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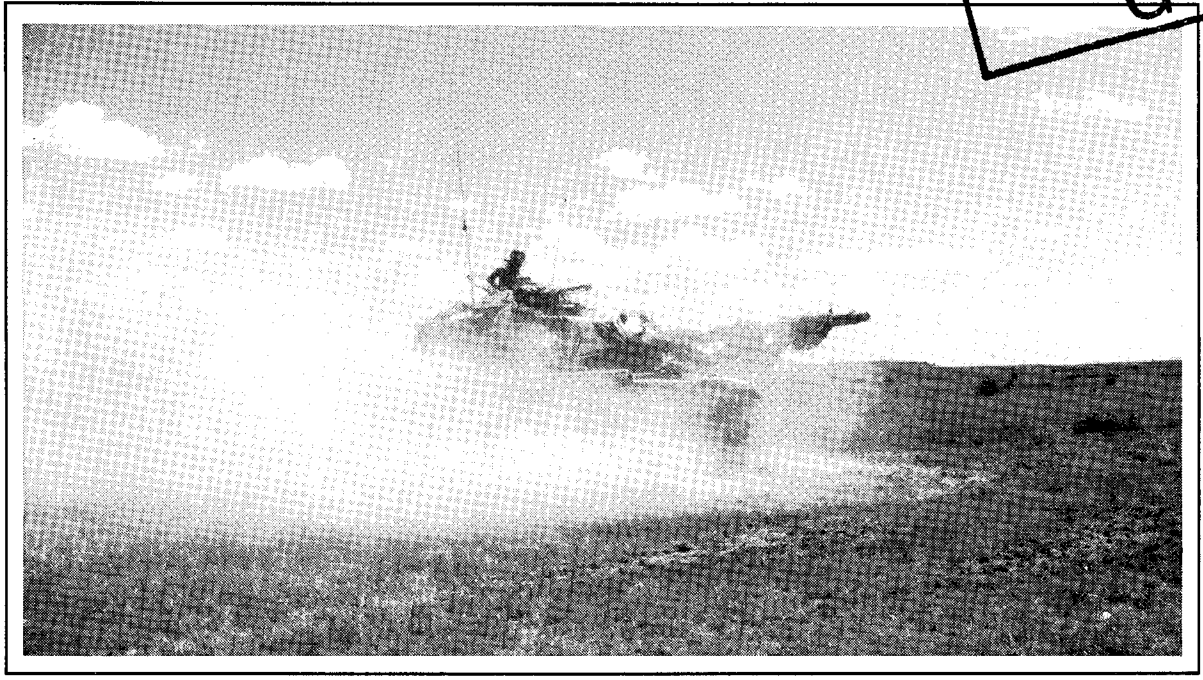
# Tracked Vehicle Traffic Effects on the Hydrologic Characteristics of Central Texas Rangeland

by
Thomas L. Thurow, Steven D. Warren, and Deirdre H. Carlson



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The initial change and the temporal recovery pattern of hydrologic, soil, and vegetation characteristics following tracked vehicle passage were documented. Treatments included wet and dry soil moisture conditions at the time of vehicle passage and tracking intensities of 0, 1, 4, and 10 passes by a Bradley Infantry Fighting Vehicle. The study was conducted at Fort Hood, Texas. Tracking on dry soil did not create significantly different infiltration rates or interrill erosion compared to untracked conditions. In contrast, tracking on wet soil created significantly lower infiltration and significantly greater interrill erosion rates, with the initial response and recovery period being greater as the number of vehicle passes increased. Bulk density in the top 50 mm was strongly correlated with infiltration rate immediately following the vehicle traffic. This correlation decreased with the recovery time and the strongest predictive factor became the percent exposed soil. This change can be attributed to the natural amelioration of soil structure and the replacement of bunchgrasses by annual grasses and forbs that provided less cover. After 2 years the soil structure, vegetation cover, and standing crop had recovered to the point that no significant difference existed between treatments in terms of infiltration rate or interrill erosion.

