J. Range Manage.
54:138-143 March 2001

# Chain diker effects on seeded grass establishment following disk chaining

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## Abstract

**Placing basins in rangeland seedbeds to capture rainfall has enhanced seeded grass establishment, but it has not been practical on debris-littered land following rootplowing for brush control. A disk chain tested previously will traverse land littered with debris or shrubs while tilling the soil for seedbed preparation. A chain diker is an implement designed to form 10-cm deep basins with a volume of 3.9 ± 0.9 liters on tilled land. Combining the 2 implements provided tillage, land smoothing and basin formation in the soil with a single pass on debris littered land. Our 4-year study compared established grass densities on disk-chained seedbeds with and without chain diking at 5 locations in west Texas where land was rootplowed for honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) control. At 4 locations seedbeds were aerially seeded with 2 kg $ha^{-1}$ pure live seed (PLS) of WW Spar bluestem (*Bothriochloa ischaemum* (L.) Keng). At 1 location a mixture of 6 grasses, including Spar bluestem, was aerially seeded at 2.8 kg $ha^{-1}$ PLS. Evaluations were based on established grass densities at the end of the first growing season. At 3 locations, a seeding-before-diking treatment was included to simulate seed dropping from a seedbox mounted over the disk-chain's roller. In the Rolling Plains region of northwest Texas (4 sites), when growing-season rainfall was less than 400 mm, chain-diked seedbeds increased grass densities 2.6 times (P = 0.05) compared to non-diked seedbeds. When growing-season rainfall was greater than 500 mm, grass densities on diked seedbeds were similar to non-diked seedbeds. In the Trans-Pecos region of far-west Texas (1 site), where average growing-season rainfall is 337 mm, diked seedbeds produced 33% greater grass densities (P = 0.05) than non-diked seedbeds with rainfall of 552 mm. Densities of kleingrass (*Panicum coloratum* L.) and Spar bluestem were significantly greater in the diked seedbeds compared to non-diked seedbeds, and the other 4 grasses were not significantly influenced by seedbed methods. Grass densities were similar whether seeding after diking or before diking. Since long-term, growing-season rainfall has averaged below 500 mm between 65% to 87% of the time at these locations, our data suggests that it would be advantageous to include chain diking in combination with disk chaining for grass establishment on rootplowed land littered with brush debris.**

## Resumen

**El poner cuencas en la cama de siembra de pastizales para capturar la lluvia aumenta el establecimiento de zacates, pero no ha sido practico en terrenos con gran cantidad de mantillo y basura proveniente del control de arbustos con arado de subsuelo. Una cadena de disco, probada previamente, cruzaría el terreno con los residuos de plantas realizando una labor de labranza para preparar la cama de siembra. La cadena diqueadora. es un implemento diseñado para formar en terrenos labrados cuencas de 10 cm de profundidad de un volumen de 3.9 ± 0.9 liters. La combinación de los dos implementos provee la labranza, el mullido del suelo y la formación de cuencas con un solo paso en el terreno. Nuestro estudio de 4 años comparo la densidad de zacates establecidos en camas de siembra formadas con cadena de discos con y sin el paso de la cadena diqueadora, este estudio se realizó en 5 localidades del oeste de Texas donde se controlo el mezquite (*Prosopis galndulosa* Torr. var. *glandulosa*) mediante arados de subsuelo. En 4 localidades la siembra se realizó con avión a una densidad de 2 kg $ha^{-1}$ de semilla pura viable (SPV) de "WW Spar bluestem" (*Bothriochloa ischaemum* (L.) Keng), en la otra localidad se sembró un mezcla de 6 zacates incluyendo "Spar bluestem", la siembra se realizó con avión a una densidad de 2.8 kg $ha^{-1}$ de SPV. Las evaluaciones se basaron en las densidades de zacates establecidos al final de la primer estación de crecimiento. En 3 localidades se incluyó un tratamiento consistente en la siembra antes del diqueo para simular la caída de semilla de la caja de siembra montada sobre el rodillo de la cadena disqueadora. En la región de Rolling Plains al noroeste de Texas (4 sitios), cuando la lluvia durante la estación de crecimiento fue menos de 400 mm, las densidades de zacates en las camas de siembra con cuencas se incrementó 2.6 veces (P = 0.05) en comparación con las camas de siembra sin cuencas. Cuando la lluvia durante la estación de crecimiento fue mas de 500mm las densidades de zacates fueron similares en las camas de siembra con y sin cuencas. En la región de Trans-Pecos, situada muy al oeste de Texas (1 sitio), donde el promedio de precipitación durante la estación de crecimiento es de 337 mm, la densidad de zacates en las camas de siembra con cuencas fue mayor en 33% (P = 0.05) que las densidades de las camas de siembra sin cuencas con una precipitación de 552 mm. Las densidades de zacate "klein" (*Panicum cloratum* L.) y "Spar bluestem" fueron significativamente mayores en las camas de siembra con cuencas que en las sin cuencas, la densidad de los otras cuatro especies de zacates no fue influenciada significativamente por la preparación de la cama de siembra; las densidades de zacates fueron iguales sembrandolos antes o después de la formación de los diques. Dado que en estas localidades la lluvia durante la estación de crecimiento ha promediado arriba de 500 mm entre el 65 y el 87% de las veces, nuestros datos sugieren que sería ventajoso incluir la cadena de diqueo en combinación con la cadena de discos para el establecimiento de**

