1992

Soil Strain Under Three Tractor Configurations

Gerald R. Kinney
Iowa State University

Donald C. Erbach
United States Department of Agriculture

Carl J. Bern
Iowa State University, cjbern@iastate.edu

Soil Strain Under Three Tractor Configurations

Abstract
Soil compaction can cause significant crop yield reductions. Effective management of soil compaction caused by tractors requires an understanding of the influence of the tractive system on soil compaction. Soil strain under tractors equipped with single rear wheels, dual rear wheels, or steel tracks was measured and compared. Tractors were of nearly equal mass. Strain was measured by using soil-strain transducers installed at 100-, 150-, 200-, and 300-mm depths beneath the soil surface. Soil strain was defined as the change in transducer length divided by the initial length of the transducer when installed in the soil. Soil strain at 100- to 245-mm depth was significantly greater for the tractor with single rear wheels than for the other tractors. The difference in soil strain caused by tractors with different tractive systems decreased with soil depth.

Keywords
Soil compaction, Tracked vehicles

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
This article is from *Transactions of the ASAE* 35 (1992): 1135–1139, doi:10.13031/2013.28711. Posted with permission.

Soil Strain Under Three Tractor Configurations

G. R. Kinney, D. C. Erbach, C. J. Bern
Member ASAE Member ASAE Member ASAE

Abstract

Soil compaction can cause significant crop yield reductions. Effective management of soil compaction caused by tractors requires an understanding of the influence of the tractive system on soil compaction. Soil strain under tractors equipped with single rear wheels, dual rear wheels, or steel tracks was measured and compared. Tractors were of nearly equal mass. Strain was measured by using soil-strain transducers installed at 100-, 150-, 200-, and 300-mm depths beneath the soil surface. Soil strain was defined as the change in transducer length divided by the initial length of the transducer when installed in the soil. Soil strain at 100- to 245-mm depth was significantly greater for the tractor with single rear wheels than for the other tractors. The difference in soil strain caused by tractors with different tractive systems decreased with soil depth. **Keywords.** Soil compaction, Tracked vehicles.

Introduction

Considerable research has been conducted to identify the effects of compaction on soil properties and productivity. Research in Indiana has shown a 25 to 50% corn-yield reduction in soils compacted by vehicular traffic (Gaultney et al., 1982). Erbach et al. (1988) reported a 13% corn-yield reduction in trafficked areas relative to nontrafficked areas. Yield reduction in trafficked areas can significantly affect crop production because a typical row-crop farmer will traffic approximately 80% of a field in one-crop year (Erbach, 1988). Soil compaction has been estimated to cost farmers in the United States more than one billion dollars per year in production loss (Raghavan et al., 1976).

Article was submitted for publication in September 1991; reviewed and approved for publication by the Power and Machinery Div. of ASAE in May 1992.

Joint contribution of USDA-Agricultural Research Service, National Soil Tilth Laboratory, and Journal Paper No. J-14456 of the Iowa Agriculture and Home Economics Experiment Station, Ames, IA. Project No. 2694. Mention of companies, trademarks, or commercial products is for the information and convenience of the reader and does not constitute an official recommendation or endorsement by the USDA-Agricultural Research Service, or Iowa State University over other equipment not mentioned.

The authors are **Gerald R. Kinney**, Formerly National Science Foundation Undergraduate Research Assistant, Agricultural and Biosystems Engineering Dept., Iowa State University, Ames; **Donald C. Erbach**, Agricultural Engineer, USDA-Agricultural Research Service, National Soil Tilth Laboratory, Ames, IA; and **Carl J. Bern**, Professor, Agricultural and Biosystems Engineering Dept., Iowa State University, Ames.

Pressure exerted near the soil surface is greater for a tractor with a wheel-type tractive system than for a track-type tractor (Brixius and Zoz, 1976). This difference in pressure decreases with depth in the soil profile. Moreover, pressure from a conventional wheel-type tractor is greater than that from either a track-type tractor or a tractor with dual rear wheels (Brixius and Zoz, 1976; Reaves and Cooper, 1960; Soehne, 1958). Bulk density of soil in the track of a track-type tractor has been shown to be less than that in the track of a tractor with dual rear wheels (Taylor and Burt, 1975; Bashford et al., 1988; Erbach et al., 1988).

