Management of Sand Shinnery Oak for Control of the Boll Weevil (Coleoptera: Curculionidae) in the Texas Rolling Plains

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ABSTRACT Sand shinnery oak, *Quercus havardii* Rydb., occurs on ca. 230.2 thousand ha in the Texas rolling plains. Litter deposited by this range shrub provides one of the best overwintering habitats for the boll weevil, *Anthonomus grandis grandis* Boheman, in the region. Several sand shinnery oak management strategies were compared to evaluate methods for elimination of the shrub and associated litter. Overwinter survival rates for boll weevils caged in the litter were used as a biological indicator of treatment success. Tebuthiuron herbicide, applied at 1.1 kg (AI)/ha, provided a 98% reduction in shinnery oak cover and litter, but 3 years elapsed from treatment application to a significant reduction in boll weevil overwinter survival rates. The addition of fire and shredding to the tebuthiuron treatment did not hasten the rate of habitat disappearance, and boll weevil winter mortality rates were not increased in comparison to the tebuthiuron-only treatment. The herbicide glyphosate did not provide adequate control of the shinnery oak, and litter was not reduced enough to affect boll weevil survival. Fire alone was the least effective approach for shinnery oak management. The litter layer began to reaccumulate 8 months after the fire. Three years after the fire, boll weevil survival was significantly ($P < 0.05$) higher and emergence continued longer into the summer compared to survival and emergence in the untreated plots. There was a significant ($P < 0.05$) increase in percentage of frequency of grasses and forbs in the tebuthiuron-only treatment compared to the untreated check. Tebuthiuron seems to be the best currently available option for reduction of sand shinnery oak and the associated litter layer.

MUCH RESEARCH has been directed towards control of the boll weevil, *Anthonomus grandis grandis* Boheman, during the growing season, but little information on boll weevil control by management of the overwintering habitat is available. Hunter (1909) suggested that litter in and near cotton fields should be raked and burned in the fall and winter to destroy winter habitat. Isely (1930) demonstrated experimentally the value of winter-habitat destruction, and he found that summer infestations could be reduced when winter habitat was eliminated. Walker and Hopkins (1956) used insecticides to control boll weevils in winter habitat litter. Slosser and Boring (1980) concluded that management of overwintering habitat for boll weevil control was a desirable objective in the Texas rolling plains, and Slosser et al. (1984b) have shown that shelterbelts can be effectively managed to reduce litter.

Sand shinnery oak, *Quercus havardii* Rydb., is a deciduous shrub, which occurs on ca. 1.4 million ha in eastern New Mexico, northwestern Texas, and western Oklahoma (Pettit 1979). This oak grows on sandy soils, and its distribution corresponds with major cotton producing areas in the aforementioned states. The close proximity of shinnery oak and cotton presents major problems for landowners. For the rancher, control of shinnery oak with foliar herbicides is often impractical because adjacent cotton may be damaged. Sand shinnery oak provides one of the best winter habitats for boll weevils in the Texas rolling plains (Boring 1972, Bottrell et al. 1972, and Slosser et al. 1984a), and the farmer's cotton crop suffers from infestations that originate from leaf litter of this shrub. Summer infestation rates in cotton are correlated with proximity to favorable overwintering habitat (Rummel and Adkisson 1970), and cotton planted near shinnery oak is likely to have continued boll weevil pressure. Additionally, shinnery oak competes with herbaceous forage plants and during the preleaf bud stage, shinnery oak is toxic to livestock (Sperry et al. 1968).

Sand shinnery oak can be controlled with phenoxy herbicides such as 2,4,5-T or silvex (Robinson and Fisher 1968). However, the period for most favorable results coincides with a period of early growth for cotton, which is highly susceptible to phenoxy herbicides. Tebuthiuron, another herbicide formulated as a 20% AI pellet, effectively controlled sand shinnery oak when applied at a rate of 0.6 to 1.1 kg (AI)/ha (Pettit 1979, Jacoby and Meadors 1982). Tebuthiuron was effective when applied in late winter and early spring before cotton planting, and the pelleted formulation reduced the potential for drift.

