectare. The mechanical control production variables were modeled using the Statistical Analysis System program for the General Linear Models procedure. For each production variable, four models were fitted to the data from each treatment for a total of 16 models. The dependent production variables: cost per hectare, hectares per hour, and stems per hectare were modeled with the independent variable: stems per hectare. Semilog and log-log models of the dependent and independent variables were also determined. The selection of the "best fit" model was based upon the respective magnitudes of the mean square error, and the coefficient of determination.

Four models depicting the response characteristics of the four treatments were first fitted to the production variable, hectares per hour. The four models which were fitted to the data were, hectares per hour versus stems per hectare, the natural log of hectares per hour versus stems per hectare, hectares per hour versus the natural log of stems per hectare, and the natural log of hectares per hour versus the natural log of stems per hectare. Subsequent analysis of the production variables, stems cut per minute and cost per hectare, were modeled by substituting these variables in the place of hectares per hour and finding the best simple cartesian, semilog, and log-log models.

The third production variable modeled was cost per hectare. In this phase of the analysis, costs were determined on the following basis:

1. Two men were employed at $3.35 per man-hour to cut stems in the axe and pruner treatments.

2. The contracted rotary saw cost was calculated on a flat rate basis of $40 per hour.

3. Mower costs were calculated on the basis of

a. $5.63 per hour ($900 per month) for the driver.

b. $32.50 per hour for the local rental of a 1.8 m wide "Sidewinder" mower and Ford 3600 tractor.

Effect of Tree Size on Machine Cutting Time

In February of 1982, trees ranging from 1 to 53 cm in diameter were cleared from selected plots using the mobile rotary saw. A total of 187 observations were made of the cutting time required to sever each respective tree at the base. Cutting time in this study, should not be confused with the cutting time variable for removing all trees in experimental plots, as previously discussed. In this phase, cutting time was the time required to sever an individual tree at it's base. This time initiated the moment the rotary saw blade came in contact with the base of the tree and terminated as soon as the trunk was severed. On larger trees, blade repositioning and setup to complete cuts was necessary, but this time was not added to the cutting time. Once severed, the diameter of each tree was measured and recorded to the nearest cm.

Prediction of Cutting Time from Basal Diameter

Initially, cutting time and the natural log of cutting time were analyzed by an ANOVA procedure to determine if equal variances could be assumed between diameters. Data collected from the study was analyzed and regression equations fitted to one simple cartesian, two semilog and one log-log model. The four models which were fitted to the data were: cutting time versus diameter; the natural log of cutting time versus diameter; cutting time versus the natural log of diameter, and the natural log of cutting time versus the natural log of the diameter.

Prediction of Tree Height From Basal Diameter

In February of 1982 all eastern redcedars which had been cut in the treated plots were counted and their respective heights and diameters measured. Heights were measured to the nearest decimeter and diameters to the nearest centimeter from 1653 trees.

Height and the natural log of height recordings were first analyzed by an ANOVA procedure to determine if equal variances could be assumed between diameters. Afterwards, simple cartesian, semilog and log-log models were fitted by regression analysis to the data. The four models which were fitted to the data were: height versus diameter; the natural log of height versus diameter; the height versus the natural log of diameter, and the natural log of height versus the natural log of diameter.

CHAPTER IV

RESULTS AND DISCUSSION

Analysis of Stem Counts and Cutting Times

The average number of large and small stems in the various treatments and the average cutting time in hours for each treatment are listed in Table 1. F tests from the ANOVA procedure performed on the large stem counts revealed significant differences due to replications and treatments (Table 2). The differences due to replication were expected, since the plots had been blocked by stem number. The difference due to treatments was attributable to the fewer number of large stems in the plots receiving the rotary saw treatment. An analysis of the number of small stems contained in each plot revealed that no differences between plots could be detected due to either replication or treatment.

An analysis of the recorded machine cutting time for large stem removal in the axe, mower, and pruner plots and the removal of all stems in the saw plots (Table 1) revealed a significant difference due to replication and treatment (Table 2). The difference due to replications was expected, since the treatments had been blocked in this manner. The significantly longer cutting time associated with the plots receiving only the rotary saw was also expected since the cutting time included the time to cut both large and small stems compared to only large stems for the other treatments.

Table 1. Treatment stem counts and cutting times.

Treatment	Large Stems Number/Plot	Large Stems Machine Cutting time (hr)	Small Stems Number/Plot	Small Stems Plot Cutting time (hr)
Saw + Axe	38.8	0.11	22.4	0.06
Saw + Mower	40.7	0.09	16.6	0.82
Saw + Pruner	45.6	0.12	40.1	0.07
Saw Only	26.4	0.14[1]	32.7	----

[1]Time for "saw only" actually is total time to cut both large and small stems.

Table 2. Comparison of stem counts and treatment time for replications and various treatments.

Data Compared	Analysis on non-transformed data						Analysis on rank tranformed data					
	Rep (PR>F)	Treat (PR>F)	Treatments Compared	R^2	MSE	CV	Rep (PR>F)	Treat (PR>F)	Treatments Compared	R^2	MSE	CV
Large stems in all plots	0.0001	0.0013	PMAS[1]	0.92	82.851	24.0	0.0001	0.0002	PAMS	0.72	12.951	19.5
Small stems in all plots	0.2159	0.0902	PSAM	0.44	408.250	72.3	0.0880	0.0720	SPAM	0.50	80.620	48.5
Machine Time[2]	0.0001	0.0192	SPAM	0.82	0.0009	25.5	0.0001	0.0221	SPAM	0.83	27.127	28.2
Machine Time of large stems	0.0001	0.2172	PAM	0.83	0.0007	24.8	0.0001	0.1879	PAM	0.82	17.986	30.3
Cut Time of small stems	0.5119	0.0001	MPA	0.95	0.0109	32.9	0.2184	0.0001	MPA	0.83	17.861	30.2
Total Time	0.0540	0.0001	MPAS	0.95	0.0086	26.2	0.0012	0.0001	MPAS	0.85	24.37	26.7

[1]Legend: A = Axe; M = Mower; P = Pruners; S = Rotary Saw. Treatments underlined are not significantly different at the 95% level of probability according to Duncan's New Multiple Range Test.

[2]Large stems only in axe, mower and pruners treatments and both large and small stems in rotary saw treatments.

A similar F test procedure performed on the machine cutting time to remove just the large stems in the other treatments revealed no differences among them.

The cutting time required to remove the smaller stems using a hand axe, long handled pruners, and a tractor mounted mower were also examined. Analysis of the data revealed that mower cutting time was significantly higher than that of the axe or pruner treatments (Table 2). No significant difference in cutting time due to replications was found. The time required to cut only the small stems in the rotary saw plots could not be directly evaluated, as both large and small stems were cut in the same operation.

The total time required for the removal of all stems, small and large, was analyzed next. In the axe, pruner, and mower treatments this variable included the time required to sever the large stems in each plot with the rotary saw plus the time for small stem removal using one of the methods mentioned above. In the rotary saw plots, the total time variable was comprised of only the machine time which was required to sever all stems, small and large. Normal statistical parametric procedures performed on the raw data revealed that the total time required to remove stems in the mower plots was significantly greater than the removal time for all other treatments. The observed significance level for differences due to replication was at the 5% confidence level.

In making comparisons among the different treatments, the significant difference due to the lesser number of large stems in the rotary saw plots presented a problem. In an attempt to overcome this difficulty the raw data was transformed and evaluated on the basis of the Rank Transformation procedure as outlined by Conover and Iman

(1981). With this method the same statistical parametric procedures as previously outlined were performed, but on the ranking numbers of the data, rather than on the raw data itself. A comparison of the statistical parameters evaluated by both methods is give in Table 2. Unfortunately, the difference due to large stem counts could not be overcome using this method. However, in the case of large and small stem counts, the mean square errors were reduced.

Analysis of Production Variable Data

Analysis of three production variables (hectares cleared per hour, stems cut per minute, and total cost per hectare) with the independent variable: stems per hectare, were compared using four regression equations involving a simple cartesian, two semilog and one log-log model. The statistical parameters associated with the estimates of the intercepts and slopes for hectares cleared per hour were all significant with the exception of the mower treatment (Table 3). The estimates of the intercepts and slopes for the prediction equations are listed in the table.

Data recorded from those treatments which were cleared with the rotary saw and hand axe were first analyzed. The best fitting of the log models, based on the mean square error (MSE) and coefficient of determination (R^2), was a semilog equation of the natural log of hectares per hour versus stems per hectare (Table 3). Mean square error and R^2 for this model were 0.017 and 0.833, respectively. In the plots treated with the rotary saw plus the tractor mounted mower, the R^2's were so low that no attempt was made to select a "best-fit" model. From the plots which received the rotary saw plus pruner

Table 3. Comparison of four models (derived from the total time required to cut large and small stems) to determine the best fit of Ha/Hr to Stems/Ha.

Treatment	Independent Variable	Dependent Variable	Intercept Estimate	Intercept P> T	Slope Estimate	Slope P> T	MSE	R^2
Saw + Axe								
	Stems/Ha[1]	Ha/Hr	5.3553	0.0001	-0.0173	0.0003	0.143	0.859
	Stems/Ha	LnHa/Hr	1.7904	0.0001	-0.0054	0.0006	0.017	0.833
	LnStems/Ha	Ha/Hr	11.1327	0.0001	-1.6776	0.0008	0.184	0.819
	LnStems/Ha	LnHa/Hr	3.5327	0.0002	-0.5092	0.0020	0.023	0.767
Saw + Mower								
	Stems/Ha	Ha/Hr	0.5828	0.0001	-0.0002	0.7942	0.012	0.104
	Stems/Ha	LnHa/Hr	-0.5554	0.0060	-0.0003	0.8066	0.039	0.009
	LnStems/Ha	Ha/Hr	0.7155	0.5880	-0.0329	0.6455	0.011	0.032
	LnStems/Ha	LnHa/Hr	-0.3124	0.6062	-0.0598	0.6467	0.038	0.037
Saw + Pruner								
	Stems/Ha	Ha/Hr	4.7199	0.0001	-0.0095	0.0021	0.464	0.761
	Stems/Ha	LnHa/Hr	1.6295	0.0001	-0.0034	0.0003	0.030	0.863
	LnStems/Ha	Ha/Hr	11.3298	0.0001	-1.6762	0.0001	0.176	0.910
	LnStems/Ha	LnHa/Hr	3.8279	0.0001	-0.5660	0.0001	0.019	0.915
Saw Only								
	Stems/Ha	Ha/Hr	7.6530	0.0002	-0.0268	0.0103	2.748	0.633
	Stems/Ha	LnHa/Hr	2.1191	0.0001	0.0062	0.0003	0.040	0.866
	LnStems/Ha	Ha/Hr	19.4640	0.0001	-3.2849	0.0001	0.524	0.524
	LnStems/Ha	LnHa/Hr	4.3934	0.0001	-0.6608	0.0001	0.016	0.946

[1]Legend: Ha = hectares; Ln = natural log.

treatments, the model of the natural log of hectares per hour versus the natural log of stems per hectare produced the best fit. In this model the R^2 was 0.915 and the MSE was 0.019. The lower coefficient of determination and higher mean square error calculated for the axe, in contrast to the pruner treatment, might be attributed to the differences in cutting technique between the two methods. It was observed in the field, that stems were always severed with the first shearing thrust when pruners were employed. This was not always the case with the ax. It was often necessary to make repetitive cuts to sever single stems. This misjudgement by the axe-wielder in conjunction with the dulling of the blade increased the cutting time variability in those plots.

In the plots which received only the rotary saw treatment, the log-log model fit the data best. The calculated R^2 was 0.946 with a MSE of 0.016. For comparison purposes the log-log plots of the data by treatment are given in Figures 1, 2, 3 and 4. These plots were judged to be the most compatible for the comparison since R^2's were high and MSE's were consistently low. The variable: natural log of hectares per hour, was found to be inversely proportional to the natural log of stem per hectare in all but the mower treatments. The poor correlation between the two variables for the mower treatments is reflected by the nebulous array of data given in the scatterplot of Figure 2.