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The authors are grateful for the cooperation and funding provided by the E. Paul and Helen Buck Waggoner Foundation and the W.T. Waggoner Estate, Vernon, Tex.; Pitchfork Land and Cattle Co., Guthrie, Tex.; Weatherby Ranch, Big Lake, Tex.; University Lands, Midland, Tex.; Brush Control and Range Improvement Association, Albany, Tex.; Hardcastle Ag-Air, Vernon, Tex.; Post Contractors, Post, Tex.; Chucks Dozer Service, Big Lake, Tex.; and Lucans Flying Service, Pecos, Tex.. We want to thank Gerral Schulz, Texas Agr. Exp. Sta., Vernon, Tex., who fabricated the equipment, and the Texas Agr. Ext. Ser. and NRCS at Vernon, Tex. and Big Lake, Tex., for their assistance with site locations and soils maps.

Manuscript accepted 8 May 2000.

**zacates en tierras con residuos de arbustos sujetos a control con arado de subsuelo**

**Key Words: seedbed, rangeland seeding, brush control, honey mesquite, *Prosopis glandulosa***

Alteration of soil surface topography by basin tillage (pitting) favorably changes soil water availability for seed germination on rangeland (McGinnes 1959). Evans and Young (1987) found 343 times more seedlings in 9-cm pits than on smooth soil. Similarly, the utilization of small dikes between rows, also called basin tillage, to trap rainfall for increased dryland row crop production was tested in the 1930s, but lack of adequate equipment and poor weed control delayed its commercial use until recent times (Lyle and Dixon 1977, Jones and Clark 1987). Advantages of basin tillage were the basis for development of the arid land seeder in New Mexico (Abernathy and Herbal 1973), the range improvement machine in Montana (Erickson and Currie 1982), land imprinter in Arizona (Dixon and Simanton 1977), and the Forest Service Hodder Gouger (Lawson 1980). Although innovative, each has been too costly or impractical for extensive range seedings especially on debris-littered rootplowed land. A summary statement in the 1990 Seedbed Ecology Symposium was "the need for novel equipment for range seeding is critical" (Young 1990).

A disk-chain implement developed by Wiedemann and Cross (1982) used an anchor chain modified by the addition of disk blades welded to alternate chain links and swivels at each end of the chain to till the soil as it was pulled diagonally. It was effective in preparing seedbeds on debris-littered land and was energy efficient (Wiedemann and Cross 1987). Seedbeds prepared by disk-chaining increased seeded grass stands by 100% in clay loam soil and 42% in sandy loam soil compared to seedbeds prepared by a smooth chain on land rootplowed for honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) control (Wiedemann and Cross 2000).