Our objectives in this study were to investigate several sand shinnery oak control strategies, determine floristic changes following the various treatments, determine the influence of selected shinnery oak control techniques on rate of leaf litter decomposition, and determine overwinter survival rates of boll weevils in control treatments. The goal was to develop a control strategy that would provide the fastest elimination of leaf litter and still provide acceptable levels of shinnery oak control.

Materials and Methods

The study area was located in Kent County, about 10 km northwest of Jayton, Tex. Rainfall averages 52 cm annually. The study site was located in a gently undulating area and supported a fairly uniform stand of sand shinnery oak with occasional small thickets of hybrid oaks. Soils were find sands of the Brownfield (Arenic Aridic Paleustalfs) and Nobscot (Arenic Haplustalfs) series (Richardson and Girdner 1973).

Seven treatments were arranged in a randomized complete block design with three replications. Plot size was 30.5 m wide by 91.4 m long. Treatments were: (1) tebuthiuron herbicide only, (2) shred + tebuthiuron, (3) burn + tebuthiuron, (4) shred + burn + tebuthiuron, (5) burn only, (6) glyphosate herbicide only, and (7) untreated check. Glyphosate was applied on 12 October 1979 with a power sprayer. Rate of application was 2.2 kg (AI)/ha in 190 liters of water. Tebuthiuron pellets (20% AI) were applied at a rate of 1.1 kg (AI)/ha with a hand-operated spreader to the tebuthiuron-only plots on 24 January 1980. Shinnery oak was shredded with a tractor-powered rotary shredder on 10 March 1980. Burn plots were burned on 11 March 1980. Tebuthiuron was applied to shredded or burned plots on 14 March 1980 at a rate of 1.1 kg (AI)/ha. A fence was installed around the plots during September 1979 to exclude cattle.

Leaf litter was collected from three 1-m^2 locations each fall from areas in each plot with remaining leaf litter. A pink bollworm gin trash machine was used to separate leaf and stem litter from soil and small organic debris. Shinnery oak stems were removed from the samples. Leaf samples were oven-dried at 140°C for 24 h and average weight of leaves per m^2 was calculated. Pretreatment samples were obtained 24 September 1979, and posttreatment samples were taken 12 November 1980, 14 October 1981, and 11 October 1982.

Visual estimates of the percentage of area covered by the shinnery oak canopy were taken in each plot to determine treatment effects. The estimates were made at the time leaf litter samples were taken in the fall. The same person made estimates in 1979, 1980, and 1982, but no estimates were made in 1981.

Cotton squares damaged by ovipositing boll weevils were collected weekly from mid-September through early November in Knox County, 40 km NE of our study site. Squares were taken to the laboratory at Vernon, and the immature boll weevils were reared under diapause-inducing conditions and adults were maintained under diapause-inducing conditions as described by Slosser et al. (1984a). After adults were fed on squares and small bolls for 2 to 4 weeks, they were taken to the shinnery oak plots, placed on the litter surface, and covered with a screen emergence cage. A collecting jar on the top of each cage was checked biweekly for emerging weevils from April through early July. Overwinter survival rates were used as a biological indicator of habitat suitability, as influenced by treatment, for the winter-spring periods of 1979–1980, 1980–1981, 1981–1982, and 1982–1983.

Boll weevil survival was compared only in the burn-only and untreated check plots during 1979–1980. Two pyramid-shaped cages, measuring 84 by 84 and 74 cm tall, were placed in each plot, and 300 boll weevils were placed in each cage on 20 and 21 November 1979. As fire reached the areas where boll weevils were caged during the controlled burn on 11 March 1980, the cages were removed until after the fire passed and then were immediately set back in place.

Boll weevil survival was compared in all seven treatments during the winter-spring periods of 1980–1981, 1981–1982, and 1982–1983. Three cone-shaped cages, measuring 33 cm in diameter at the base and 56 cm tall, were placed in each plot. Within each plot, cages were placed over areas with leaf litter because boll weevils do not select grassy areas for overwintering sites (Adkisson et al. 1965, Boring 1972). A total of 125 boll weevils were placed in each cage on 23 October and 16 November 1980; 150 were placed in each cage on 5 and 6 November 1981, and 225 were placed in each cage on 4 and 16 November 1982. The sample size varied because an equal number could not be collected each year. The cage sizes used did not influence survival rates (unpublished data).