The second production variable modeled was the number of stems cut per minute (Table 4). The same semilog and log-log combinations used to model the hectare per hour equations were also used to model the stems per minute (dependent) and stems per hectare (independent) variables. A comparison of the different models revealed that the log-log equations yielded the highest R^2's and lowest MSE's in all but the mower

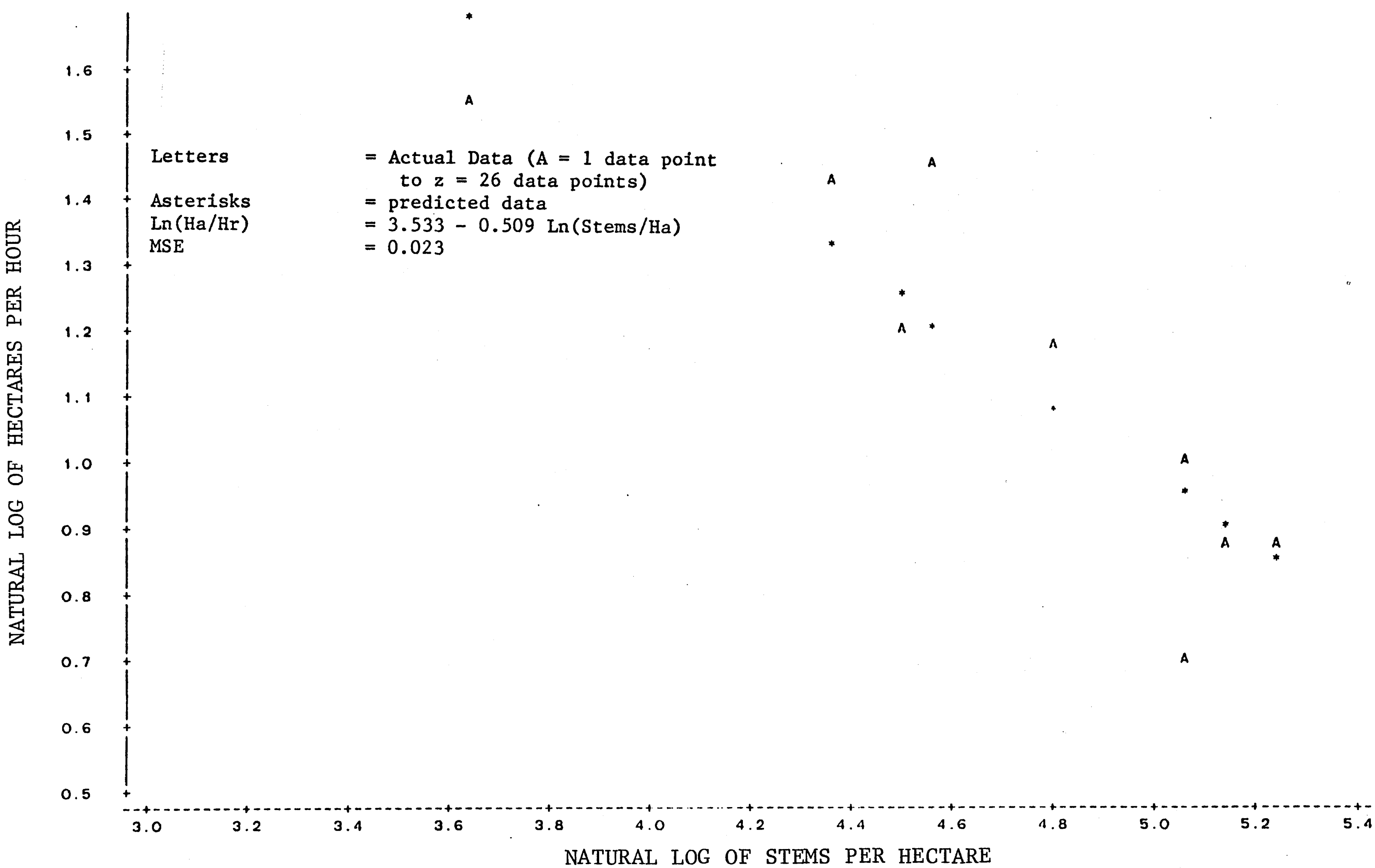

Fig. 1. Saw plus axe treatment log-log model for the production variable hectares per hour.

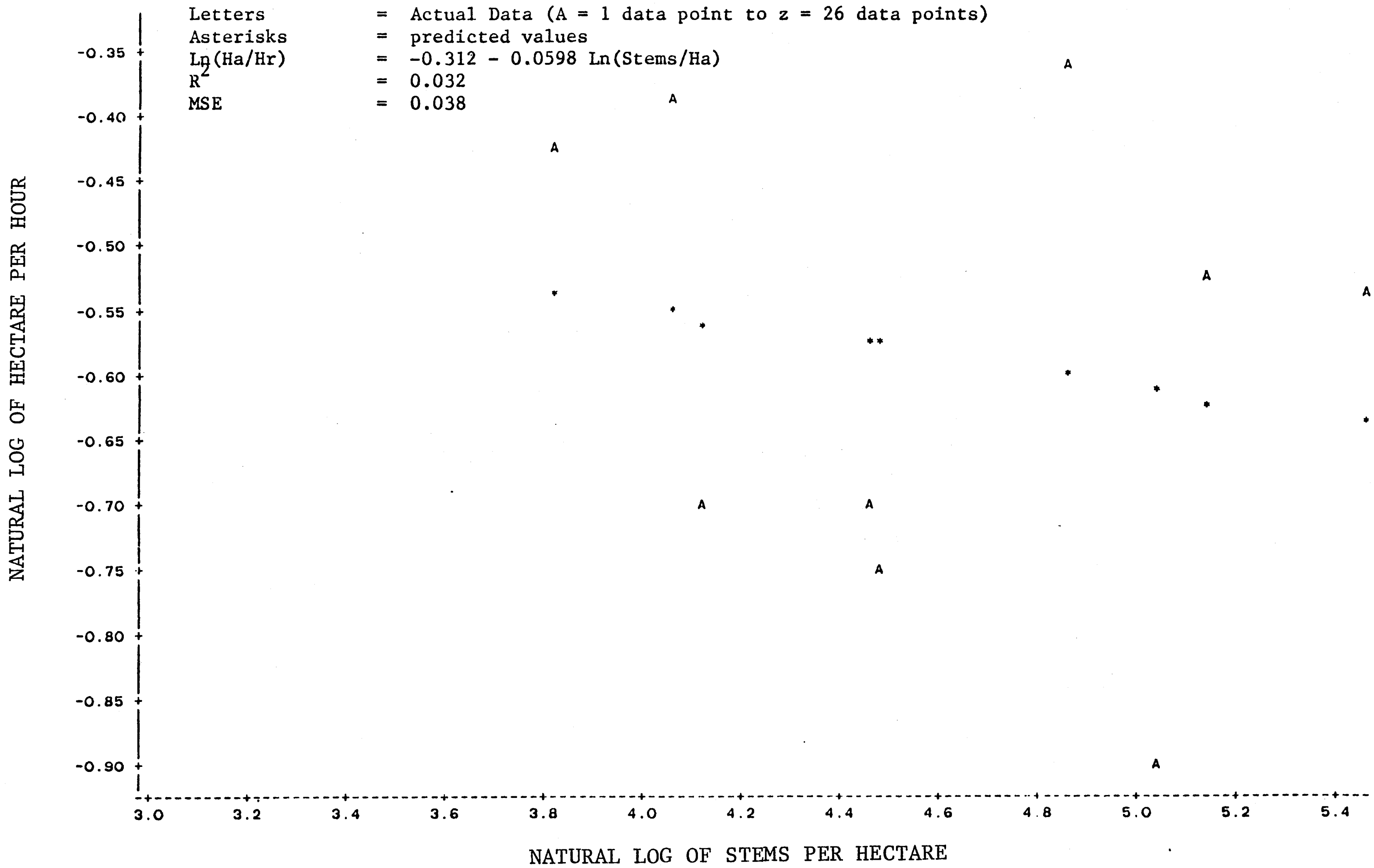

Fig. 2. Saw plus mower treatment log-log model for the production variable hectares per hour.

Letters = Actual Data (A = 1 data point to z = 26 data points)
Asterisks = predicted data
Ln(Ha/hr) = 3.828 - 0.566 Ln(Stems/Ha)
R^2 = 0.915
MSE = 0.019

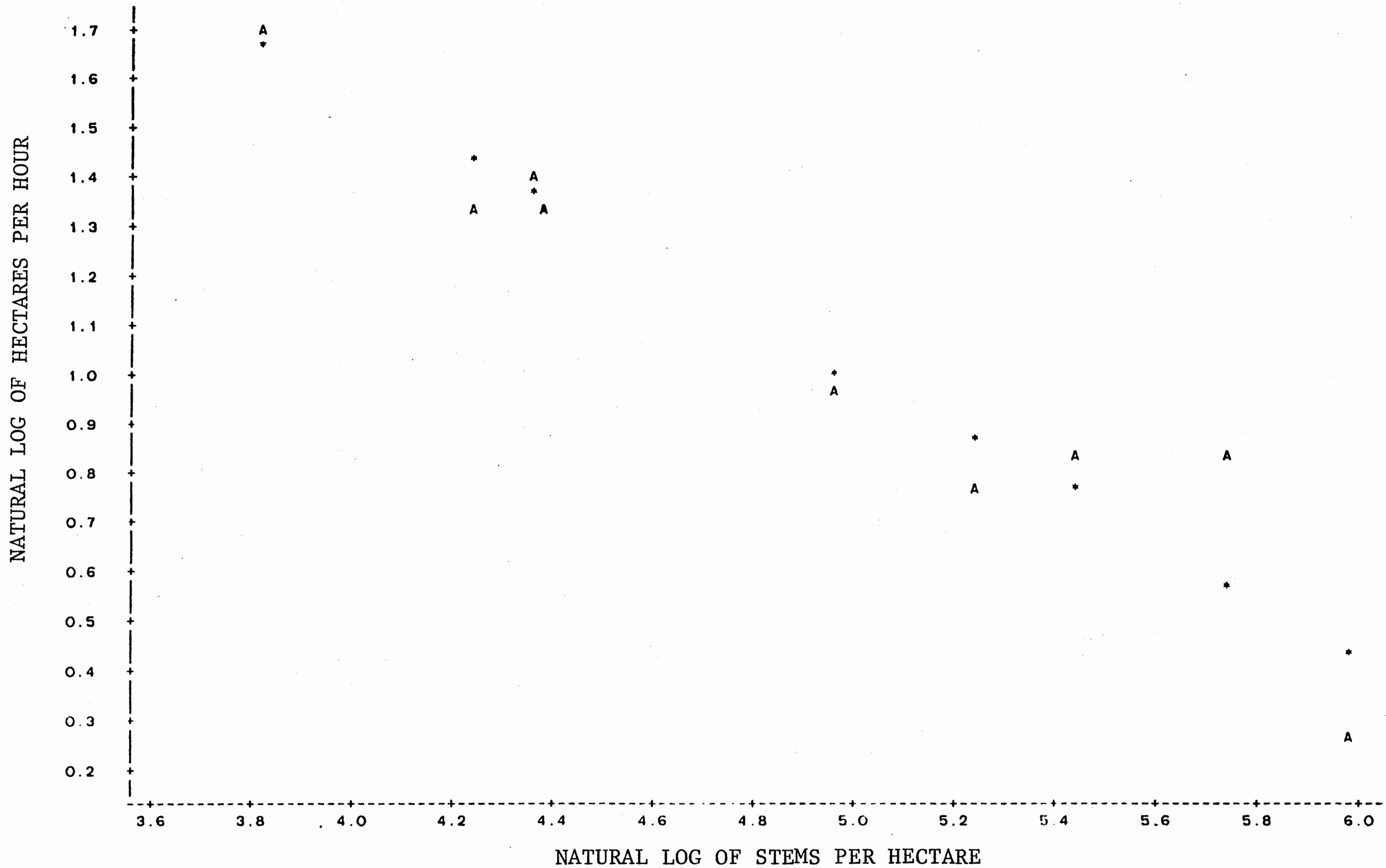

Fig. 3. Saw plus pruner treatment log-log model for the production variable hectares per hour.

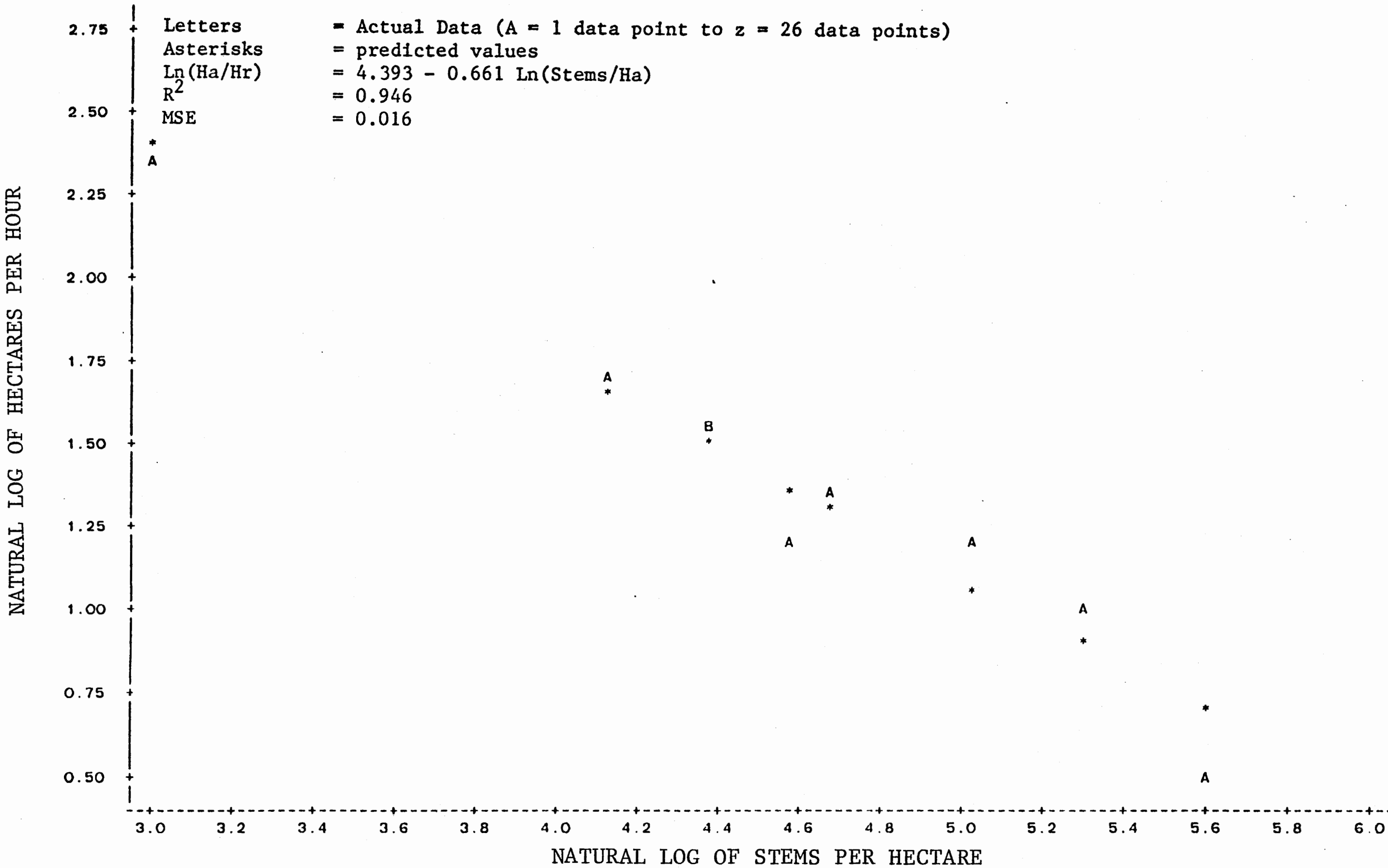

Fig. 4. Rotary saw treatment log-log model for the production variable hectares per hour.