A chain diker developed by Bruce Smallacombe in Australia to trap rainfall on fallow wheat land used specially shaped paddles welded to an anchor chain to form about 45,000 diamond-shaped basins per hectare in tilled soil as the chain rotated (Wiedemann and Smallacombe 1989). Each basin was about 10-cm deep with a volume of 3.9 ± 0.9 liter. Force required to pull the modified chain was 0.94 kN $m^{-1}$ of width as determined by Wiedemann and Cross (1994).

**Fig. 1. Chain diker attached to rear of the disk chain was designed to form basins in soil tilled by the disk chain during seedbed preparation on land littered with brush debris. The implement is called a disk-chain-diker (Wiedemann and Cross 1994).**

Combining the disk chain and the chain diker as a single unit (Fig. 1) resulted in an implement that provided tillage, land smoothing and basin formation in one operation. Additionally, it was designed to traverse brush debris. The combined unit was termed a "disk-chain-diker." Required force to pull the disk-chain-diker was 2.29 ± 0.09 kN per disk blade, and 20% of that force was attributed to the chain diker (Wiedemann and Cross 1994). At 5 km $h^{-1}$ (the recommended rangeland speed), 3.16 kW per blade of power would be required for pulling.

Information is lacking on the chain diker's efficacy for rangeland seeding. The objective of this study was to compare chain-diked seedbeds with non-diked seedbeds by comparing the density of established grass plants following the first growing season after seeding rootplowed land tilled by a disk chain.

## Materials and Procedures

### Study Sites

Four research sites were located in the Rolling Plains vegetational resource region of northwest Texas. Three were 40 km south of Vernon (33°57' N, 99° 05' W, elevation 367 m) (Waggoner Ranch) and 1 was 15 km southwest of Guthrie (33°33' N, 100°27' W, elevation 535 m) (Pitchfork Ranch). A fifth site was in the Trans-Pecos resource region of far-west Texas, 8 km north of Big Lake (31°16' N, 101°31' W, elevation 816 m) (Weatherby Ranch). Average annual rainfall is 641mm near Vernon, 545 mm at Guthrie, and 472 mm near Big Lake. Rainfall is highly variable, and the mean distribution is bimodal, with a peak in May and another in September. Rainfall during the 4-year study is presented in Table 1. The average frost-free growing season is more than 200 days, extending from March into November. Growing-season rainfall was tabulated for the period April through October, and the long-term average is 471 mm at Vernon, 437 mm at Guthrie, and 374 mm at Big Lake.

All sites had productive soils suitable for grass seeding. Sites were nearly level to gently sloping uplands (0 to 3% slope), and soils were deep, well drained, and slow to moderately permeable. Soils were classified at the Vernon sites as Tillman clay loam (mixed, thermic Typic Paleustolls), at the Guthrie site as Paducah loam (mixed, thermic Typic Haplustalfs), and at Big Lake site as Reagan loam (mixed, super active, thermic Ustic Haplocalcids). Texture was clay loam at Vernon, varied from mostly loam to a sandy loam at Guthrie, and varied from mostly loam to a clay loam at Big Lake. All sites were infested with regrowth honey mesquite varying in height from 1.8 to 3.0 m. Sites had been aerially sprayed, chained, and re-sprayed several times over

**Table 1. Annual and monthly rainfall near the Vernon, Guthrie, and Big Lake sites for the specified year.[1] Growing-season rainfall is April through October.**

| Month | Vernon | | | Big Lake | Guthrie[2] |
|---|---|---|---|---|---|
| | 1988 | 1989 | 1991 | 1990 | 1991 |
| | ---(mm)--- | | | | |
| Jan. | 22 | 26 | 70 | 9 | - |
| Feb. | 5 | 79 | 0 | 41 | - |
| Mar. | 51 | 11 | 13 | 30 | - |
| Apr. | 28 | 6 | 2 | 121 | 0 |
| May | 3 | 122 | 129 | 91 | 73 |
| Jun. | 115 | 112 | 110 | 0 | 163 |
| Jul. | 50 | 13 | 91 | 97 | 8 |
| Aug. | 9 | 88 | 69 | 58 | 207 |
| Sep. | 152 | 145 | 131 | 124 | 29 |
| Oct. | 10 | 18 | 66 | 61 | 76 |
| Nov. | 20 | 0 | 7 | 46 | - |
| Dec. | 27 | 6 | 117 | 17 | - |
| Total | 492 | 626 | 805 | 695 | - |