Three permanent 30.5-m line transects, arranged in a Z pattern, were established in each plot. Botanical composition in each plot was based on percentage of frequency data collected along the lines at 0.3-m intervals and herbage yields were estimated by clipping standing biomass in quadrats, 1 m^2 each, in each plot as described by Jacoby et al. (1983). Grass data were collected by species, but forbs were harvested as a composite sample. Posttreatment samples were taken over several days during November 1980 and 1981 and during October 1982.

Data were subjected to analysis of variance and Duncan's (1951) multiple range test ($P < 0.05$). The inverse sine transformation was used for plant frequency data. The relationship between average percentage of boll weevils surviving and average weight of leaf litter in each of the treatments was analyzed by linear correlation. The inverse sine

Table 1. Average weight of leaf litter (g/m²) in a sand shinnery oak management study

Treatment	Year			
	1979[a]	1980	1981	1982
Tebuthiuron	806.3a	500.5ab	606.9bc	11.2a
Shred + tebuthiuron	709.7a	542.4ab	297.9ab	85.5a
Burn + tebuthiuron	714.0a	274.7a	145.0a	49.1a
Shred + burn + tebuthiuron	857.0a	343.0ab	136.0a	28.8a
Burn	642.0a	231.2a	339.8ab	312.3b
Glyphosate	709.7a	256.4a	511.0bc	342.0b
Untreated check	684.0a	637.2b	684.4c	619.6c

Values within a column followed by the same letter are not significantly different ($P < 0.05$; Duncan's [1951] multiple range test).
[a] Before treatment.

Table 2. Estimated percentage of area covered by sand shinnery oak

Treatment	Year[a]		
	1979[b]	1980	1982
Tebuthiuron	93.3b	71.7a	0.6a
Shred + tebuthiuron	60.0a	53.3a	2.2a
Burn + tebuthiuron	85.0b	63.3a	4.2a
Shred + burn + tebuthiuron	90.0b	53.3a	1.9a
Burn	95.0b	63.3a	66.9c
Glyphosate	56.7a	51.7a	39.4b
Untreated check	60.0a	73.3a	72.8c

Values within a column followed by the same letter are not significantly different ($P < 0.05$; Duncan's [1951] multiple range test).
[a] No data for 1981.
[b] Before treatment.

transformation was used for the percentage of boll weevil survival data and litter weights were transformed to $\log_{10}$ values. The map showing distribution of shinnery oak was developed from Landsat images taken 25 June 1980 and from consultation with U.S. Department of Agriculture, Soil Conservation Service personnel.

Results and Discussion

Changes in Litter. Pretreatment samples in 1979 indicated that all areas with sand shinnery oak contained equivalent amounts of litter (Table 1). The untreated check maintained a similar amount of litter from 1979 to 1982. Amounts of litter were similar among treatments in 1980, although treated plots contained less litter than in 1979. Burning reduced the litter, but the fire was cool and did not burn as much as we expected, probably because of the light fuel load. Fire had no apparent effect on the shinnery root system. Even though most shinnery oak stems were killed in the burn-only treatment, vigorous basal sprouting occurred during the spring of 1980 and restored the original amount of cover within 8 months. Defoliation in the burn plots during the fall added a new litter accumulation.

Plots treated with tebuthiuron did not respond to treatments immediately. After initial uptake, shinnery plants went through several defoliation and refoliation cycles until the plants eventually died. This process was evident well into the second growing season following treatment, when plants eventually died, and this response was typical of other tebuthiuron treatments on shinnery oak (Jacoby and Meadors 1982). Although the shinnery oak was gradually dying, the litter layer continued to accumulate. Poor shinnery oak control was obtained in the glyphosate treatment.