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# Foreword

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The work was performed by the Environmental Natural Resources Division (EN) of the Environmental Sustainment Laboratory (EL), U.S. Army Construction Engineering Research Laboratories (USACERL). Thomas L. Thurow is an Associate Professor and Deirdre H. Carlson is a Research Associate for the Department of Rangeland Ecology and Management, Texas A&M University, College Station. Dr. William Severinghaus is Chief, CECER-EN, and William Goran is Chief, CECER-EL.

LTC David J. Rehbein is Commander and Acting Director of USACERL, and Dr. Michael J. O'Connor is Technical Director.

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Distribution

# TRACKED VEHICLE TRAFFIC EFFECTS ON THE HYDROLOGIC CHARACTERISTICS OF CENTRAL TEXAS RANGELAND

T. L. Thurow, S. D. Warren, D. H. Carlson

**ABSTRACT.** *The initial change and the temporal recovery pattern of hydrologic, soil, and vegetation characteristics following tracked vehicle passage (tracking) were documented in a split-plot experiment. Treatments were characterized by different soil moisture conditions at the time of vehicle passage (wet or dry) and different tracking intensities (0, 1, 4, and 10 passes by a M2 Bradley Infantry Fighting Vehicle). The study was conducted at Fort Hood, located in the Cross-Timber Prairie ecological resource zone of Texas. Dry-tracked (tracking disturbance imposed on dry soil) plots did not have significantly different infiltration rates or interrill erosion than control plots at any time during the study. In contrast, wet-tracked (tracking disturbance imposed on wet soil) plots had significantly lower infiltration and significantly greater interrill erosion rates, with the initial response and the period of recovery being greater as the number of vehicle passes increased. Bulk density in the top 50 mm was the variable most strongly correlated with infiltration rate immediately following the vehicle traffic. This correlation decreased with passage of recovery time and the strongest predictive factor became the percent exposed soil. This change can be attributed to the natural amelioration (e.g., clay expansion and contraction associated with wetting and drying, activity of soil biota) of soil structure and the death and decomposition of bunchgrasses in the tracks which were replaced by annual grasses and forbs that provided less cover. After two years the soil structure, vegetation cover and standing crop had recovered to the point that there was no longer any significant difference between treatments in their collective influence on infiltration rate or interrill erosion.*

***Keywords.*** *Tracked vehicle impact, Military training sites, Interrill erosion, Infiltration, Temporal response.*

Adverse environmental impact associated with use of tracked vehicles has been reported in conjunction with construction activities (McKyes et al., 1980), logging practices (Moehring and Rawls, 1970; Froehlich, 1974; Burger et al., 1983), agricultural practices (Van Doren, 1959; Brixius and Zoz, 1976), and military maneuvers (Goran et al., 1983; Braunack, 1986; Shaw and Diersing, 1990). These studies document that tracked vehicles crush and uproot vegetation and compact the soil. The collapsed pore structure of the soil slows water infiltration (Lull, 1959; Warkentin, 1971) and may result in poor soil aeration that can inhibit root growth, nutrient uptake, and seedling emergence (Chancellor, 1977).

The alteration of the physical properties of the soil may limit or prevent reestablishment of former plant communities, resulting in long-term reductions of vegetation cover (Wilson, 1988; Shaw and Diersing, 1990) and/or shifts in species composition toward undesirable annuals (Wilshire and Nakata, 1976; Braunack, 1986; Wilson, 1988; Shaw and Diersing, 1990). The loss of vegetation cover results in less interception and dissipation of raindrop energy and contributes to a reduction of infiltration rates and an increase in erosion rates (Thurow, 1991). The increased susceptibility to rill and gully formation and reduction in water quality may impair future use and productivity of the site (Goran et al., 1983; Diersing et al., 1988) and may increase the cost and difficulty of rehabilitation (McDonagh et al., 1979).