Table 4. Comparison of four models (derived from the total time required to cut large and small stems) to determine the best fit of Stems/Min to Stems/Ha.

Treatment	Independent Variable	Dependent Variable	Intercept Estimate	Intercept P> T	Slope Estimate	Slope P> T	MSE	R^2
Saw + Axe								
	Stems/Ha[1]	Stems/Min	3.2025	0.0076	0.0224	0.0114	0.883	0.623
	Stems/Ha	LnStems/Min	1.2056	0.0003	0.0044	0.0135	0.037	0.606
	LnStems/Ha	Stems/Min	-5.3233	0.0831	2.3921	0.0036	0.644	0.725
	LnStems/Ha	LnStems/Min	-0.5616	0.3006	0.4908	0.0024	0.023	0.753
Saw + Mower								
	Stems/Ha	Stems/Min	-0.0100	0.9498	0.0094	0.0001	0.045	0.900
	Stems/Ha	LnStems/Min	-1.0250	0.0001	0.0083	0.0001	0.036	0.897
	LnStems/Ha	Stems/Min	-3.6532	0.0031	0.0031	0.0007	0.078	0.825
	LnStems/Ha	LnStems/Min	-4.4067	0.0001	0.9402	0.0001	0.038	0.890
Saw + Pruner								
	Stems/Ha	Stems/Min	3.7509	0.0031	0.0179	0.0034	1.991	0.728
	Stems/Ha	LnStems/Min	1.4268	0.0001	0.0026	0.0014	0.029	0.788
	LnStems/Ha	Stems/Min	-7.8239	0.0391	2.9831	0.0020	1.712	0.766
	LnStems/Ha	LnStems/Min	0.2664	0.4358	0.4340	0.0003	0.019	0.864
Saw Only								
	Stems/Ha	Stems/Min	4.5370	0.0005	0.0170	0.162	1.345	0.586
	Stems/Ha	LnStems/Min	1.5155	0.0001	0.0028	0.0185	0.039	0.571
	LnStems/Ha	Stems/Min	-2.3944	0.2493	1.9605	0.0021	0.771	0.763
	LnStems/Ha	LnStems/Min	0.2990	0.3127	0.3392	0.0007	0.016	0.823

[1]Legend: Ha = hectares; Ln = natural log; Min = minute.

treatments. The R^2's and MSE's in the saw plus axe, saw plus pruner, and rotary saw models were 0.753, 0.023; 0.864, 0.019; 0.823, and 0.016; respectively. The empirical "best-fit" model for the plots receiving the tractor mounted mower treatments was difficult to determine. A comparison of the coefficients of determination revealed a variation of only 1% between the log-log and the best semilog model. Differences in mean square errors varied by only 0.002, so either model adequately fit the data.

An examination of the observed significance levels governing the intercept parameters of the log-log models indicated that the null hypothesis, H_o: the intercepts are zero, could be accepted except for those plots which were mowed. The acceptance of the null hypothesis simplified the prediction equations to a coefficient times the natural log of the number of stems per hectare. The log-log plots for each treatment are given in Figures 5, 6, 7, and 8. An examination of the four treatment response curves revealed that the natural log of stems per minute was directly proportional to the natural log of stems per hectare. The log-log prediction equations for these skatter diagrams may be utilized by simply substituting the appropriate values of the intercept and slope from Table 4, in conjunction with the stem densities, into the generalized formula:

$$Ln(stems/min) = a + b\ Ln(stems/ha)$$

where

a = The estimated log-log model intercept.

b = The estimated log-log model slope.

Ln(stems/min) = The natural log of the number of stems cut per minute.

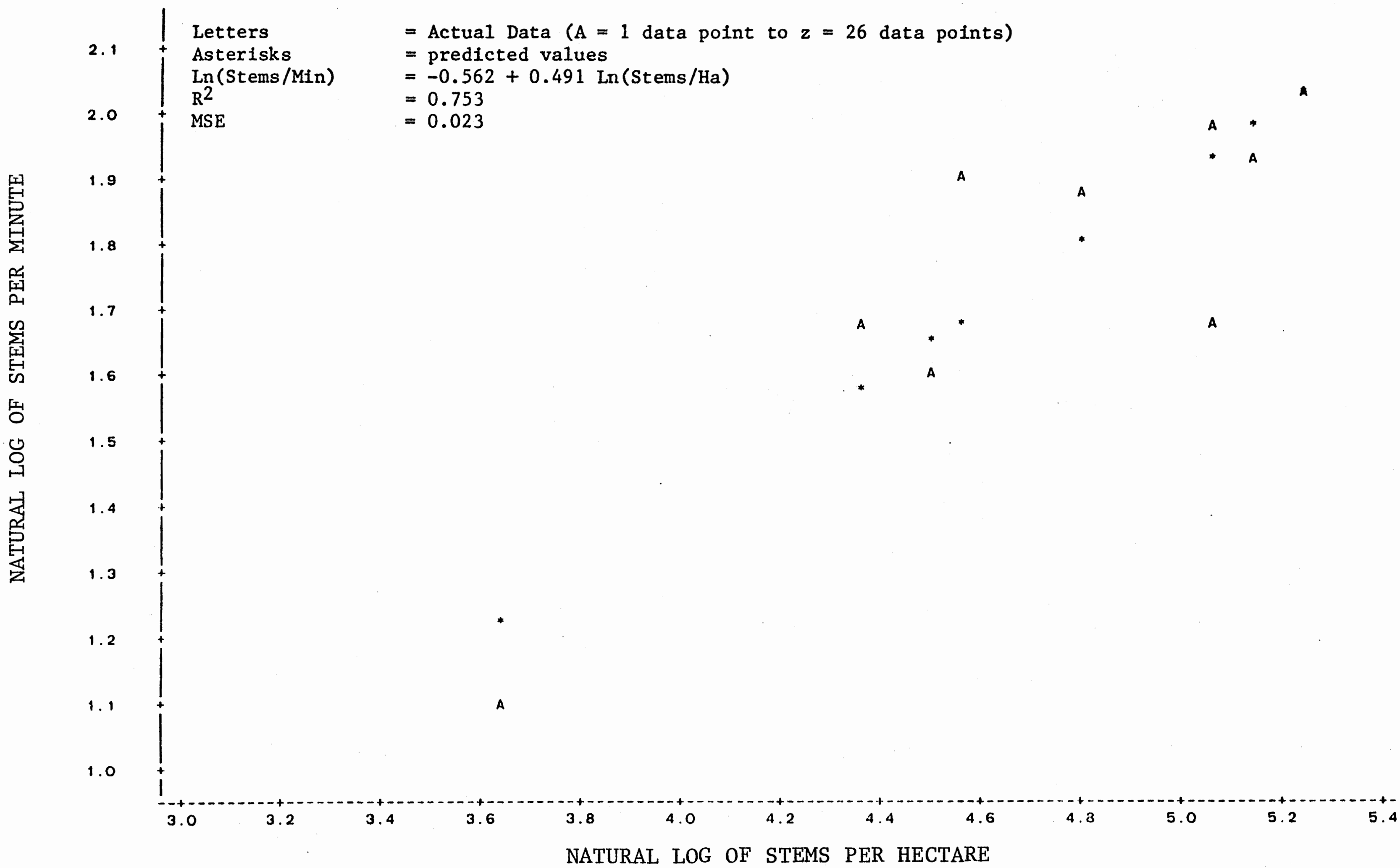

Fig. 5. Saw plus axe treatment log-log model for the production variable stems per minute.

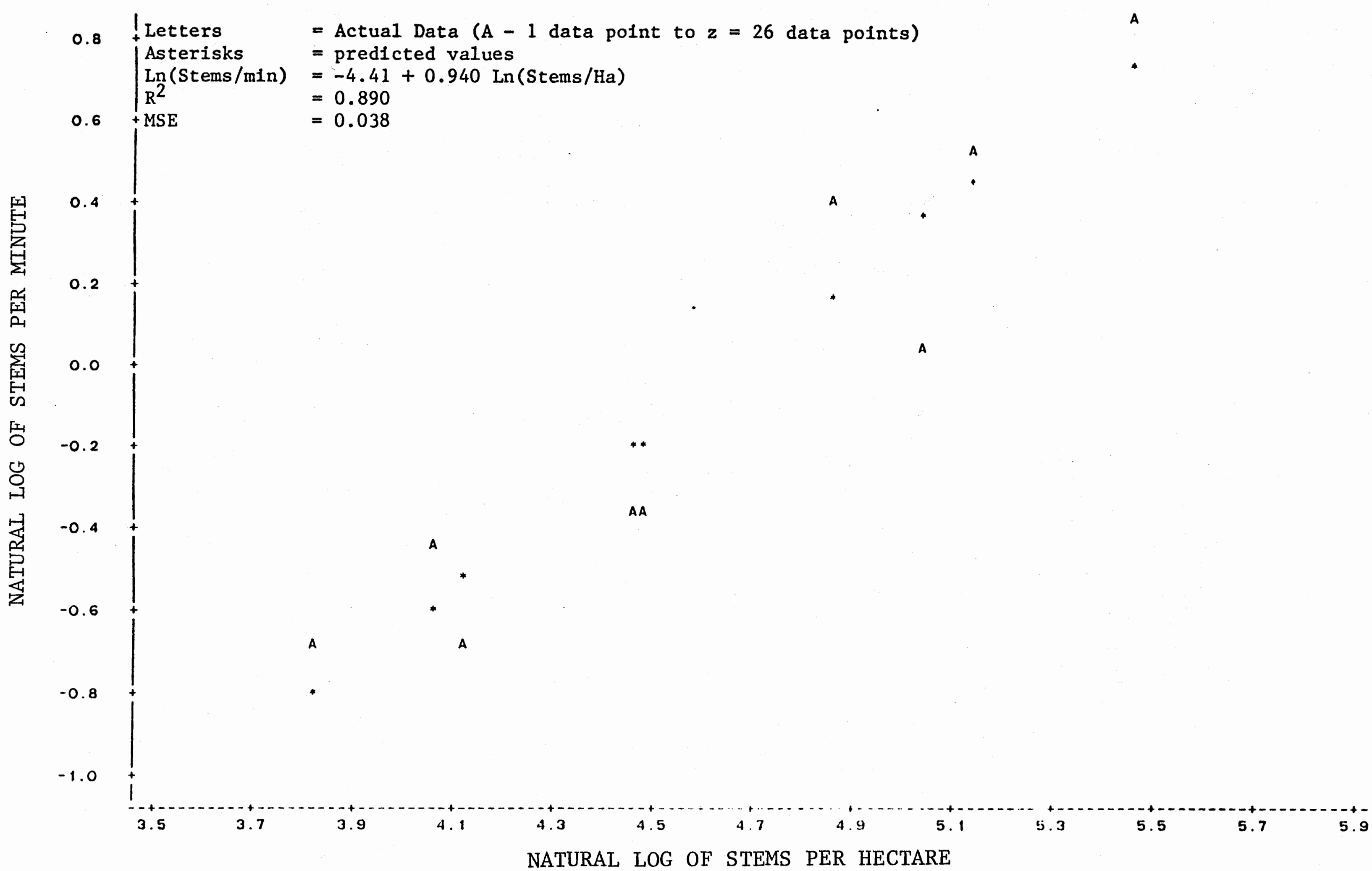

Fig. 6. Saw plus mower treatment log-log model for the production variable stems per minute.