Significant changes in litter weight were apparent by October 1981, 19 months after treatment. There was less litter present in the tebuthiuron treatments combined with fire or shredding. Litter in the burn-only treatment had accumulated to half of the original amount, and litter in the tebuthiuron-only treatment was equal to that in the untreated check. There were significant differences in litter weights by October 1982, 31 months after treatment. The tebuthiuron treatments contained the least litter; the burn-only and glyphosate treatments were intermediate, and the check plots contained the most litter (Table 1).

Changes in Shinnery Oak Cover. Estimates of shinnery oak cover in each treatment are given in Table 2. The pretreatment estimates ranged from ca. 90% cover in four of the treatments to ca. 60% in the other three treatments. The reduced cover in some plots can be attributed to small grassy areas and to wind-caused blowout areas, which are depressed areas devoid of vegetation and surrounded by mounds of sand.

There were no significant differences in cover between treatments in November 1980. With the exception of the untreated plots, canopy cover declined in all treatments from 1979 (pretreatment) to 1980. The summer of 1980 was unusually hot and dry, and low rainfall probably reduced the uptake of tebuthiuron, which reduced shinnery oak response to treatments. By October 1982, there were significant differences in shinnery oak cover between treatments. The least cover occurred in the treatments where tebuthiuron was applied, but there were no differences among these treatments. The addition of shredding or burning to tebuthiuron did not reduce cover compared to the tebuthiuron only treatment. Shinnery oak cover in the burn only treatment was similar to that in the untreated check, and the cover in the glyphosate treatment was about half that of the untreated check.

Changes in Boll Weevil Survival Rates. The study site was adjacent to fields historically planted to cotton. However, boll weevils were absent from these cotton fields from 1979 to 1982 presumably because cold winters (1977 and 1978) and the hot, dry summer of 1980 suppressed populations. After 1981 the land was leased to another grower who did not plant cotton. Therefore, natural boll weevil populations did not occur adjacent to the shinnery oak plots as expected, and we could not determine

Table 3. Overwinter survival of boll weevils in a sand shinnery oak management study

Treatment	% Survival			
	1980[a]	1981	1982	1983
Tebuthiuron	—	1.15ab	2.07a	2.42a
Shred + tebuthiuron	—	0.44ab	1.19a	3.56a
Burn + tebuthiuron	—	0.80ab	2.67a	1.63a
Shred + burn + tebuthiuron	—	0.71ab	1.56a	2.42a
Burn	0.11a	0.62ab	3.04a	10.96c
Glyphosate	—	0.18a	3.19a	6.57b
Untreated check	0.50a	1.87b	2.00a	7.26b

Values within a column followed by the same letter are not significantly different ($P < 0.05$; Duncan's [1951] multiple range test).

[a] Plots burned 11 March 1980. In 1980, all survivors emerged by 29 May. The 1981, 1982, and 1983 data represent survivorship for the first, second, and third full years following treatments during the spring of 1980.

treatment effects on local migrating populations. Because we could not sample for native populations, we used caged boll weevils to determine overwinter survival.

Overwinter survival rates for boll weevils were similar in all tebuthiuron treatments throughout this study (Table 3). Total percentage of survival in the spring of 1981 ranged from 0.44% in the shred + tebuthiuron treatment to 1.15% in the tebuthiuron-only treatment, and these values were similar to the 1.87% survival rate in the untreated check. Of these treatments, only the amount of litter in the burn + tebuthiuron treatment (Table 1) was significantly smaller than the amount in the check, but the litter in this treatment provided adequate winter shelter, as evidenced by survival rates comparable to those in the check.

Boll weevil survival in the spring of 1982 ranged from 1.19% in the shred + tebuthiuron treatment to 2.67% in the burn + tebuthiuron treatment, and these values were similar to the 2.00% survival in the check. There was significantly less litter in three of the four tebuthiuron treatments in the fall of 1981 compared to the check (Table 1); but as in the preceding year, the remaining litter provided sufficient habitat, as evidenced by survival rates comparable to survival in the check.