The use of tracked vehicles for military maneuvers has impacted many rangeland sites throughout the U.S. In some regions, management of timing, intensity, and frequency of use can limit the environmental impact of military tracked vehicles (Braunack, 1986; Wilson, 1988). However, in fragile ecosystems the effects of a single pass may persist for decades (Prose, 1985). The degree of hydrologic impact associated with tracked vehicle traffic and the rate of subsequent recovery are dependent on a host of site characteristics including vegetation type, soil texture, soil moisture content at the time of impact, and subsequent climatic characteristics. Clay mineralogy significantly influences amelioration of soil compaction through expansion and contraction in wetting-drying and freezing-thawing cycles. Plant root growth and soil microfauna also aid soil compaction amelioration. Infiltration rate integrates a large array of soil and vegetation parameters into an environmentally meaningful index. Thus, by measuring the change in infiltration rate, the net effects of the soil and vegetation degradation and recovery associated with a particular activity can be monitored.

The interrelationships between soil and vegetation variables and the resultant short- and long-term hydrologic impacts of tracked vehicle activity are poorly understood. The objective of this research was to document how soil moisture conditions (wet or dry) combined with the

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intensity of disturbance (number of passes by a tracked vehicle) affect soil and vegetation parameters that influence infiltration and runoff. By studying the temporal response pattern of these parameters, insights can be gained regarding the dynamics associated with change in hydrologic condition. Managers must understand these interrelationships to make informed decisions regarding the anticipated environmental impacts of, and recovery from, tracked vehicle use on rangelands.

## STUDY SITE

The study area was located on the eastern edge of the Cross-Timber Prairie ecological resource region within the Fort Hood Military Reservation near Killeen, Texas (31°4′N, 97°44′W). The climate is humid subtropical with annual precipitation (1951 through 1988) averaging 860 mm (NOAA, 1989) distributed evenly throughout the year. Average maximum/minimum temperatures range from 14/1° C in January to 36/23° C in July. The average frost-free growing period is 260 d (Huckabee et al., 1977). Elevation of the site is 275 m.

Soil at the site was a Typic Ustochrept (Brackett clay loam) that is shallow, well-drained, and slowly to moderately permeable (Huckabee et al., 1977). The A1 horizon was clay loam to loam, approximately 150 mm thick. The clay loam B2 horizon was about 250 mm thick. The underlying Cr horizon, approximately 500 to 700 mm thick, was weakly to strongly cemented limestone. The slope of the site was 3%. The area was classified as an Adobe range site in excellent condition (Huckabee et al., 1977). The vegetation which dominated the site was a mix of late succession bunchgrass species including little bluestem [*Schizachyrium scoparium* (Michx.) Nash], sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], Texas wintergrass (*Stipa leucotricha* Trin. and Rupr.) and tall dropseed [*Sporobolus asper* (Michx.) Kunth]. The area had been off limits to military vehicles for the past 50 years, receiving only light grazing and periodic burning.

## METHODS

A split-plot design with three replicates was used to study the initial impact and recovery pattern of the hydrologic condition of the site as influenced by the number of passes and the antecedent soil moisture when the military vehicle tracking occurred. On 7 June 1989 a water-spreading truck was used to apply water to half of the site. The antecedent soil moisture at the time of tracking on 8 June (20 h after water was applied) was 5% and 14% (oven-dry basis – 105° C) in the top 100 mm on the two treatments, hereafter referred to as dry and wet treatments, respectively. Field capacity of the undisturbed soil was 25%. An M2 Bradley Infantry Fighting Vehicle was used to impose the tracking treatments on the wet and dry soils at three different intensities (1, 4, and 10 passes). A control area (0 passes) was reserved as a reference point for responses unrelated to the tracking activity. The ground pressure of the M2 Bradley Infantry Fighting Vehicle is 54 kPa (Foss, 1987), significantly less than many types of equipment commonly used for activities such as farming, construction, or transmission line installation (Byrnes et al., 1982).