[1]Climatological Data, NOAA, Asheville, N.C. 28801 at Lake Kemp near Vernon, Tex., Guthrie Tex., and Cope Ranch near Big Lake, Tex.
[2]At-site measurement during growing season near Guthrie (Pitchfork Ranch).

the past 30 years except the Big Lake site which had only been chained once.

## Equipment

Integral mounted rootplows were pulled with large crawler tractors (175 kW or larger) at depths of 30 to 35 cm to sever honey mesquite roots below the bud zone. The disk chain was constructed from 76-mm-diameter anchor chain with 711-mm-diameter, notched, disk blades welded to alternate chain links. Two, 10-blade gangs with swivels on either end were attached in a triangular configuration and held in place by a 508-mm-diameter flexing roller for a center brace 10.8-m wide (Fig. 1). The unit was pulled by a 104 kW or larger crawler tractor.

The chain diker used the same size anchor chain as the disk chain. Two steel plates 280 x 100 x 13 mm were bent slightly (38 mm depth midway along the length) and welded longitudinally on opposite sides of the chain link to form paddles (Fig. 2). Two, 4.9-m-long diking chains with swivels on each end were pinned in series and attached to the rear of the large rolling brace of the disk chain, 32 links in all. All attachments were flexible so the unit could traverse logs and stumps. Additional disk chain and chain diker details plus construction drawings have been previously described (Wiedemann 1990). When chain diking was used as a separate operation, the disk-chain gangs were replaced by a small smooth chain and the roller and diking chain was pulled as a unit. A 58-mm-diameter anchor chain pulled in a U-shape between 2 crawler tractors (104 kW or larger) accomplished the "smooth" chaining operation.

An Air Tractor 502 aircraft with a 582-kW turbine engine (Air Tractor, Inc., Olney, Tex. 76374) and an Ag-Truck aircraft (Cessna Aircraft Co., Wichita, Kans. 67277) were both equipped with Transland spreaders (Transland Inc., Harbor City, Calif. 90710) for aerial seeding. Seeds were metered through a standard gate box on both planes, and special blending with cracked grain was required to meter chaffy seed. Swath widths were 12 m (Ag-Truck) or 15 m (Ag-Tractor), and flight lines were 366- to 732-m long. The Ag-Truck was used at the Big Lake site only.

## Treatments and Experimental Design

Rootplowing for honey mesquite control was conducted in winter months. Seedbeds were prepared 1 to 14 days prior to spring seeding. Disk-chained seedbeds with dikes were prepared with a single pass of the disk-chain-diker. Disk-chained seedbeds without dikes were prepared with the diking chain removed from the disk chain. At 3 sites, seeding was conducted between the disk chaining and diking operations. This simulated seed being dropped behind the roller from a seedbox mounted over the roller. At 1 site, a chained seedbed was prepared by 2 passes of the smooth anchor chain pulled in opposite directions. Treatments were installed in 1988 (Year-1, Vernon), 1989 (Year-2, Vernon), 1990 (Year-3, Big Lake), and 1991 (Year-4, Vernon & Guthrie). Plot size varied from 31 x 122 m to 61 x 305 m (width x length). Treatments were replicated 4 times at each site.