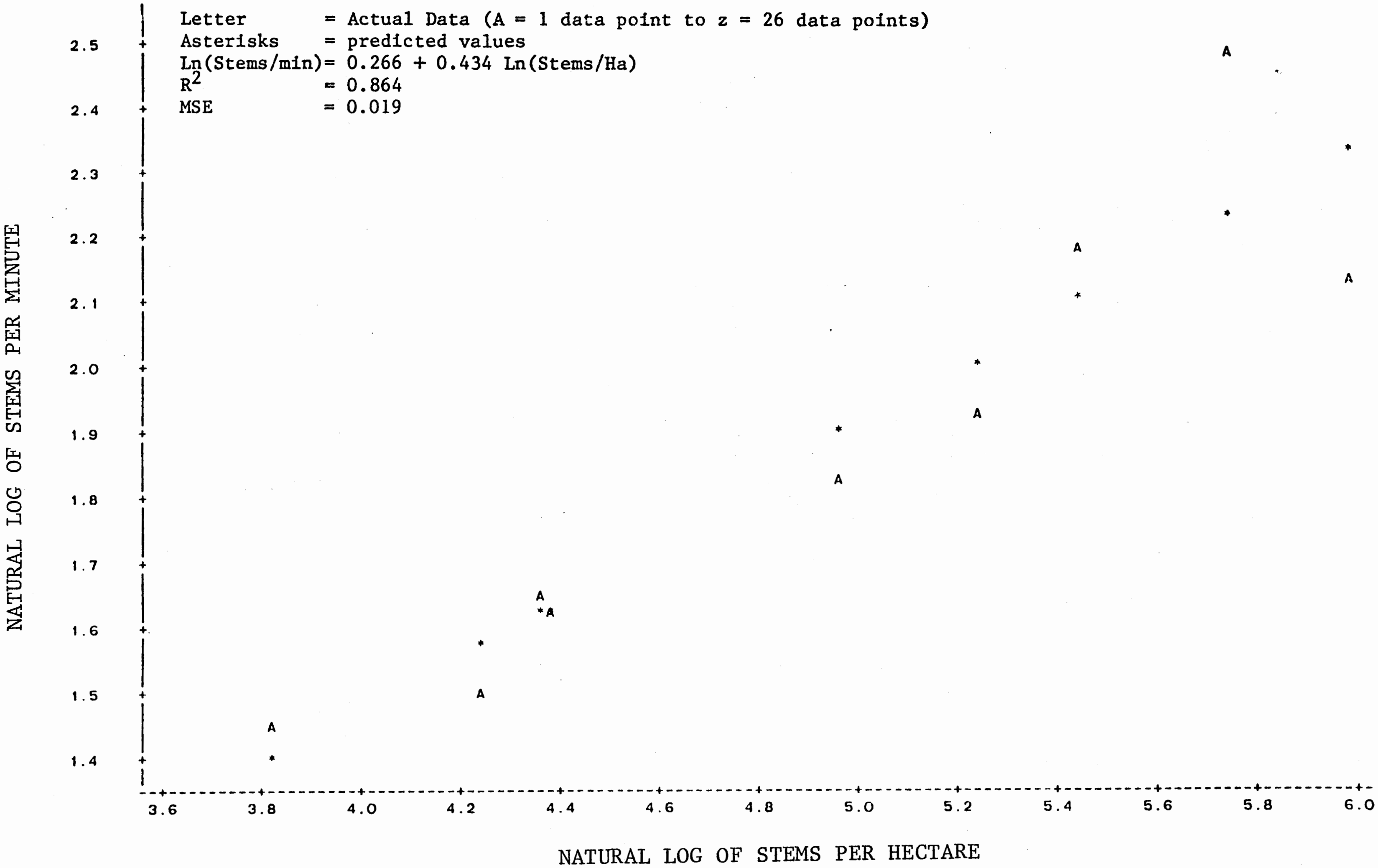

Fig. 7. Saw plus pruner treatment log-log model for the production variable stems per minute.

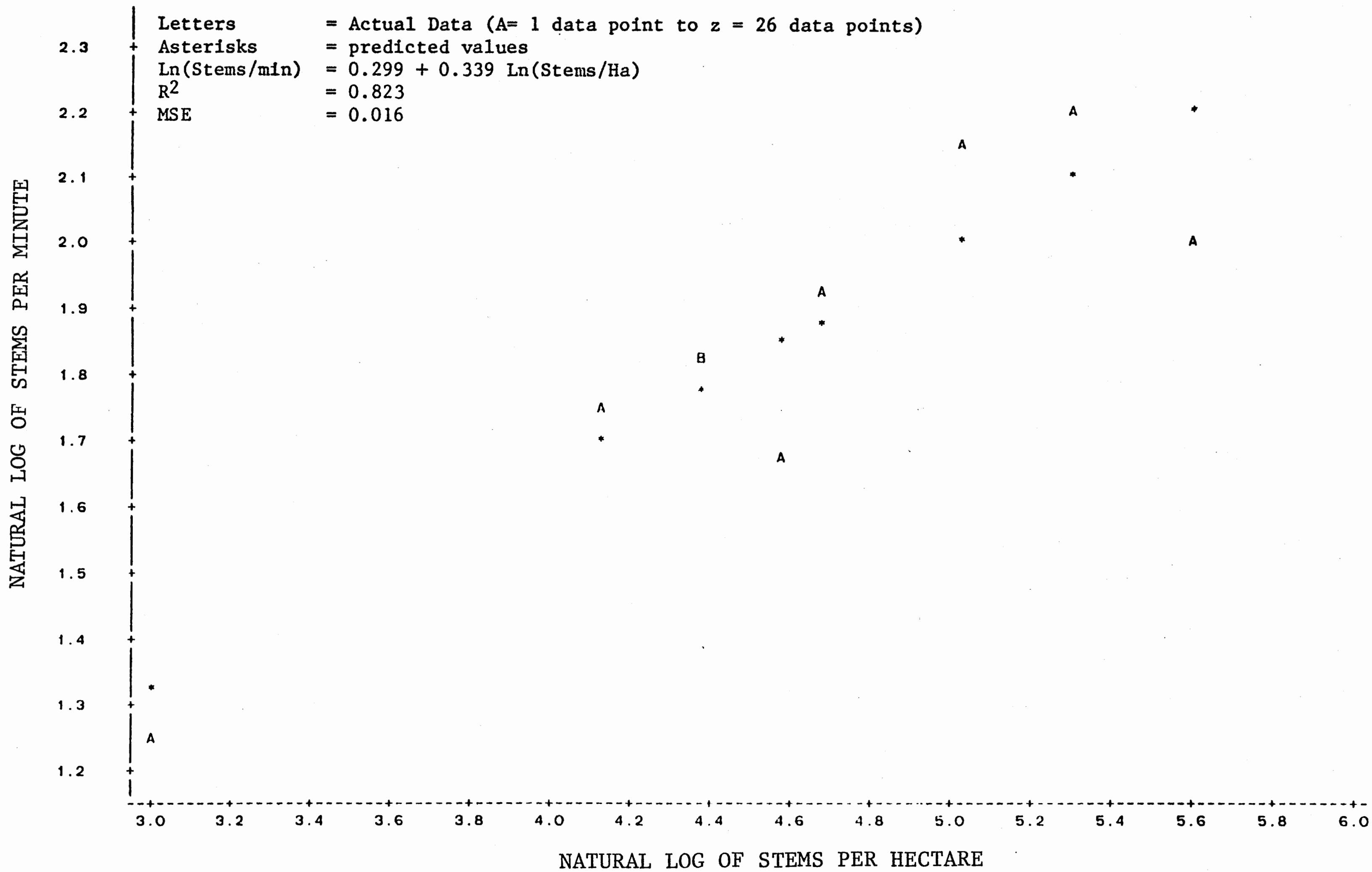

Fig. 8. Rotary saw treatment log-log model for the production variable stems per minute.

Ln(stem/ha) = The natural log of the number of stems per hectare.

Models used to fit the cost per hectare data followed the same semi-log and log-log patterns as previously outlined. Log-log models were found to most accurately predict the costs associated with the saw plus pruner and rotary saw treatments (Table 5). Determination coefficients and MSE's were 0.872 and 0.031 for saw plus pruner and 0.946 and 0.016 for rotary saw treatments, respectively. The best model for predicting the axe treatment response characteristics was a semilog equation of the natural log of cost per hectare versus stems per hectare. The R^2 and MSE were 0.732 and 0.038, respectively. The cost per hectare versus stem per hectare model was not selected because of the 100 fold jump in the mean square error and the reduction in the R^2. A log-log model of the data reduced the R^2 to 0.643, and increased the MSE to 0.050. All models for the plots receiving the mower treatment showed a poor correlation between cost and stem density, consequently no "best fit" model was found.

Plots of the four log-log cost per hectare models are given in Figures 9, 10, 11, 12. The natural log of cost per hectare was found to be directly proportional to the natural log of stems per hectare in all but the mower plots. The scatter diagram in conjunction with the low R^2 (0.016) for this treatment would indicate that the cost of clearing stems with the mower was not dependent upon the number of small stems in the plot. Practically speaking, this observation held true; it was noted that cutting time (and corresponding cost) in the field was uneffected by the number of small stems in the plot. The mower was found to sever small stems just as readily as the native grasses in the clearing operation.

Table 5. Comparison of four models (derived from the total time required to cut large and small stems) to determine the best fit of Cost/Ha to Stems/Ha.

Treatment	Independent Variable	Dependent Variable	Intercept		Slope		MSE	R^2
			Estimate	P> T	Estimate	PR> T		
Saw + Axe								
	Stems/Ha[1]	Cost/Ha	2.6431	0.1867	0.0558	0.0048	3.855	0.702
	Stems/Ha	LnCost/Ha	1.4640	0.0001	0.0060	0.0032	0.038	0.732
	LnStems/Ha	Cost/Ha	-14.4718	0.0962	0.0962	0.0152	5.264	0.593
	LnStems/Ha	LnCost/Ha	-0.4133	0.5927	0.5536	0.0093	0.050	0.643
Saw + Mower								
	Stems/Ha	Cost/Ha	85.0948	0.0003	0.0119	0.9081	313.760	0.002
	Stems/Ha	LnCost/Ha	4.4286	0.0001	0.0001	0.9096	0.040	0.002
	LnStems/Ha	Cost/Ha	68.0848	0.2327	3.9894	0.7332	308.849	0.018
	LnStems/Ha	LnCost/Ha	4.2442	0.0002	0.0433	0.7434	0.040	0.016
Saw + Pruner								
	Stems/Ha	Cost/Ha	4.0393	0.0141	0.0366	0.0005	4.252	0.830
	Stems/Ha	LnCost/Ha	1.5532	0.0001	0.0034	0.0015	0.053	0.785
	LnStems/Ha	Cost/Ha	-18.1364	0.0125	5.7935	0.0011	5.298	0.800
	LnStems/Ha	LnCost/Ha	-0.7225	0.1283	0.5824	0.0002	0.031	0.872
Saw Only								
	Stems/Ha	Cost/Ha	2.6118	0.0464	0.0731	0.0001	2.827	0.926
	Stems/Ha	LnCost/Ha	1.5698	0.0001	0.0062	0.0003	0.040	0.866
	LnStems/Ha	Cost/Ha	-19.3395	0.0210	6.7080	0.0021	9.037	0.763
	LnStems/Ha	LnCost/Ha	-0.7045	0.0374	0.6608	0.0001	0.016	0.946

[1]Legend: Ha = hectares; Ln = Natural log.

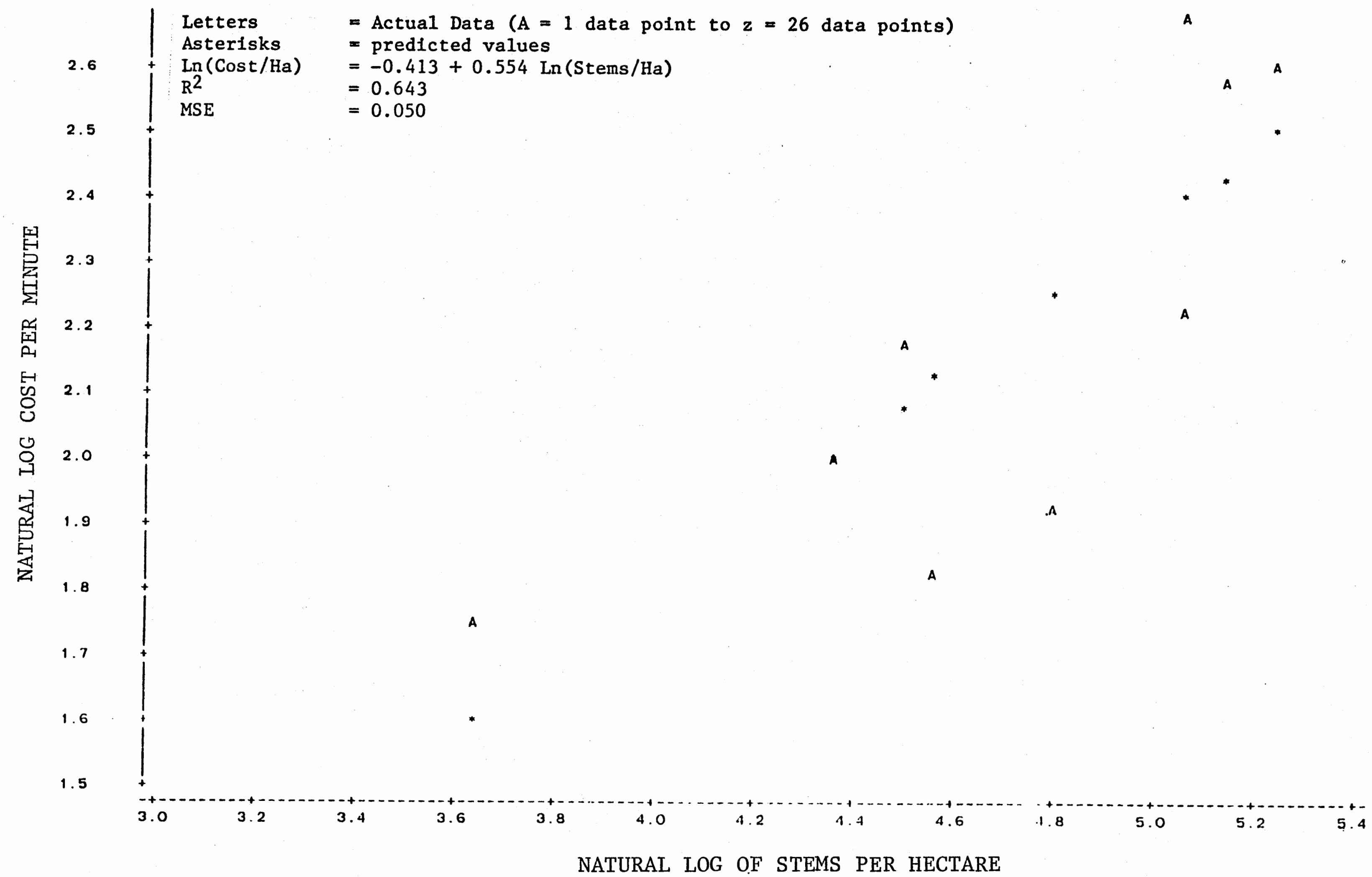

Fig. 9. Saw plus axe treatment log-log model for the production variable cost per hectare.