Boll weevil survival in the spring of 1983 was significantly lower in the tebuthiuron treatments compared to the untreated check. Survival ranged from 1.63% in the burn + tebuthiuron treatment to 3.56% in the shred + tebuthiuron treatment compared to 7.26% in the check. The leaf litter remaining in the tebuthiuron treatments had been reduced to an average of 43.7 g/m^2 compared to 619.6 g/m^2 in the check (Table 1). About 2.2% of the area in these treatments contained living shinnery oak and leaf litter, compared to 72.8% of the area in the check (Table 2). Although overall survival was higher in the spring of 1983 compared to the preceding 2 years, the available habitat was reduced ca. 98% by the third year after treatment. As Slosser et al. (1984b) have shown, in the fall migrating boll weevils tend to avoid habitats of marginal quality (i.e., habitats with little leaf litter). Thus, higher survival rates in most treatments in 1983 were probably a reflection of very favorable winter conditions rather than an indication that the remaining habitat in the tebuthiuron treatments was capable of supporting high numbers of overwintering boll weevils.

The purpose of shredding and burning was to reduce or eliminate the litter and shinnery oak stems. Tebuthiuron was used to prevent continued accumulation of litter. The results of these treatments show that shredding and burning in combination with tebuthiuron did not hasten habitat decay (litter disappearance) or reduce boll weevil survival when compared to the tebuthiuron-only treatment.

There was no significant relation between percentage of survival and leaf litter weight the first 2 years after treatment. A significant relation was found between percentage of survival and leaf litter weight the third year, and $R^2 = 0.70$ was significant at the $P < 0.05$ level. Lowest survival rates occurred in plots containing the least litter. It took about 2.5 years for tebuthiuron to reduce the shinnery oak habitat effectively. Slosser et al. (1982) also reported that litter habitat changed slowly following application of picloram herbicide.

Overwinter survival rates in the burn-only and the untreated check are compared in Table 3. There was 0.11% survival in the burn-only plots,

Table 4. Percentage of major vegetational components in a sand shinnery oak management study 8, 20, and 32 months after treatment

Treatment	1980			1981			1982		
	Grass	Forbs	Oak	Grass	Forbs	Oak	Grass	Forbs	Oak
Tebuthiuron	27.8a	1.7ab	2.5a	58.1c	9.5a	0.8a	50.9b	30.7cd	0.6a
Shred + tebuthiuron	19.3a	0.5ab	7.6abc	57.8c	8.2a	0.3a	38.8ab	39.6d	0.6a
Burn + tebuthiuron	23.4a	1.0ab	3.8ab	58.3c	11.0a	0.1a	36.4ab	38.5d	2.1a
Shred + burn + tebuthiuron	29.2a	0.3a	3.9ab	66.2c	11.1a	0.7a	36.4ab	46.4d	0.7a
Burn	22.6a	0.4a	21.2d	32.0ab	9.0a	30.7c	25.8a	8.3a	26.8bc
Glyphosate	30.0a	0.9ab	13.6bcd	49.7bc	11.7a	17.2b	37.1ab	20.3bc	21.2b
Untreated check	17.3a	3.3b	17.7cd	24.4a	12.6a	31.3c	19.4a	12.3ab	34.1c

Values within a column followed by the same letter are not significantly different ($P < 0.05$; Duncan's [1951] multiple range test).

while 0.50% survived in the check plots in 1980. Although these values are not significantly different at the $P < 0.05$ level, they are significantly different at the $P < 0.10$ level. This suggests that fire killed some boll weevils in the leaf litter. Survival in the burn-only and check plots were similar in 1981 and 1982, the first and second full years following the burning. In the spring of 1983, 10.96% of the boll weevils survived in the burn-only plots compared to 7.26% in the check plots, a significant difference at $P < 0.05$. Fire reduced overwinter survival rates in 1980 and 1981, while in 1982 and 1983, survival was higher in the burn only plots compared to survival in the check plots. In a previous study, Slosser et al. (1982) reported that fire suppressed survival rates for only 1 year following burning.