Various soil and vegetation parameters affecting hydrologic characteristics were measured (four samples/replication) in the vehicle paths immediately following the initial impact and at two-month intervals for two years thereafter. Soil samples from the surface 100 mm were collected and analyzed for soil texture by the particle size distribution technique (Gee and Bauder, 1986), soil organic carbon content using the Walkley-Black technique (Nelson and Sommers, 1986), soil aggregate stability by the wet-sieve method (Kemper and Rosenau, 1986), and gravimetric soil moisture at depths of 0 to 50 and 50 to 100 mm (Gardner, 1986). Bulk density was sampled at 0 to 50- and 50 to 100-mm depths by the core method (Blake and Hartge, 1986). Microrelief was measured using a relief meter (Kincaid and Williams, 1966). An ocular estimate (Bonham, 1989) of canopy cover provided by rock, litter, forbs and grasses was made for each sample plot (0.5 $m^2$). Each sample plot was then harvested and sorted as either forb, grass, or litter. Vegetation was dried at 60° C for 72 h and weighed to estimate above-ground biomass. Species composition of the canopy cover was determined in June prior to the treatments and during June of the following two years using the line-point transect technique (Bonham, 1989) on two 100-point (one point/30 cm) transects/replication/treatment.

During June and August of each year, rainfall simulation studies using a drip-type rainfall simulator (Blackburn et al., 1974) were conducted to determine infiltration rate and interrill erosion potential in each treatment. The 0.5-$m^2$ sample plots (four/replication) were pre-wet by applying 100 L of water via a mist-type nozzle over a 1.1-$m^2$ circular area. The plots were covered with plastic for 24 h to allow the soil to drain to field capacity. This procedure reduced variability in antecedent soil moisture that would have occurred between sample dates and allowed direct comparison of all periods. Simulated rainfall was applied at a rate of 76 mm $h^{-1}$ (10-year storm return period) for 30 min. Runoff was measured at 5-min intervals for 30 min. Infiltration rates were determined by calculating the difference between the applied rainfall and runoff volumes. At the conclusion of the sampling period, a 1-L subsample of thoroughly mixed runoff was taken, filtered through a No. 1 Whatman filter paper, and the filter plus sediment were oven-dried and weighed. Total sediment loss (interrill erosion) was calculated by multiplying the weight of the dried sample by the total volume of runoff.

Data were analyzed using analysis of variance procedures for a split-plot design (SAS Institute, 1988). Where appropriate, means were separated using the Duncan's new multiple range test. Significance levels were determined at $P < 0.05$. Correlation analysis was used to assess the degree of linear association of the variables.

## RESULTS

Particle size separates [sand = 24.8%, SE ± 0.2; clay = 46.9%, SE ± 0.2 (> 50% smectite, < 10% kaolinite)], organic carbon content (5.2%, SE ± 0.1) and aggregate stability (72.9%, SE ± 0.3) showed no difference between treatments or seasons. Microrelief was significantly reduced on the dry-tracked 4-pass and 10-pass treatments but recovered to the control level within two months. In

Table 1. Canopy cover (%) of later-succession bunchgrasses on dry- and wet-tracked treatments sampled in June prior to tracking treatment and each June one and two years later*

| | 0 Passes | | 1 Pass | | 4 Passes | | 10 Passes | |
|---|---|---|---|---|---|---|---|---|
| Year | Dry | Wet | Dry | Wet | Dry | Wet | Dry | Wet |
| | (%) | | | | | | | |
| 1989 | 65.0a | 68.4a | 62.0a | 70.4a | 72.1a | 64.3a | 74.0a | 68.6a |
| 1990 | 61.5a | 64.8a | 53.4a | 60.7a | 49.9b | 47.3b | 32.7c | 33.6c |
| 1991 | 64.7a | 65.9a | 64.3a | 63.2a | 54.8ab | 43.9b | 53.6b | 50.7b |

* Values with the same letter within a sample date are not significantly different (P > 0.05).