In Year-1, disk-chaining+diking, disk-chaining, and smooth-chaining treatments were installed at the Vernon site (clay loam). In Year-2, disk-chained seedbeds with and without diking were installed at

**Fig. 2. Paddles on an anchor chain form basins in the soil as the chain rotates; unit is called a chain diker (Wiedemann and Cross 1994).**

**Table 2. Grass species and seeding rate (pure live seed) at each site.**

| Year | Site | Grass Species | Rate |
|---|---|---|---|
| | | | (kg/ha) |
| 1 | Vernon | 'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) | 2.8 |
| 2 | Vernon | 'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) | 2.3 |
| 3 | Big Lake | 'Haskel' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.) | 1.01 |
| | | 'Selection 75' kleingrass (*Panicum coloratum* L.) | 0.45 |
| | | 'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) | 0.40 |
| | | Green sprangletop (*Leptochloa dubia* (H.B.K.) Nees) | 0.38 |
| | | Plains bristlegrass (*Setaria macrostachya* H.B.K.) | 0.34 |
| | | Blue panic (*Panicum antidotale* Retz.) | 0.22 |
| | | Total | 2.80 |
| 4 | Guthrie | 'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) | 2.3 |
| 4 | Vernon | 'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) | 2.1 |

the Vernon location. In Year-3, disk-chaining+diking, disk chaining, and seeding before the diking operation were installed at the Big Lake site (loam). In Year-4, the same 3 treatments as Year-3 were installed at Vernon (clay loam) and Guthrie (loam).

'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) was seeded at 2.2 kg $ha^{-1}$ pure live seed (PLS) at 4 sites, and it was part of a mixture with 5 other grasses at Big Lake, (Table 2). When Spar was seeded alone, it was blended in a 1 to 3 (seed to grain) mixture of cracked grain to aid in seed metering from an aircraft (Wiedemann and Cross 1990).

Seeding dates were 25 May 1988, 21 April 1989, 26 February 1990, 13 March 1991 (Guthrie), and 13 April 1991 (Vernon). Each swath of the aircraft was perpendicular to all seedbed preparation methods in a block to minimize the effect of any irregularities in the seeding rate during seeding. A randomized-block experimental design was used each year.

Plots were evaluated at the end of the first growing season (November). Established plant densities were determined from 100, 0.1 $m^2$ quadrat samples per plot. Plant densities of 5 plants $m^{-2}$ or greater were considered to be successful for rangeland seeding (GPAC 1966).

## Statistical Analysis

Analysis of variance was used each year to determine effects of seedbed methods on established plant densities (plants $m^{-2}$). Means were separated by a protected Least Significant Difference method at P=0.05 (SAS System v6.12, SAS Institute, Inc., Cary, N.C. 27511). Standard errors were calculated for all means.

# Results and Discussion

## Rainfall

The selected sites from west to far-west Texas were intended to provide a growing-season rainfall gradient decreasing from 471 mm to 337 mm. In reality, 1 site received 367 mm, 21% below normal, and all others sites were above 500 mm. This included a site at 64% above normal rainfall. These amounts of rainfall masked the value of collection basins for low-rainfall conditions.

## Year-1 Vernon

Established grass densities were influenced by seedbed methods ($P = 0.036$). Grass densities on disk chained and diked seedbeds were significantly greater ($P = 0.05$) than those on non-diked disk-chained seedbeds or those on smooth chained seedbeds (Table 3). Rainfall during the growing season at this site was 367 mm, 21% below normal. Diking increased grass densities 2.6 times over non-diked seedbeds when rainfall was below normal, less than 400 mm. Only the grass densities on the diked seedbeds reached or exceeded the successful level (≥ 5 plants $m^{-2}$).

At a nearby research farm (50 km) the same year, chain diking in a wheat (*Triticum aestivum* L.) production test significantly increased grain production compared to no diking when rainfall was 22% below normal during the growing season. When rainfall in later years was normal (444 mm) to 48% above normal, diking did not improve yields. Diking reduced runoff by 40% over the 3-year period compared to no diking (Wiedemann and Clark 1996). We would anticipate a similar reduction in runoff on tilled rangeland.