Spring emergence patterns were altered by fire. In 1980 boll weevils emerged only on 25 March in the burn-only plots, whereas emergence continued through 29 May in the check plots. This same trend occurred in 1981. Spring emergence ended on 29 May in the burn only plots, but emergence continued through 12 June in the check plots. However, in 1982 and 1983 the trend of later emergence from check plots was reversed. The last boll weevils emerged from the check plots on 18 May, but the last boll weevils emerged from the burn-only plots on 10 June 1982. In 1983, the last boll weevils emerged from the check plots on 2 July, whereas the last boll weevils emerged from the burn-only plots on 14 July. Boll weevil spring emergence terminated earlier in the burn-only treatment immediately after and 1 year after the fire, compared to that in the check plot. However, 2 and 3 years after the fire, spring emergence lasted longer in the burn-only treatment. The litter structure may have been altered, and the interstices may have been bigger than those in the check, where the action of rain and wind compressed them. The altered microenvironment may have provided better insulation, which improved survival and delayed spring emergence in 1982 and 1983.

Overwinter survival rates for boll weevils in the glyphosate treatment are shown in Table 3. In the spring of 1981, survival in the glyphosate treatment was similar to that in other treatments, except the check. Overwinter survival rates in the glyphosate and check plots were equal in 1982 and 1983 (Table 3). The glyphosate treatment did reduce the area covered by shinnery oak (Table 2) and the amount of litter (Table 1) 3 years after treatment. However, these reductions in habitat did not significantly reduce boll weevil survival rates, and glyphosate did not control the shinnery oak.

Changes in the Plant Community. The percentage of grass was similar in all plots in 1980 (Table 4), the growing season following treatments. Forbs occurred more frequently in the untreated plots than in the treatments that were burned. Significant reductions in live shinnery oak frequency were evident in the tebuthiuron treatments.

By 1981, grass had become the dominant vegetational component in the tebuthiuron treatments, but percentage of forbs became similar in all treatments. The frequency of grass was greater in glyphosate plots than in untreated plots. Shinnery oak was significantly less frequent in the tebuthiuron treatments, and most shinnery oak occurred in the burn-only and untreated check plots.

Percentage of forbs increased dramatically in 1982 (Table 4) as a result of favorable rains during spring. The increase in forb frequency apparently reduced grass frequency. The only significant differences in frequency of grasses occurred between the tebuthiuron-only treatment, which had the most grass, and the burn-only and untreated plots, which had the least grass. The frequency of forbs was significantly lower in the burn only and untreated plots also, and forbs occurred most frequently in the tebuthiuron treatments. The frequency of shinnery oak was significantly lower in the tebuthiuron treatments, and shinnery oak occurred most frequently in the burn-only and untreated check plots. Vegetation changes during the study were most evident in plots treated with tebuthiuron, regardless of companion treatment. Grass became dominant as shinnery oak was reduced by tebuthiuron. Frequency of perennial grasses increased through the study.

Herbage yield (kg of grass and forbs/ha) followed trends similar to percent frequency changes (Table 4). No significant differences were seen between treatments the first year, owing to the drought of 1980. Grass yield in 1981 was significantly higher in tebuthiuron-treated plots than in the burn-only and untreated plots. Forb production was similar in all plots in 1981. Forb and grass yields were greater in the tebuthiuron plots in 1982 than in the burn only and untreated plots. Tebuthiuron without companion treatments yielded more grass than the other tebuthiuron treatments in 1982. In 1982, there were 403 kg/ha of grass plus forbs in the untreated check, while there were 2,988 kg/ha in the tebuthiuron-only treatment.

Management Implications of Shinnery Oak. There are ca. 230.2 thousand ha of sand shinnery oak in the Texas rolling plains (Fig. 1), and 48% occurs in five western counties, Crosby, Garza, Motley, Dickens, and Kent. These five counties are in the boll weevil suppression zone, established in 1964 to prevent the movement of fall migrating boll weevils onto the Texas high plains (Rummel et al. 1975). One reason the suppression program has continued for the past 21 years is the large amount of favorable winter habitat within the suppression zone. Migrating boll weevils from east and south of the control zone provide a constant inoculum, and it is probably these migrants that mandate the continued suppression efforts, because they find abundant winter habitat. Elimi-