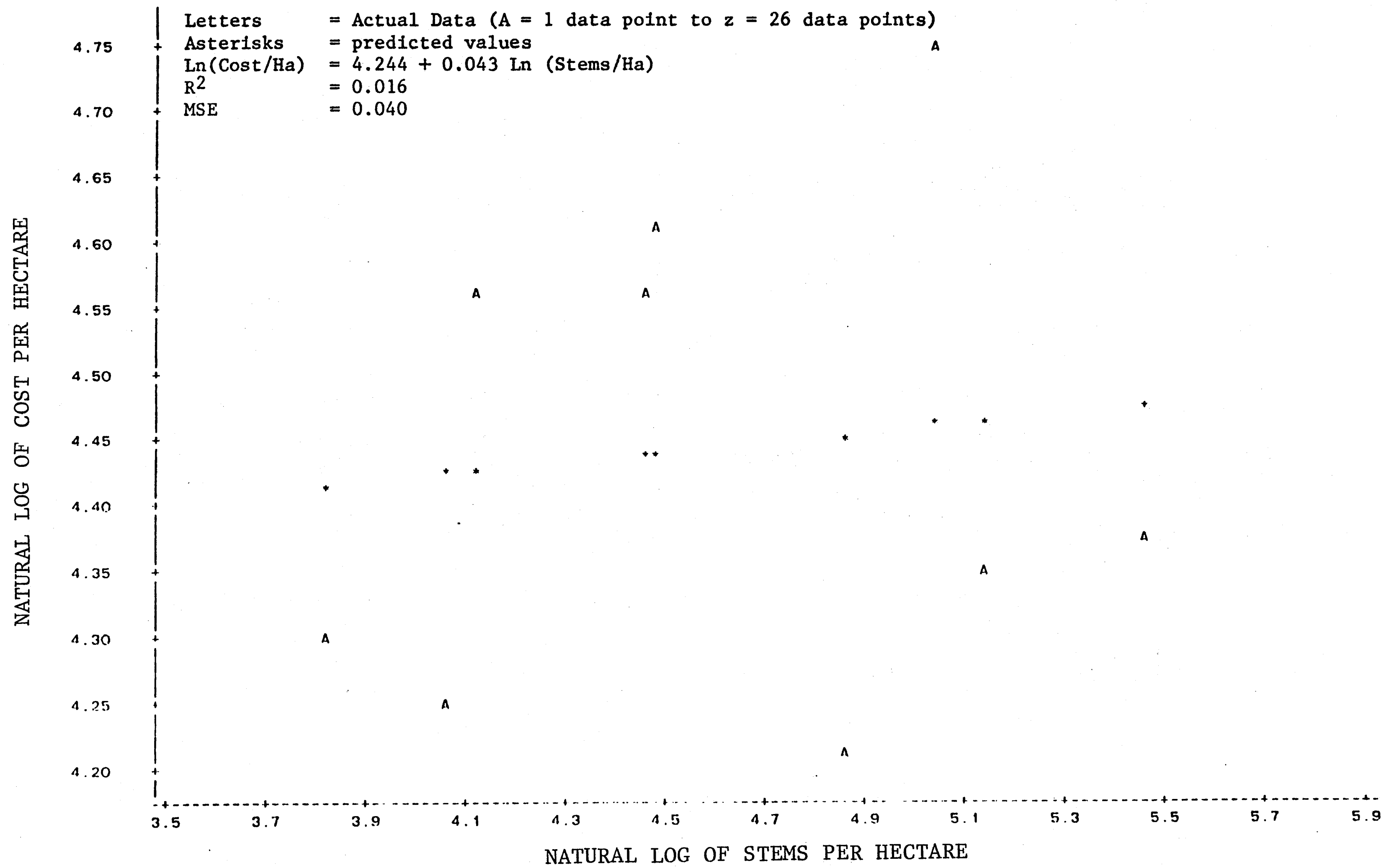

Fig. 10. Saw plus mower treatment log-log model for the production variable cost per hectare.

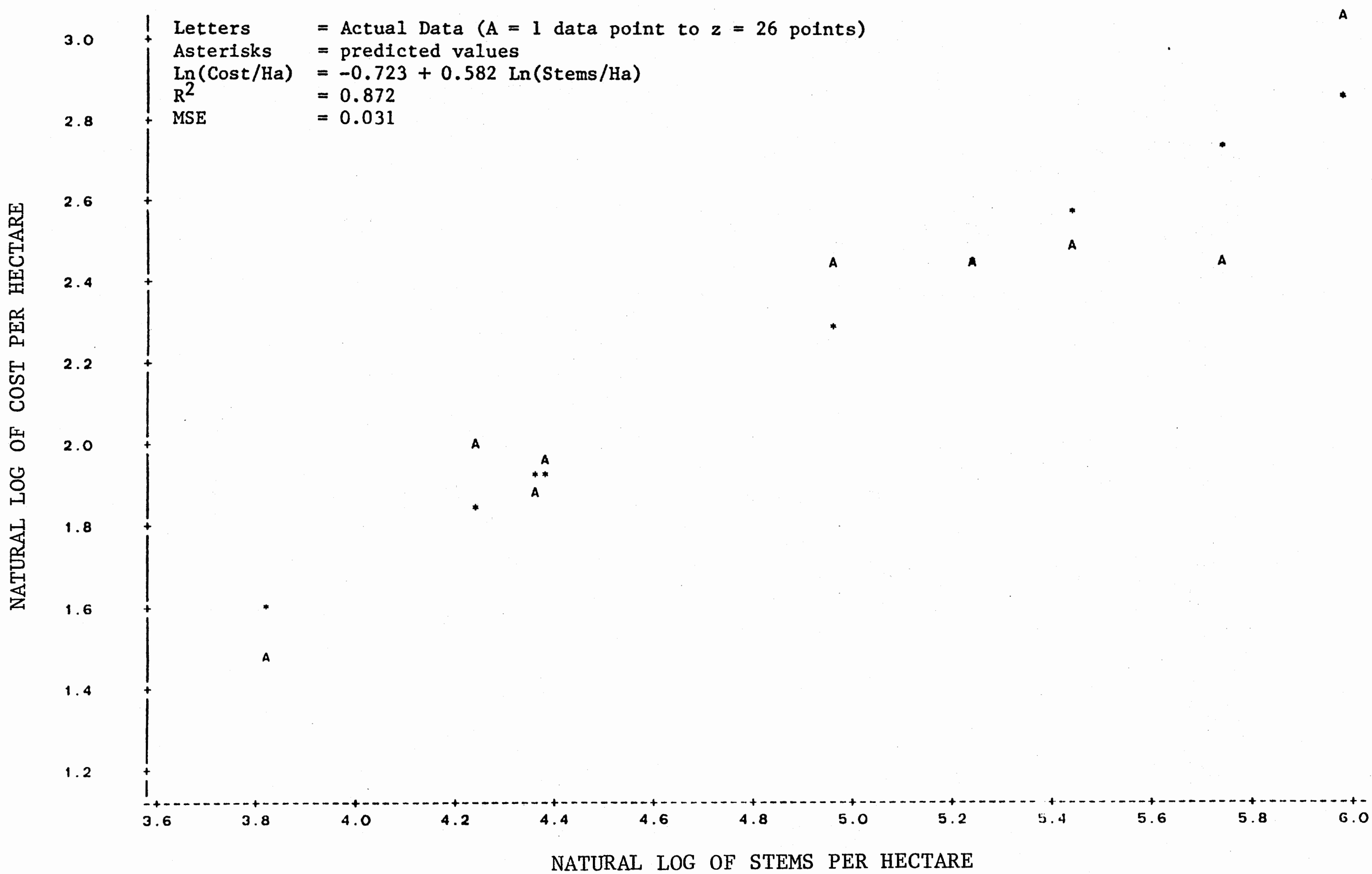

Fig. 11. Saw plus pruner treatment log-log model for the production variable cost per hectare.

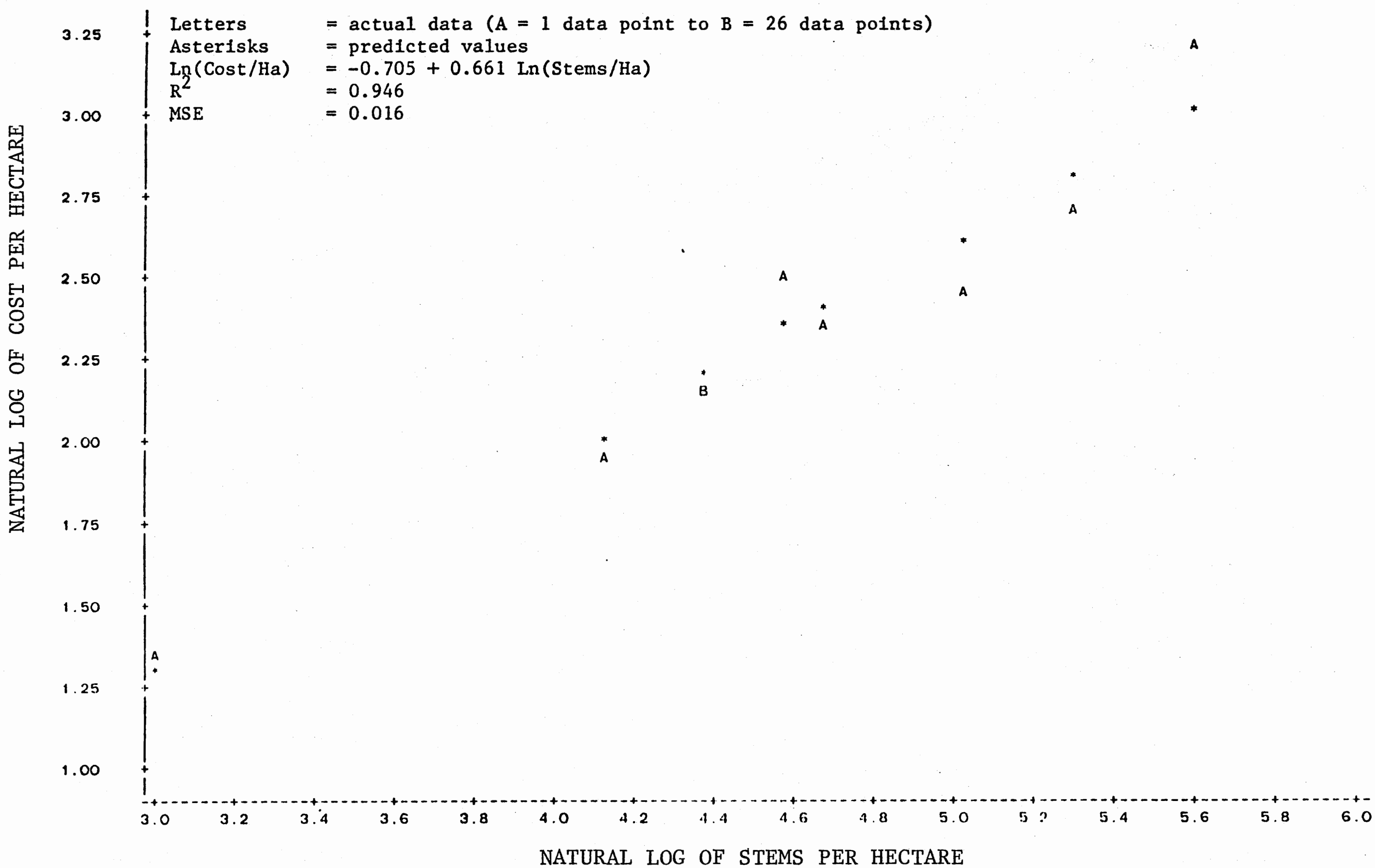

Fig. 12. Rotary saw treatment log-log model for the production variable cost per hectare.

The cost per hectare production variable was ultimately the one of most interest, because it determined the most economical method to use. To evaluate the economical differences between the treatments, the cost per hectare production equations were further refined by three progressive steps. Log-log models were selected for the comparative analysis because they were consistently among the equations which displayed the highest R^2's and lowest MSE's. To make a comparison, predicted data from both models would have to be derived by first transforming the equations to exponential form and then calculating new values. The procedure outlined would be subject to the assumption that invariance was true, i.e. that the transformations performed produce data that accurately depict a field situation. To verify this assumption, similar experiments would have to be conducted and the predicted values from the transformed equations compared with the field results.

Initially all log-log models were analyzed using a multiple regression analysis procedure to determine if the null hypothesis of equal intercepts was true. The null hypothesis was rejected after an observed significance level of $P > T = 0.0001$ was calculated. The source of the highly significant observed significance level was traced to the mower data. Later analysis revealed that the mower regression equation differed significantly in intercept and slope in comparison to all other treatments.

The second step of the analysis tested the null hypothesis of equal slopes for the non-mower treatment models. Subsequent calculations produced an observed significance level greater than 0.10, which indicated that the null hypothesis could not be rejected.

In the third and final step, non-mower regression equations were compared for equivalence. Axe and pruner regression equations were found to be statistically equivalent. However, from field experience it was felt that pruner cutting of small stems was more effective and safer than removal by axe. The collective equation of the axe and pruner treatments was then compared to the rotary saw equation by the null hypothesis, H_o: The combined axe and pruner cost equation and the rotary saw equation are the same. The subsequent calculations revealed that the observed significance level was less than 0.05 and therefore the null hypothesis was rejected. The final cost prediction equations are given in Table 6. The exponential, transformed equations are also given and are valid only if invariance may be assumed true.

To predict the performance of the rotary saw in removing only large stems, models of the production variables were determined from data pertaining to those plots where only large stems were cut. The models with their respective parameters are given in Table 7. Models of the same variables but derived from the cutting time data for all stems in the rotary saw plots, are also given for comparison. Linear models of the production variables derived from the large stem cutting times were not as precise as the models derived from the rotary saw ("all stems") treatment. For every large stem model studied, the R^2 decreased and MSE increased, in comparison to the models derived from the "all stems" treatments. The only exception to this was found between the mean square errors of the cost per hectare models. The loss of precision associated with the models derived from the large stem cutting time data may be attributed to the inability of the simple cartesian model to explain the response characteristics of the data as accurately.