## Year-2 Vernon

Grass densities on diked seedbeds following disk chaining were not significantly greater ($P > 0.10$) than those on non-diked seedbeds (Table 3). Rainfall was 504 mm or 9% above normal. Rainfall amounts greater than 100 mm in both May and June increased grass establishment in all plots and nearby commercial seedings. Diking did not enhance grass establishment when growing-season rainfall was above 500 mm, and all stands were at least twice the successful level of 5 plants $m^{-2}$. Similar results were observed by Wiedemann and Clark (1996).

## Year-3 Big Lake

Analysis of variance showed that the established grass densities varied with seedbed preparation ($P = 0.038$) and grass species ($P = 0.001$). Diking significantly increased grass densities by 33% when compared to non-diked seedbeds (Table 3). However, grass densities were similar when seeding was conducted after diking or between the disk chaining and diking operations. This indicates that results from seed dropped on the soil surface from a seedbox mounted above the roller before diking would be no different from seed dropped from an aircraft or other device after diking. At this normally low-rainfall area, growing-season rainfall was 552 mm or 64% above normal. Even though rainfall amounts greater than 90 mm in April, May, and July enhanced grass establishment, the improvement due to the basins remained.

**Table 3. Effects of seedbed preparation methods on established grass densities ($\bar{x}$ ± SE).**

| Seedbed Method | Grass density |
|---|---|
| | (Plants/$m^2$) |
| Year-1 Vernon | |
| Disk-chain+diking | 11.0 ± 2.7a[1] |
| Disk-chain, no diking | 4.2 ± 1.0b |
| Smooth chaining | 2.4 ± 0.8b |
| Year-2 Vernon | |
| Disk-chain+diking | 13.5 ± 1.7a |
| Disk-chain, no diking | 12.2 ± 1.1a |
| Year-3 Big Lake[2] | |
| Disk-chain+diking | 6.4 ± 1.0a |
| Disk-chain, no diking | 4.8 ± 0.7b |
| Disk-chain/seed/diking | 5.3 ± 0.7ab |
| Year-4 Guthrie | |
| Disk-chain+diking | 4.7 ± 0.6a |
| Disk-chain, no diking | 4.8 ± 0.6a |
| Disk-chain/seed/diking | 5.4 ± 0.6a |
| Year-4 Vernon | |
| Disk-chain+diking | 24.5 ± 7.8a |
| Disk-chain, no diking | 26.0 ± 7.1a |
| Disk-chain/seed/diking | 32.4 ± 4.9a |

[1]Means in the column within the same site followed by the same letter are not significantly different at the 5% level.
[2]Species' main effect and the significant interaction is discussed in text and Table 4.

**Table 4. Influence of grass species and the effect of seedbed preparation methods on seeded grass species at the Big Lake site ($\bar{x} \pm$ SE).**

| Grass species | Species Means | Seedbeds Diked | Non-diked | Seeded/diked |
|---|---|---|---|---|
| | ----(Plants/m$^2$)---- | | | |
| Kleingrass | 1.6 ± 0.2A[1] | 2.2 ± 0.4a[2] | 1.1 ± 0.0.3b | 1.6 ± 0.1b |
| Green sprangletop | 1.4 ± 0.2A | 1.4 ± 0.3a | 1.6 ± 0.3a | 1.1 ± 0.4a |
| Spar bluestem | 1.0 ± 0.2B | 1.6 ± 0.3a | 0.7 ± 0.1b | 0.9 ± 0.2b |
| Sideoats grama | 0.5 ± 0.1C | 0.4 ± 0.1a | 0.5 ± 0.1a | 0.7 ± 0.1a |
| Plains bristlegrass | 0.5 ± 0.1C | 0.4 ± 0.1a | 0.5 ± 0.1a | 0.5 ± 0.3a |
| Blue panic | 0.5 ± 0.1C | 0.4 ± 0.2a | 0.4 ± 0.1a | 0.5 ± 0.2a |

[1]Means within the species' column (main effect) followed by the same uppercase letter are not significantly different at the 5% level.
[2]Means within a row comparing 3 seedbeds (interaction effect) that are followed by the same lowercase letter are not significantly different at the 5% level.