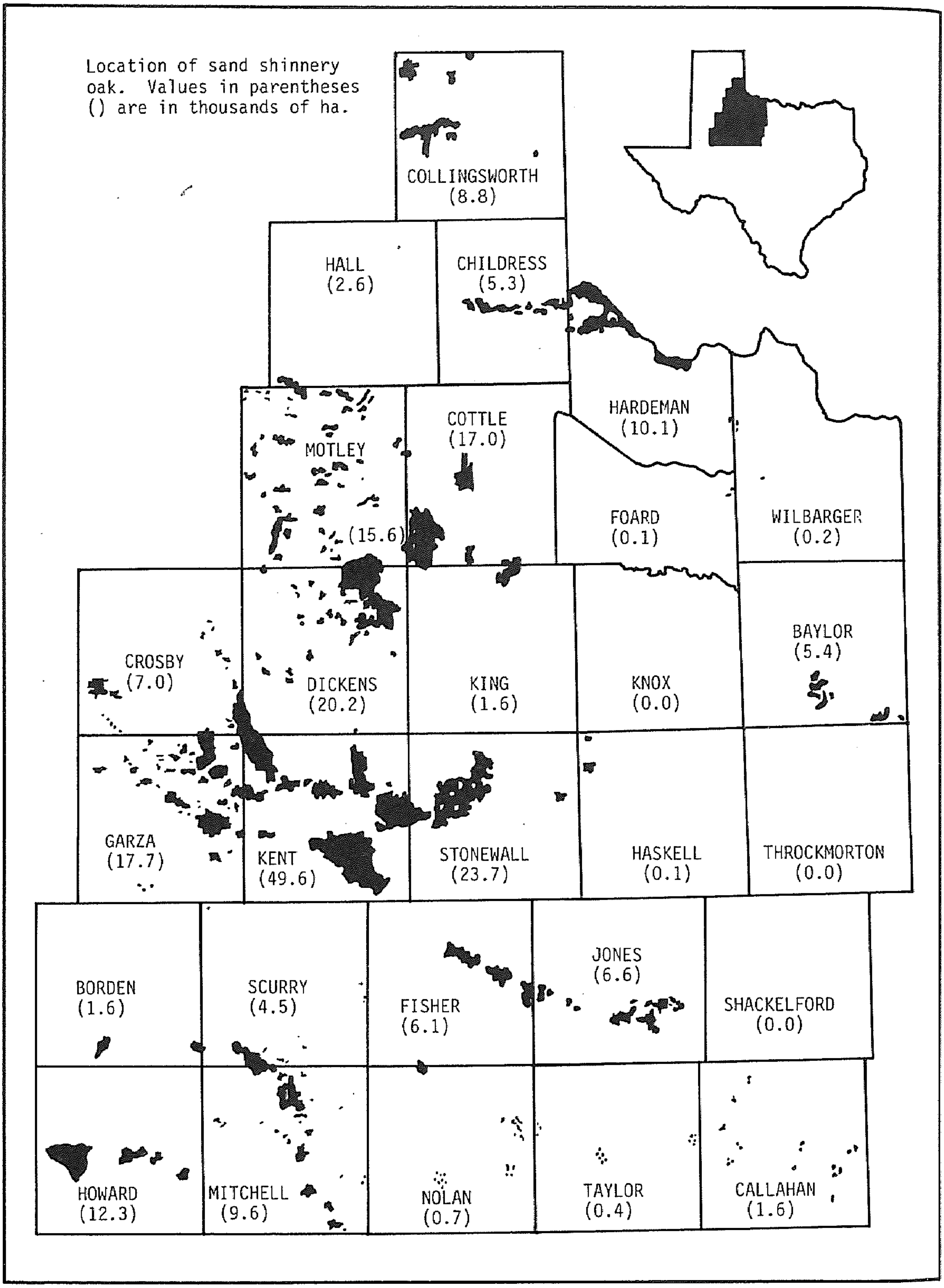

Fig. 1. Distribution and area (ha) of sand shinnery oak in 28 counties in the Texas rolling plains.

nation of shinnery oak would provide an additional strategy for reducing the boll weevil threat to rolling and high plains cotton production.

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