contrast, microrelief was reduced by a similar amount on all the wet-tracked treatments and all remained lower than the control for one year, after which there was no difference on any of the treatments. There was no difference in bulk density between treatments or seasons on the dry-tracked soils at either the 0-50 mm (1.14 Mg $m^{-3}$, SE ± 0.01) or the 50 to 100-mm depth (1.16 Mg $m^{-3}$, SE ± 0.01). On wet-tracked sites there was an initial increase in bulk density at 0 to 50 mm depth (0 pass = 1.13 Mg $m^{-3}$, SE ± 0.01, 1 pass = 1.19 Mg $m^{-3}$, SE ± 0.02, 4 passes = 1.23 Mg $m^{-3}$, SE ± 0.02, 10 passes = 1.33 Mg $m^{-3}$, SE ± 0.01). There was no difference between the control, 1-pass and 4-pass treatments after four months and there was no difference between these and the 10-pass tracking treatment six months after imposing the treatment. There was no difference in bulk density at the 50 to 100-mm depth between tracking intensities for either the dry or wet treatments.

The cover of the late succession perennial bunchgrasses (predominately little bluestem, sideoats grama, Texas wintergrass, tall dropseed) was significantly reduced on the areas subjected to the greater tracking intensities (table 1). These areas were invaded by early successional species including Texas grama [*Bouteloua rigidiseta* (Steud.) Hitchc.], Reverchon bristlegrass [*Setaria reverchonii* (Vasey) Pilger], three awn (*Aristida* spp.), day primrose (*Calyophus berlanderii* Spach) and Texas croton [*Croton texensis* (Klotzch) Muell. Arg.].

Only the 10-pass tracking treatments significantly influenced percent exposed soil compared to the untracked control. The 10-pass dry treatment contained significantly greater exposed soil two months after treatment (August, 1989) and the 10-pass wet treatment contained significantly greater exposed soil from August, 1989 through June 1990. Standing phytomass varied between treatments, especially during the first year following the tracking treatment (table 2). The standing phytomass on both the wet and dry 1- and 4-pass treatments was less than on the control during the first year, but the standing phytomass on the 10-pass dry treatment was different from the control for up to 20 months (February, 1991), and was different on the wet 10-pass treatment for up to 24 months (June 1991).

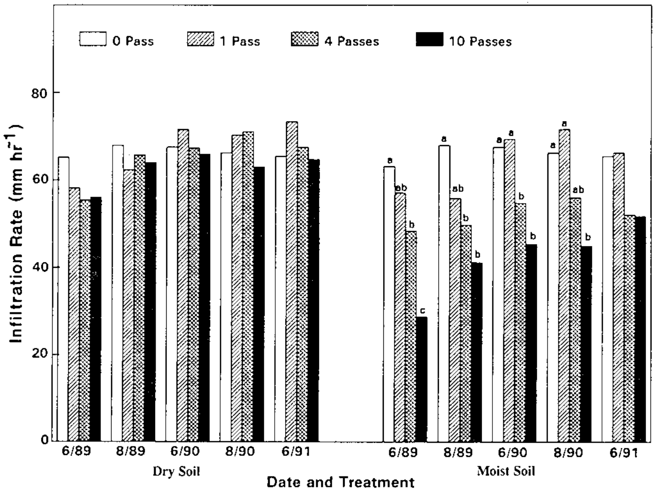

**Figure 1–Infiltration rates (mm $h^{-1}$) on dry- and wet-tracked treatments immediately following imposition of tracked vehicle disturbance (6/89) and 2 (8/89), 12 (6/90), 14 (8/90), and 24 (6/91) months following disturbance. Values with the same letter for the same treatment and sample date, or dates with no letters, are not significantly different (*P* > 0.05).**

There was no significant decline in the infiltration rate of dry-tracked plots, regardless of the number of passes by the Bradley Infantry Fighting Vehicle (fig. 1). In contrast, the infiltration rate on the wet-tracked treatments declined as the number of passes increased (fig. 1). This pattern persisted until June 1991, two years following impact. Bulk density at 0- to 50-mm depth was the variable which was most strongly correlated with infiltration rate immediately after the tracking took place (r = −0.68), but this relationship decreased after two months (r = −0.45) and was negligible after two years (r = −0.10). Microrelief was positively correlated with infiltration rate, but like bulk density, the strength of the correlation declined over time (r = 0.61 immediately after tracking, r = 0.32 after two months and r = 0.15 after two years).