Stand densities of kleingrass and green sprangletop were significantly greater than densities of Spar bluestem which was significantly greater than densities of sideoats grama, plains bristlegrass and blue panic (Table 4). Densities of the top 3 species were at or greater than 1 plant m$^{-2}$, while densities of the other species were at or below 0.5 plants m$^{-2}$. Stands of individual grass species were very sparse, but the total stand density of 5.5 plants m$^{-2}$ was considered successful, especially for this region.

The interaction between seedbed methods and grass species was significant (P = 0.004). Mean comparisons of the interaction for the different seedbeds are listed in Table 4. Kleingrass and Spar bluestem densities in the disk-chain-diked seedbed were significantly greater than non-diked or the seeded-before-diking seedbeds. Grass densities were not different among seedbeds for each of the other 4 grasses, green sprangletop, sideoats grama, plains bristlegrass, and blue panic; this caused the significant interaction. Green sprangletop densities, however, were much greater than the other 3 grass densities.

These data indicate that kleingrass and green sprangletop were aggressive in their establishment regardless of the seedbed preparation. Spar bluestem and kleingrass densities were increased 98% and 129%, respectively, by the diked seedbeds compared to non-diked seedbeds. These 3 grasses were far superior in their establishment compared to the other grasses.

### Year-4 Guthrie

Grass densities did not differ (P > 0.10) among the 3 seedbed methods, disk chaining with or without diking or seeding before the diking operation (Table 3.). Average grass density was 4.9 plants m$^{-2}$. Rainfall at the site was 556 mm which was 27% above the average for the area during the growing season. During June and August, rainfall amounts greater than 160 mm greatly influenced the success of this seeding. It appears that the basins do not influence the establishment of grass when rainfall amounts are at this level, and there is good spring rainfall for emergence and growth. All grass stands were near or above the successful level. As in previous plantings, seeding before or after diking did not make a difference.

### Year-4 Vernon

Grass densities did not differ (P > 0.10) among the 3 seedbed methods which were the same as those at the Guthrie site (Table 3.). Rainfall during the growing season was 598 mm, 30% above average. Starting in May there were 3 months with rainfall greater than 100 mm and the rest were above 60 mm. This contributed to an outstanding stand of grass, 27.6 plants m$^{-2}$. Again, diking did not influence stand establishment with this amount of rainfall.

## Conclusions and Management Implications

In the Rolling Plains region of northwest Texas (Vernon and Guthrie sites), when growing-season rainfall was below 400 mm, chain-diked seedbeds increased seeded grass densities of Spar bluestem by 2.6 times compared to non-diked seedbeds following disk chaining of rangeland rootplowed for brush control. When growing-season rainfall was greater than 500 mm, grass densities were not improved by diking. Long-term rainfall records at Vernon indicate that 65% of the time rainfall would be less than 500 mm; therefore, it would be advisable to use chain diking during seedbed preparation.

In the Trans-Pecos region of far-west Texas (Big Lake site), where average growing-season rainfall is 337 mm, diked seedbeds had 33% greater grass densities than non-diked seedbeds even though rainfall was 552 mm. Densities of kleingrass and Spar bluestem were positively influenced by diking, while green sprangletop, sideoats grama, plains bristlegrass, and blue panic densities were not influenced by seedbed methods. Since growing-season rainfall has averaged less than 500 mm 87% of the time, it would be advantageous to use diking in the seedbed preparation process.

Seeding before diking did not result in significantly different grass densities than seeding after diking. These data indicate that seed broadcast from a seedbox mounted over the rolling brace and prior to chain diking would result in similar grass stands to seed dispensed aerially or other broadcast methods after chain diking.

Because of the high probability that growing-season rainfall will be less than 500 mm in western Texas, our findings suggest that it would be advisable to use diking as a necessary part of seedbed preparation. Chain diking in combination with disk chaining (disk-chain-diker implement) when preparing seedbeds for grass seeding on rootplowed land littered with brush debris offers enhanced results, energy efficiency, and a single-pass preparation without the need for costly raking (Wiedemann and Cross 1994, 2000).

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