Table 6. Final log-log cost equations for axe, pruner and rotary saw treatments.

$$Ln(Cost/Ha) = a + b\ Ln(Stems/Ha)$$

Treatment	a	b	Transformed Equation
Axe	-0.6744	0.6013	$Cost/Ha = e^{-.6744}(Stems/Ha)^{0.6013}$
Pruners	-0.6744	0.6013	$Cost/Ha = e^{-.6744}(Stems/Ha)^{0.6013}$
Saw	-0.4333	0.6013	$Cost/Ha = e^{-.4333}(Stems/Ha)^{0.6013}$

Table 7. Comparison of production variable models for severing all stems and severing only large stems with the rotary saw.

Stems Cut	Independent Variable	Dependent Variable	Intercept Estimate	Intercept P> T	Slope Estimate	Slope P> T	MSE	R^2
All Stems[1]	Stems/Ha[2]	Cost/Ha	2.6118	0.0464	0.0731	0.0001	2.827	0.926
Large only[3]	LgStems/Ha	Cost/Ha	2.8077	0.0001	0.0684	0.0001	2.533	0.847
All Stems	Stems/Ha	Ha/Hr	7.6530	0.0002	-0.0268	0.0103	2.748	0.633
Large only	LgStems/Ha	Ha/Hr	9.4349	0.0001	-0.0425	0.0001	4.235	0.561
All Stems	Stems/Ha	Stems/Min	4.5364	0.0005	0.0170	0.1620	1.345	0.586
Large only	LgStems/Ha	Stems/Min	4.2823	0.0001	0.0232	0.0001	1.938	0.454

[1]"All Stems" treatments consisted of data obtained from 9 plots.

[2]Legend: Ha = hectares; Hr = hour; Lg = large

[3]"Large only" treatments consisted of data obtained from 27 plots.

An estimation of small stem clearing cost in saw treated plots could not be uniformly determined. The prediction equations derived for the large stem removal and total stem removal costs were found to intersect when stem densities approached 42 stems per hectare. The other production variables of hectares per hour and stems per minute experienced similar problems when densities reached 119 and 42 stems per hectare, respectively.

Prediction of Cutting Time from Basal Diameter

The null hypothesis of equal variances for cutting times between diameters was rejected because the observed significance level was found to be significant (P>F=0.0001). The null hypothesis of equal variances for the natural log of cutting times between diameters was accepted when the observed significance level was found to be nonsignificant (P>F=0.0758). Upon the premise of equal variances, only models involving the natural log of cutting time could be assumed to reflect differences due to means.

An evaluation of the statistical parameters governing the models revealed that the equation involving the natural log of cutting time with diameter most accurately portrayed the response characteristics of the data. In this case, the MSE (0.270) was lower, and R^2 (0.757) higher than that of the log-log model.

The statistical parameters associated with the semilog equation (Table 8) indicated a nonsignificant (P> T = 0.6019) observed significance level for the hypothesis test, Ho: The y-intercept is equal to zero. The null hypothesis was accepted because the observed significance level was above the 0.05 level. The elimination of the

Table 8. Regression and statistical parameters governing linear models of eastern redcedar basal diameter with cutting time.

Independent Variable	Dependent Variable	Intercept		Slope		MSE	R^2
		Estimate	P> T	Estimate	P> T		
Diameter	Cut Time	-10.5072	0.0001	1.4312	0.0001	67.7768	0.682
Diameter	LnCut Time[1]	-0.0362	0.6019	0.1089	0.0001	0.2701	0.757
LnDiameter	Cut Time	-23.9561	0.0001	13.4741	0.0001	137.4277	0.3544
LnDiameter	LnCut Time	-1.8144	0.0001	1.3459	0.0001	0.3578	0.678

[1]Ln = Natural log.

y-intercept term simplified the "best-fit" regression equation reduce to:

$$\text{Ln(cut time)} = 0.1089(\text{Dia}) \qquad (1)$$

where:

Dia = the basal diameter of the tree in centimeters.

Ln(Cut time) = the natural log of the cutting time measured in seconds.

If invariance may be assumed true, then the equation may be transformed to:

$$\text{Cut Time} = e^{0.1089(\text{Dia})}$$

From the equation parameters listed in Table 8, the prediction equations for the simple cartesian, semilog, and log-log models were plotted (Fig. 13, 14, 15, 16). In every case, each model indicated a proportional increase in cutting time with diameter. A cartesian plot of the data (Fig. 13) revealed that the majority of the stems severed in the study were less than 20 cm in diameter. The scatterplot would indicate that beyond this point, variation in cutting time for larger stems increased. This phenomenon may be attributed to the extra time expended when saw cuts overlapped on trees where two or more passes were required to sever the trunk.

Prediction of Tree Height from Basal Diameter

The null hypothesis of equal variances for stem heights between diameters was rejected when the observed significance level was found to be significant ($P>F=0.0001$). The null hypothesis of equal variances for the natural log of stem heights between diameters was also rejected because of a significant observed significance level ($P>F=0.0003$).

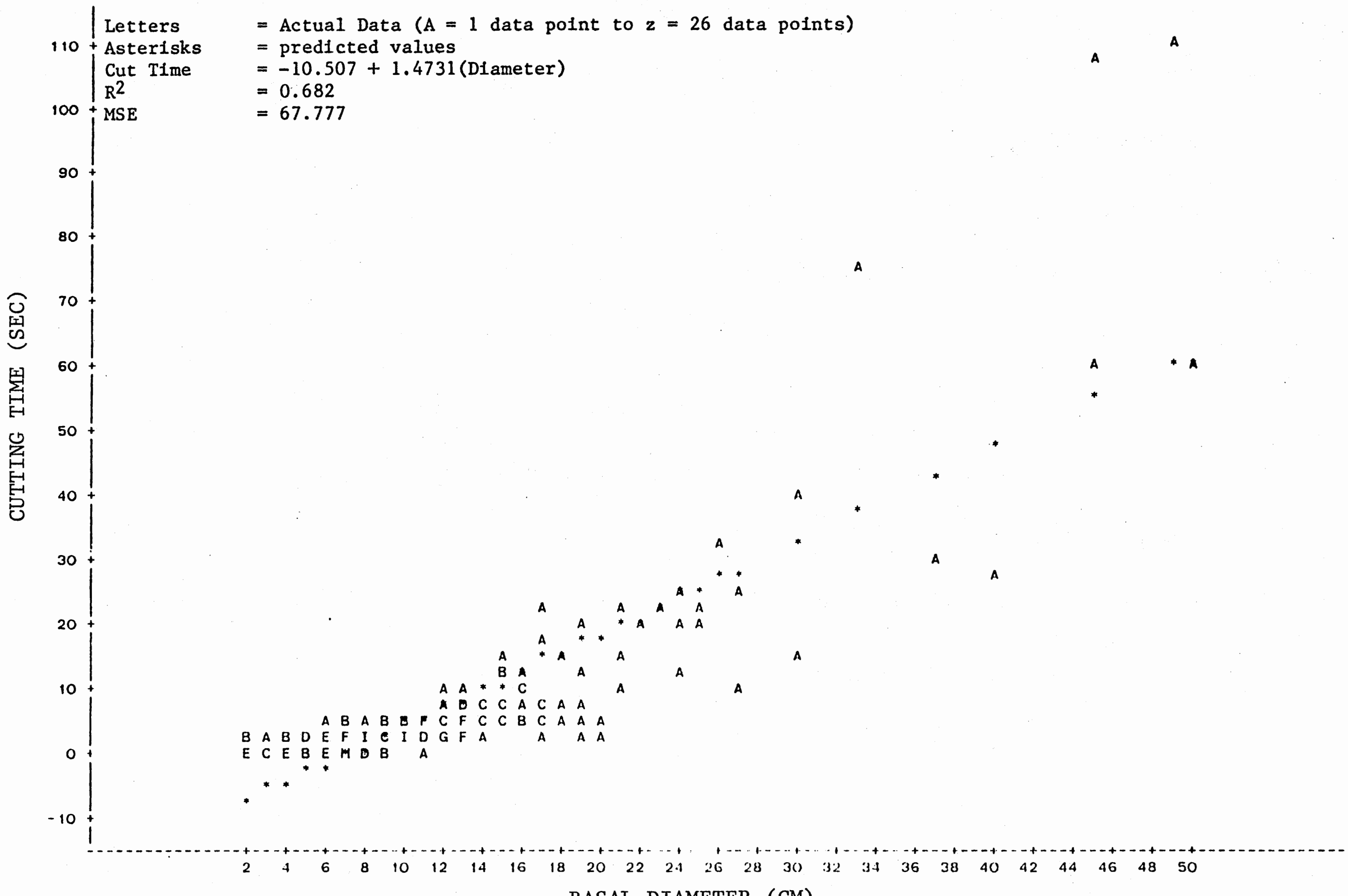

Fig. 13. Model of cutting time with basal diameter.

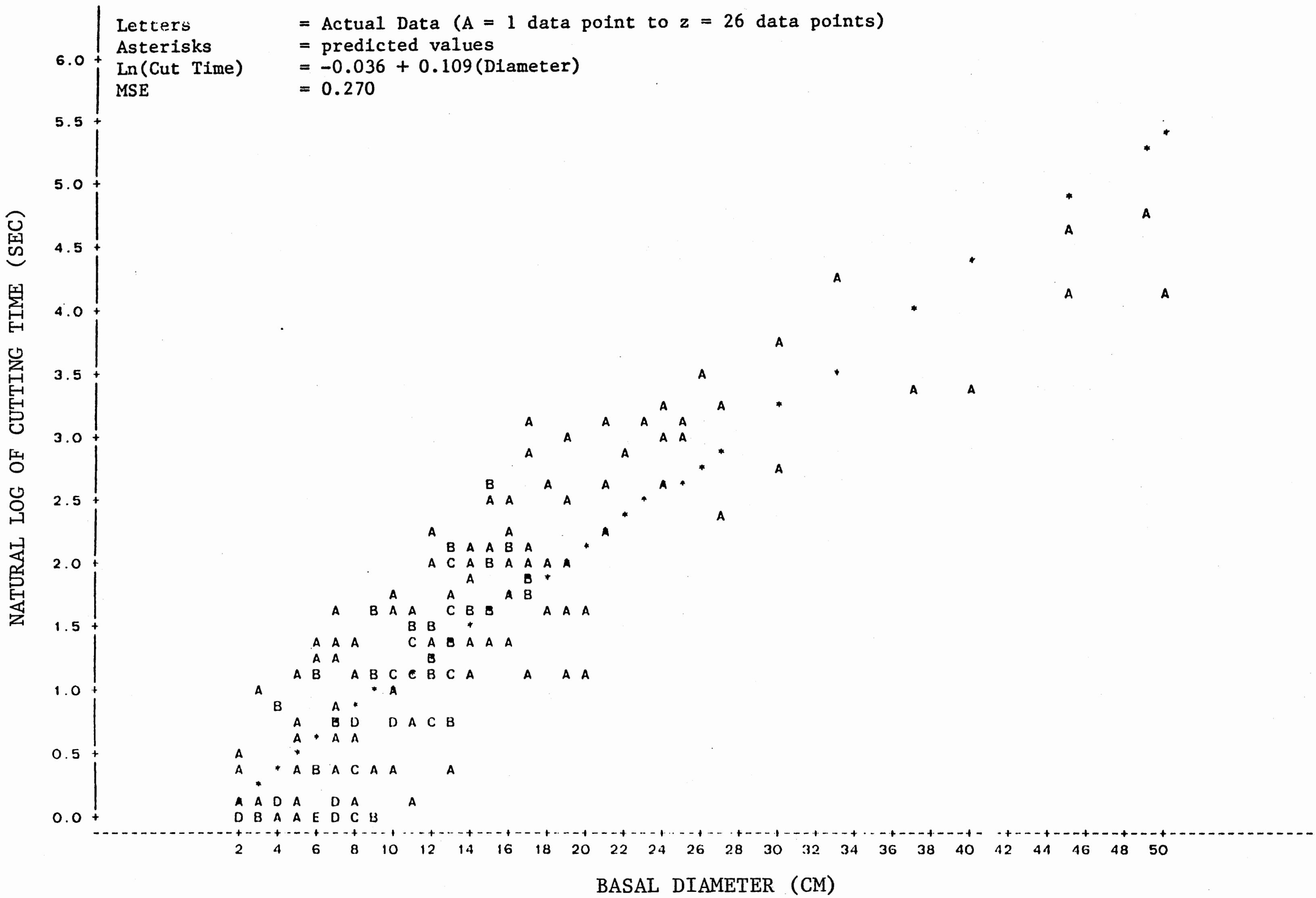

Fig. 14. Model of the natural log of cutting time with basal diameter.