Interrill erosion was not significantly affected by tracking on dry soils (fig. 2), although a general pattern of increased erosion with increased tracking intensity was evident in August 1989, and June 1990. On wet-tracked plots interrill erosion on the 10-pass treatment was significantly greater than the control for at least 12 months.

Table 2. Standing phytomass (kg/$ha^{-1}$) on dry- and wet-tracked treatments*

| | Dry-Tracked Sites | | | | | Wet-Tracked Sites | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Passes | 6/89 | 2/90 | 6/90 | 2/91 | 6/91 | 6/89 | 2/90 | 6/90 | 2/91 | 6/91 |
| | (kg $ha^{-1}$) | | | | | | | | | |
| 0 | 1669a | 1451a | 1398a | 1442a | 1618a | 1367a | 1351a | 1509a | 1372a | 1724a |
| 1 | 1494a | 950b | 1256ab | 1377a | 1524a | 1269a | 812b | 1649a | 1378a | 2020a |
| 4 | 1091a | 769bc | 1317a | 1219a | 2179a | 1000a | 772b | 1422a | 1416a | 1796a |
| 10 | 575a | 433c | 862b | 846a | 1717a | 647a | 267c | 815b | 659b | 1552a |

*The June sample dates approximate maximum standing phytomass and the February samples approximate minimum standing phytomass for the espective years. Values with the same letter within a sample date (within soil moisture treatments and across number of passes) are not significantly different (P > 0.05).

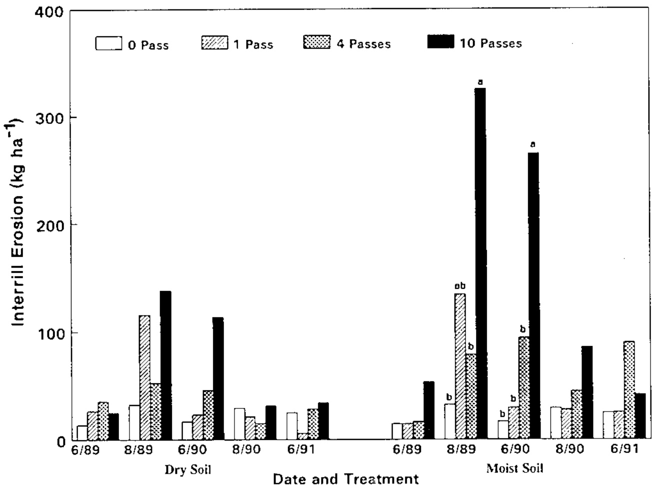

**Figure 2–Interrill erosion (kg/ha$^{-1}$) on dry- and wet-tracked treatments immediately following imposition of tracked vehicle disturbance (6/89) and 2 (8/89), 12 (6/90), 14 (8/90), and 24 (6/91) months following disturbance. Values with the same letter for the same treatment and sample date, or dates with no letters, are not significantly different ($P > 0.05$).**

While all other wet-tracked treatments were statistically similar, a positive relationship between tracking intensity and interrill erosion was evident throughout the two years of the study.

## DISCUSSION

The positive relationship between bulk density and tracking intensity is well-documented and is often found to be most pronounced in the surface 100 mm (cf. Braunack, 1986), although the depth varies according to soil, vegetation, and vehicle characteristics (Eriksson, 1975; Burger et al., 1983; Camp Dresser and McKee Inc., 1984; Adams et al., 1982). Bulk density at 0 to 50 mm was the variable most strongly correlated with infiltration rate immediately after tracking but gradually became less important over time. There were many small rain storms interspersed with hot dry periods between the first and second sample periods. The pattern of wetting and drying with the concomitant swelling and shrinking of the clay loam soil loosened the compacted soil, thus reducing the differences in bulk density between the treatments over time. Akram and Kemper (1979) likewise found that reductions in infiltration rates, as affected by soil compaction, were largely ameliorated following the first three shrink/swell cycles in clay-rich soils. As the differences in bulk density declined, the influence of other variables such as cover and phytomass became more pronounced.

Trafficking on dry soil had no significant impact on interrill erosion, regardless of intensity. On wet soils, even though the amount of runoff from tracked plots was much greater than from untracked plots, soil particles were not easily dislodged from the compacted surface. Thus, there was no significant increase in interrill erosion immediately after tracking at any intensity. After two months, however, as the shrinking and swelling process loosened the soil surface, interrill erosion was greatly increased.

The composition of the cover on the site was initially very similar and dominated by late-succession bunchgrasses. After tracking, these components of the plant community were greatly reduced on the more intensely tracked sites (table 1) and replaced by early-succession species composed mainly of annual grasses and forbs. The reduction of late-succession bunchgrass cover was related to the number of passes and was not affected by soil moisture status at the time of tracking disturbance. Such changes in species composition as a result of tracked vehicle activity have also been documented by Wilson (1988) and Shaw and Diersing (1990). The invading early-succession species provided about the same amount of canopy cover as the original bunchgrasses they replaced on the 1- and 4-pass treatments (only the 10-pass treatments had a significant increase in percent exposed soil) but the standing phytomass was significantly reduced on all the tracked sites.

The increase in dominance of early succession herbaceous cover corresponded with the continued suppression of infiltration rate after the measured soil physical properties had recovered. Most of the invading species were annuals with a single-stem growth form that is less obstructive to overland flow and interrill erosion than bunchgrass clumps (Thurow et al., 1986; Thurow, 1991; Blackburn et al., 1992). The reduction of standing phytomass associated with intensity of tracking (table 2) also contributed to differences in interrill erosion and overland flow between the treatments. The substantially reduced standing phytomass at the peak of the dormant season (February) is a reflection of the ephemeral nature of the invaders as opposed to perennial bunchgrasses. This reduction and fluctuation in standing phytomass on the invader-dominated sites would create a less constant microenvironment and reduce organic matter inputs needed to foster activity of microorganisms that can help to improve soil structure and increase infiltration rate (Lynch and Bragg, 1985; Boyle et al., 1989).

## MANAGEMENT IMPLICATIONS

Hydrologic characteristics of the site were influenced by various soil and vegetation parameters, and their degree of influence on site hydrology varied over time. Of the soil and vegetation parameters evaluated, those most affected by tracking were bulk density from 0 to 50 mm, microrelief, vegetation biomass, and amount of exposed soil. Impacts were generally greater on the wet-tracked plots than on dry-tracked plots, so future tracking impacts should be scheduled when antecedent soil moisture content of soils is low. Effects of tracked vehicle disturbance also tended to be greater with increasing number of passes; therefore, the intensity of activity should also be considered when planning training exercises.

Recovery times of soil and vegetation parameters, which in turn influence infiltration rate and interrill erosion, were relatively short on this site compared to more arid ecosystems (Webb and Wilshire, 1980; Webb et al., 1983; Prose, 1985). Infiltration and interrill erosion rates on the most intense treatment (10 pass/wet soil) recovered to control (0 pass) levels after only two years. Compaction of soils primarily occurred in the surface 50 mm. The swell/shrink action (Akram and Kemper, 1979) associated with the numerous rain and dry periods which are characteristic of central Texas summers facilitated the amelioration of the compacted clay loam soil. The late-succession species that characterize excellent range condition had not yet recovered to predisturbance levels after two years, but the cover and phytomass had improved sufficiently to a level that no longer negatively influenced infiltration rate and interrill erosion.

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