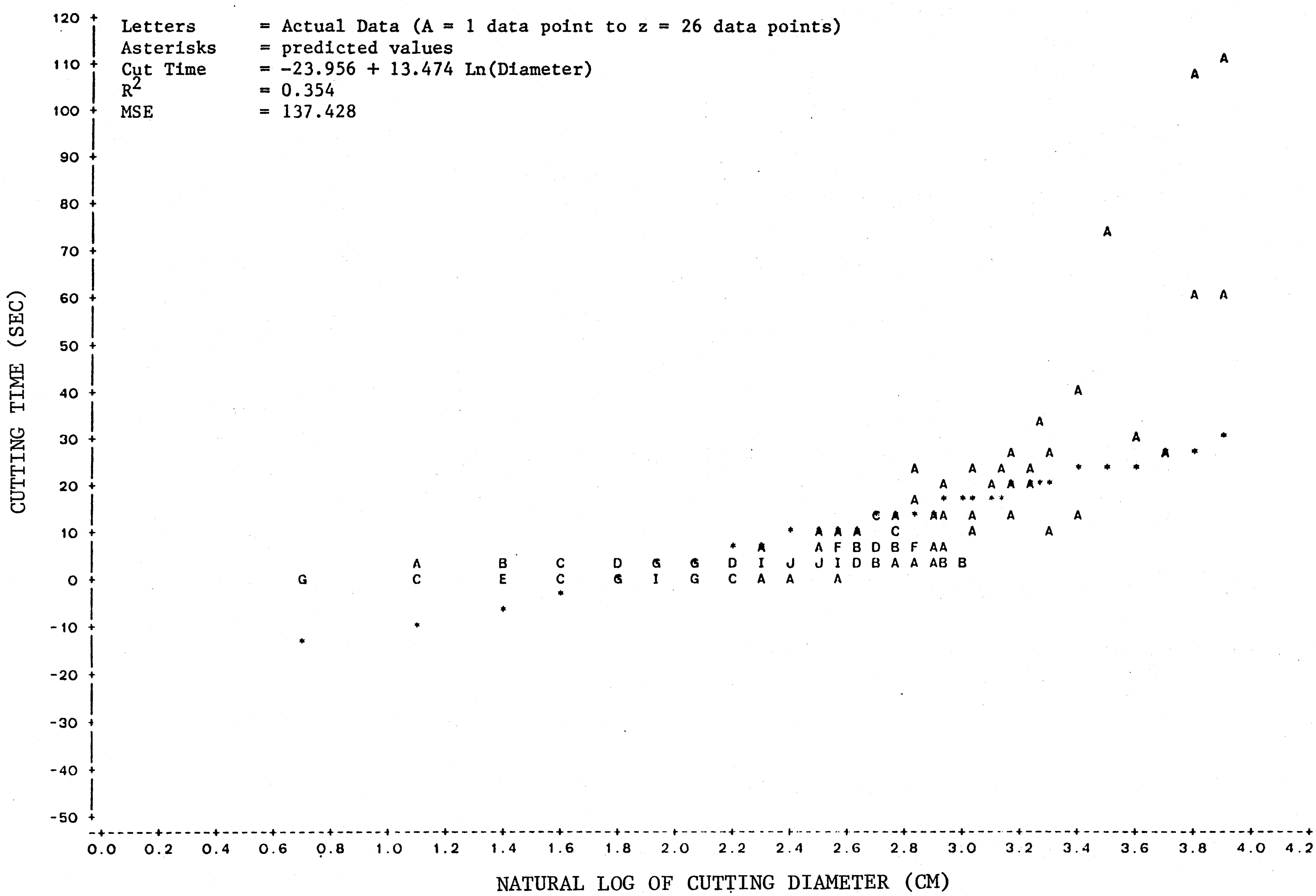

Fig. 15. Model of the cutting time with the natural log of basal diameter.

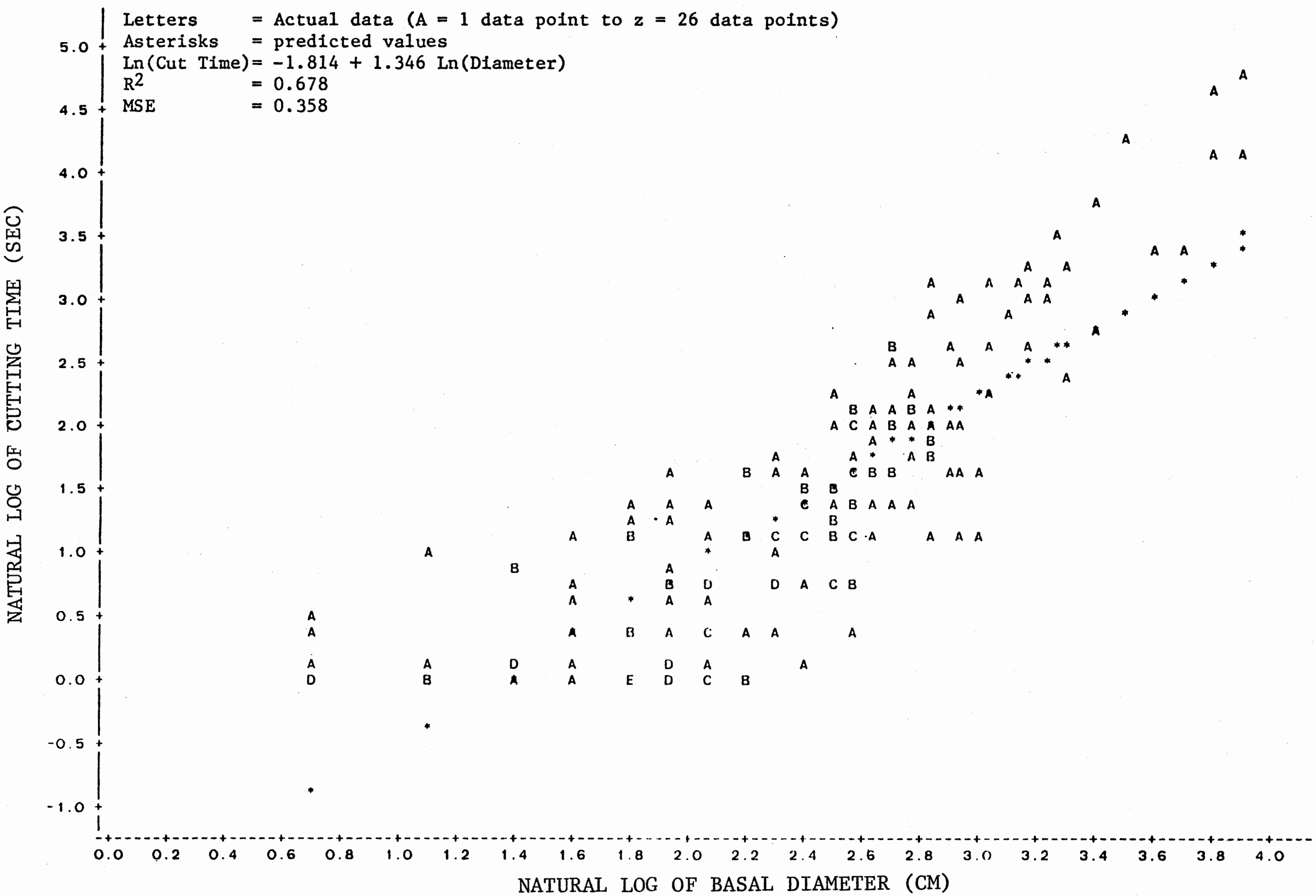

Fig. 16. Model of the natural log of cutting time with the natural log of basal diameter.

Since the null hypothesis of equal variances could not be assumed true, the subsequent analysis and conclusions may be distorted and based upon differences due to unequal variances rather than means.

The regression and statistical parameters for the four models evaluated are listed in Table 9. A comparison among the statistical parameters revealed that the log-log model most accurately depicted the response characteristics of the data. In contrast to the other models, the MSE (0.0401) was lower and R^2 highest (0.757) with the log-log model.

To visualize the response characteristics of the four models, their prediction equations were plotted (Fig. 17, 18, 19, and 20). In every case, height was found to increase proportionally with diameter. The scatterplot of the data with the prediction equation reconfirmed the adequacy of the log-log equations to model the data most accurately.

In reference to Table 9, the "best-fit" equation for modeling eastern redcedar height with basal diameter is given by the equation:

$$\mathrm{Ln(Height)} = -0.3150 + 0.5653\ \mathrm{Ln(Dia)} \tag{2}$$

where:

Ln(Dia) = the natural log of basal diameter measured in centimeters.

Ln(Height) = the natural log of height measured in meters.

If invariance may be assumed true, the equation may be transformed to:

$$\mathrm{Height} = e^{-0.3150}(\mathrm{Dia})^{0.5653} \tag{3}$$

or rearranged to predict diameter from height:

$$\mathrm{Dia} = e^{0.5572}(\mathrm{Height})^{1.7690} \tag{4}$$

Table 9. Regression and statistical parameters governing linear models of eastern redcedar heights with basal diameter.

Independent Variable	Dependent Variable	Intercept		Slope			
		Estimate	P> T	Estimate	P> T	MSE	R^2
Diameter	Height	1.0340	0.0001	0.1572	0.0001	0.2013	0.716
Diameter	LnHeight[1]	0.1997	0.0001	0.0685	0.0001	0.0684	0.586
LnDiameter	Height	0.1466	0.0001	1.1292	0.0001	0.2121	0.702
LnDiameter	LnHeight	-0.3150	0.0001	0.5653	0.0001	0.0401	0.757

[1] Legend: Ln = natural log.

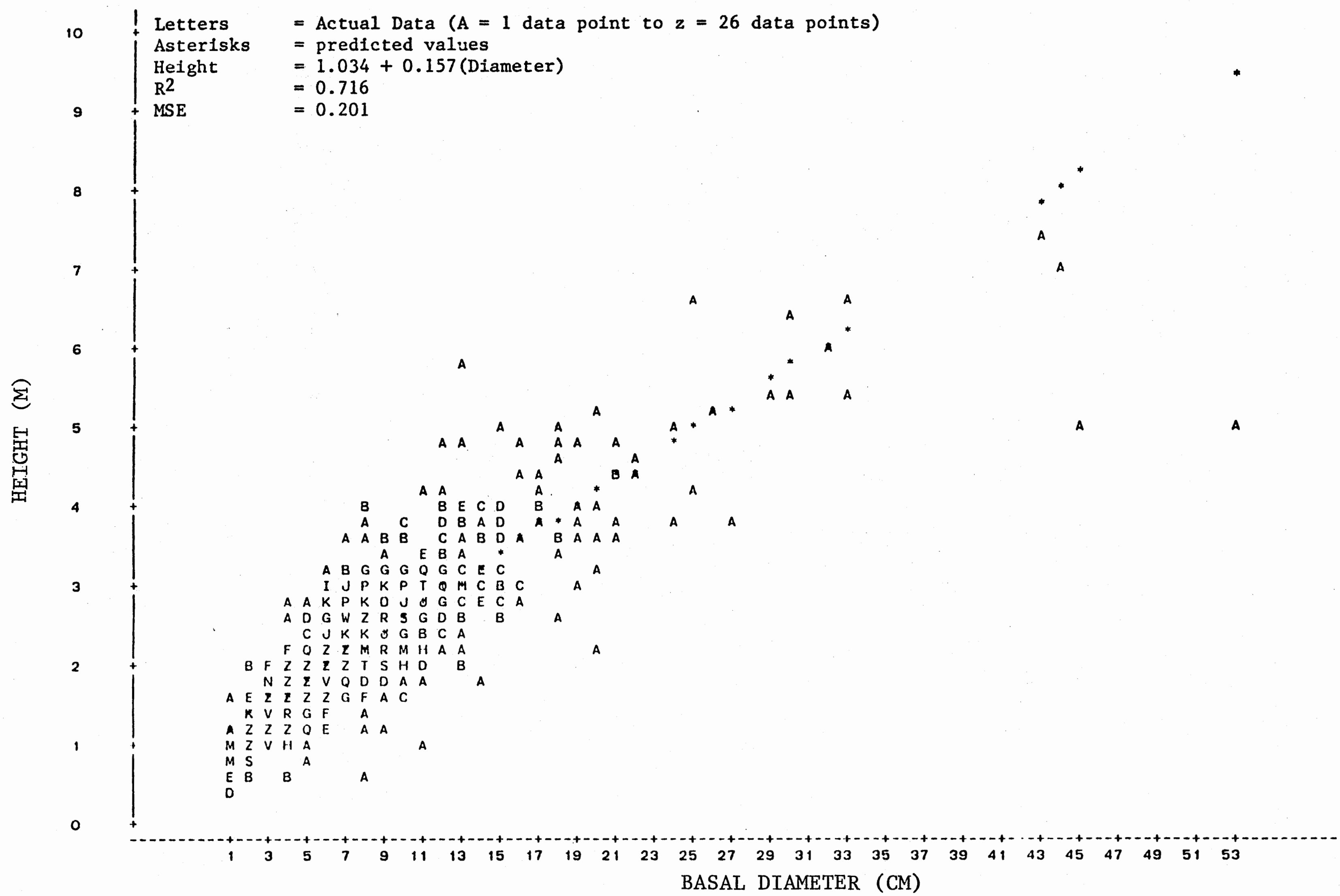

Fig. 17. Model of eastern redcedar height with basal diameter.

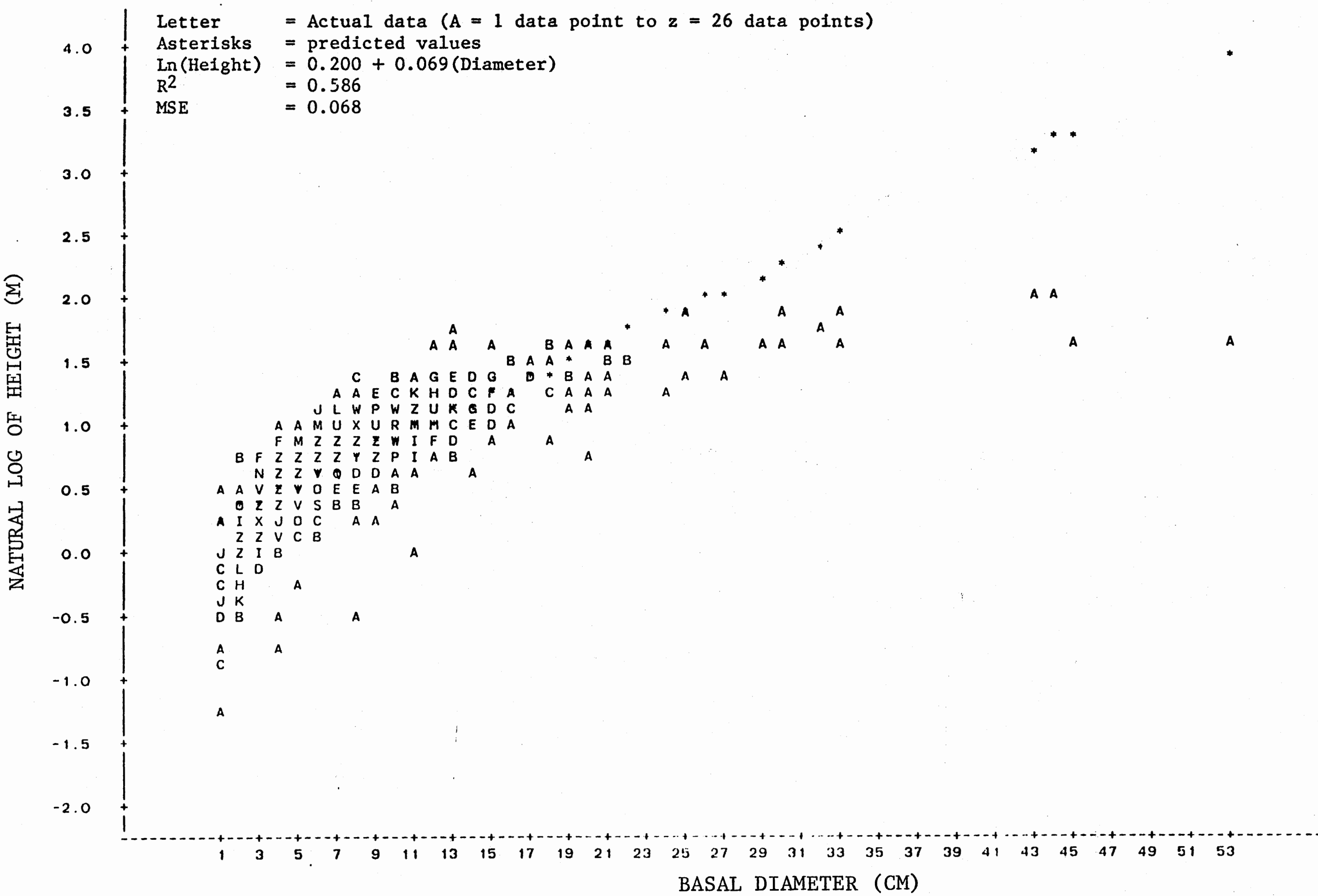

Fig. 18. Model of the natural log of eastern redcedar height with basal diameter.

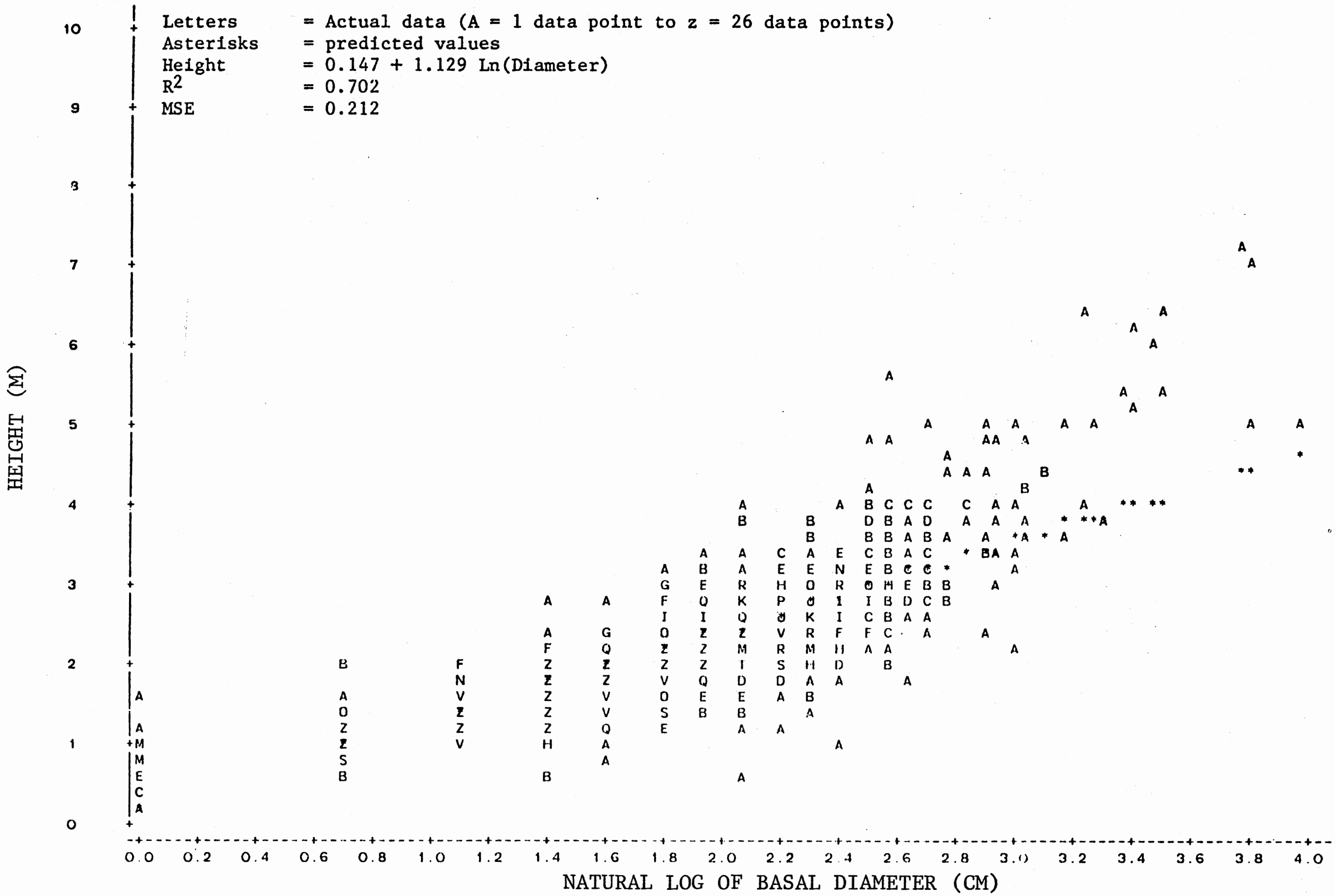

Fig. 19. Model of eastern redcedar height with the natural log of basal diameter (M).

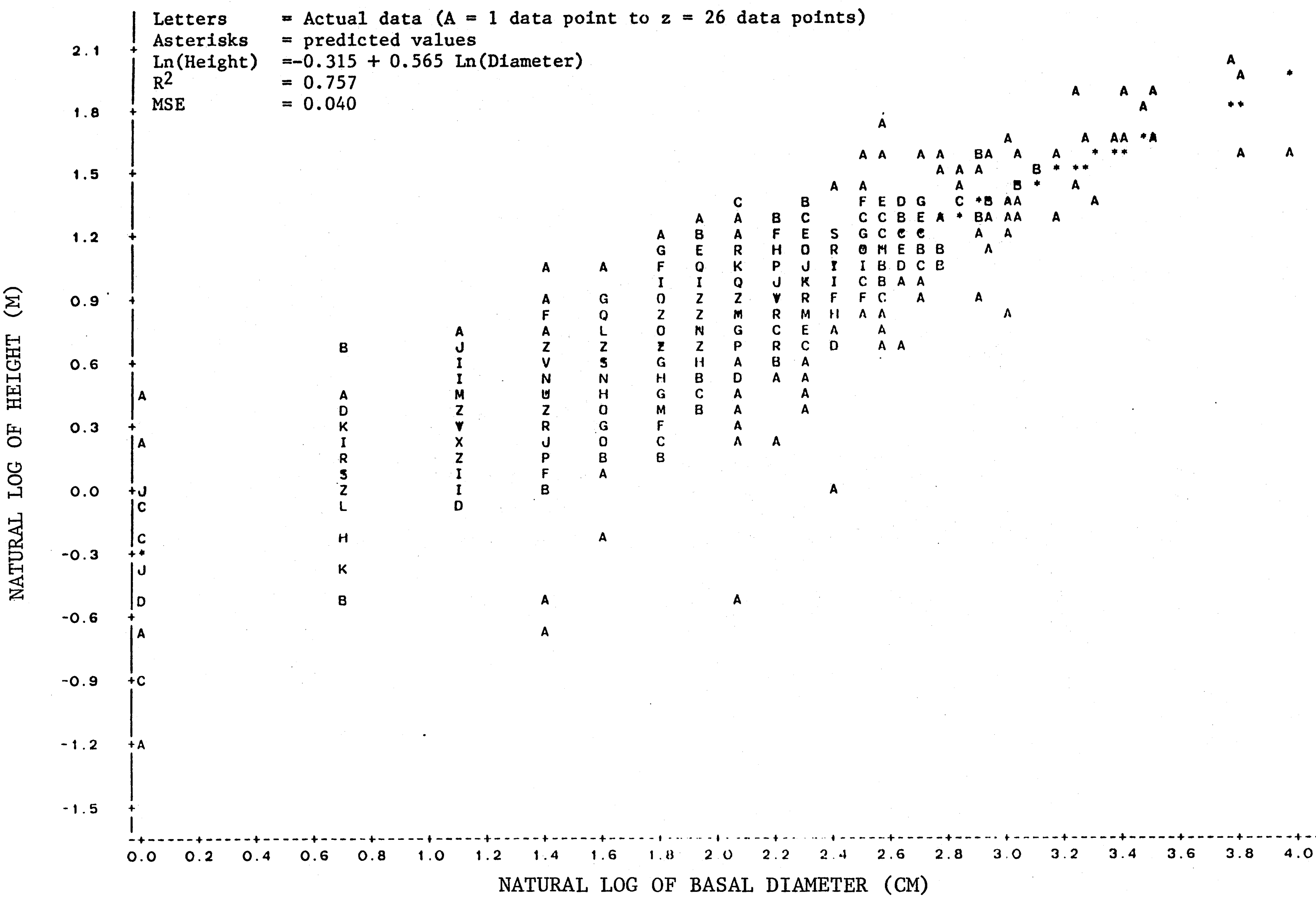

Fig. 20. Model of the natural log of eastern redcedar height with the natural log of basal diameter.

CHAPTER V

Summary and Conclusions

The machine time required to remove stems in the rotary saw plots was significantly higher than the time spent in the saw plus mower and saw plus axe plots. The source of this difference was attributed to the extra time required to remove the small stems in the rotary saw plots. No significant differences in cutting times of large stems were found among the non-saw plots. The cutting time required to remove the small stems in the non-saw plots was found to be highest in the plots treated with the mower. Because the small stem cutting time for the mower treatments was excessive, the total time required for the removal of all stems was found to be the highest of the four treatments studied.

In an evaluation of the production variables, a semilog equation of the natural log of hectares per hour versus stems per hectare was found to fit the axe plus saw data best. A model of the natural log of hectares per hour versus the natural log of stems per hectare was found to fit the saw plus pruner and rotary saw treatment data best. A "best fit" empirical equation for modeling the mower data could not be determined because of the poor correlation associated with the data and variable evaluated. With the exception of the data associated with the mower treatment, the production variable: hectares per hour, was found to be inversely proportional to the number of stems cut per hectare.

An analysis of the data associated with the production variable: stems per minute, revealed that all treatments were modeled most precisely with log-log equations. Further examination of the four treatment response curves revealed that the production variable, stems per minute, was directly proportional to the number of stems cut per hectare.

In modeling the production variable, cost per hectare, log-log equations were found to be the most accurate in predicting the costs associated with the saw plus pruner and rotary saw treatments. The best model for predicting the saw plus axe data response characteristics was a semilog equation of the natural log of cost per hectare versus stems per hectare. All models for the plots receiving the saw plus mower treatments showed poor correlation, consequently no "best fit" model could be determined. With the exception of the mower data models, cost per hectare was found to be directly proportional to the number of stems cut per hectare.

A comparison between the log-log cost models revealed that the saw plus axe and saw plus pruner regression equations were statistically equivalent. However, field experience revealed the pruner treatment to be the preferable practice. Saw plus axe and saw plus pruner treatment costs were found to be significantly less than those associated with using only the rotary saw to cut all trees. Saw plus mower treatments were found to be the costliest method of control. Clearing costs for some of the methods were derived from models and are listed for various stem densities in Table 10.

A semilog empirical equation depicting the dependency of cutting time on stem diameter was found to match the data most precisely. The

Table 10. Estimated clearing costs using pruners only on small stems, rotary saw on large stems, saw on all stems, and rotary saw on large stems plus pruners on small stems.

Stems/Ha	Pruners Only Small Stems	Saw Only Large Stems	Saw All Stems	Saw + Pruner
		Dollars/Ha		
20	0.58	4.18	3.93	3.09
60	0.93	6.91	7.60	5.97
100	1.17	9.65	10.34	8.12
140	1.37	12.38	12.66	9.94
180	1.54	15.12	14.72	11.57
220	1.69	17.86	16.61	13.05
260	1.82	20.60	18.36	14.43
300	1.95	23.33	20.01	15.73
340	2.06	26.06	21.58	16.95
380	2.17	28.80	23.07	18.13

[1]Estimate derived from model using saw data of large stems (greater than 5 cm) in saw + axe, saw + mower, and saw + pruner plots.

[2]Saw + pruner treatment costs are statistically equivalent to saw + axe treatment costs.

model of the natural log of cutting time with stem diameter most accurately portrayed the response characteristics of the data. Regardless of the model evaluated, cutting time was found to be directly proportional to the stem diameter.

An analysis of the variances associated with stem height and diameter revealed that equal variances in heights between diameters could not be assumed. A comparison between the various models studied revealed that a log-log equation most accurately depicted the response characteristics of the data. In every case, each model predicted the height to increase proportionally with diameter.

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