Research by Raper and Erbach (1988) and Gassman et al. (1989) showed that the linear-elastic properties of soil changed as load on the soil is increased. Thus, simple stress-strain relationships based upon linear-elastic theory cannot accurately predict soil compaction from knowledge of applied stress. Therefore, results predicted from model and laboratory soil-strain simulation are difficult to correlate with field measurements of soil compaction.

Erbach and Abo-Abda (1987) developed a transducer to directly measure *in situ* soil strain caused by trafficking. Modification to improve the ease of installation and to reduce the soil disturbance during installation of this soil-strain transducer was described by Erbach et al. (1991).

Objective

The objective of this study was to measure and compare soil strain created by tractors of equal mass equipped either with single rear wheel, dual rear wheel, or steel track tractive systems.

Materials and Methods

Soil displacement measured with soil-strain transducers (Erbach et al., 1991) placed at various depths in the soil profile was used to estimate soil strain beneath agricultural tractors. Each tractor had a mass of about 8 Mg. The measuring device in the transducer is a Penny and Giles Model HLP095 (Type D43638) linear potentiometer. A helical end-plate is fastened to each end of the potentiometer. The transducer is 9.5-mm in diameter, is 162 mm long when fully extended, and can measure a 50-mm displacement. The transducers were calibrated by measuring output voltage for each of two end-plate separations, or transducer lengths. The change in transducer length divided by the change in output voltage was used as the calibration factor. A tube with an outside diameter of 12.7 mm was used to install the transducers into the soil. The transducer was rotated by use of the tube and a socket wrench. When rotated, the helical end-plates pulled the transducer into the soil. The tube was removed after installation. The end-plates ensured that the transducer engaged the soil after installation.

Four transducers were installed at 200-mm intervals along the centerline of the path of each tractive device. Transducers were positioned at 100-, 150-, 200-, and 300-mm depths as measured from the soil surface to the top end-plate of each transducer. The order of transducer depth was randomly determined. When inserted, end-plate spacing was approximately 140 mm. After trafficking, transducers were removed by excavating soil from around each transducer with a small garden shovel.

Voltage to transducers was provided by a 5-VDC power supply. Transducer-voltage output was recorded with a personal computer equipped with an analog-to-digital conversion board. Data acquisition software (Labtech Notebook, Laboratory Technologies Corporation) was used to record reference voltage, time, and voltage outputs from each of the four transducers. Values were recorded at a rate of 75 samples per second. The data-acquisition system was manually started at the beginning and stopped at the end of each tractor pass.

Recorded output voltages from each transducer were converted to transducer lengths by use of the respective calibration factors. Changes in transducer lengths were converted to soil strain by dividing the change in length by the initial length.

The experiment was conducted in a field at the Agronomy-Agricultural Engineering Research Center west of Ames, Iowa. Soil in the experimental plot was a fine-loamy, mixed mesic Typic Haplaquolls (Webster silty clay loam). The field had been spring moldboard plowed to a 0.2-m depth. After plowing, the soil was tilled with a disc harrow to approximately 0.1-m depth and planted with corn (*Zea mays*, L.) in 0.76-m rows. Corn was not cultivated after planting. A randomized complete-block experimental design with six replications was used. Each 0.76-m wide by 6.1-m long experimental plot was located between corn rows in an area that had not been trafficked during or after planting. Corn plants were removed before the experiment was conducted.

A White Model 160 tractor with mechanical front-wheel drive (drive not engaged) was used to traffic the wheel-tractor plots. Clamp-on dual tires were installed on the tractor before it was used to traffic the wheel-tractor-with-duals plot. The inside-dual tire tracked the front tire and the outside dual operated on previously untrafficked soil. The tractor had a rear axle load of 4.8 Mg with single, rear wheels and 5.0 Mg with dual, rear wheels. The track-type tractor used was a Caterpillar Model D3B SA with steel tracks. The tractor was ballasted such that load was balanced at front-to-rear center of track. Specific information on each tractor is given in Table 1. Plots were trafficked at a speed of 3.5 km/h by tractors with no drawbar loads.

Measurements of soil strain, bulk density, moisture content, cone-penetration resistance, and tractive device depression were made in each plot. A mechanical sampler similar to that described by Buchele (1961) was used to obtain cores for measurement of soil-bulk density and soil moisture after trafficking. A hand-operated penetrometer with a 322-mm^2 cone was used to measure cone-penetration resistance. Maximum penetration resistance was measured, at 50.8-mm depth increments, by use of a Chatillon Model DFG-100 digital force gage. Core samples and penetration resistance measurements were also taken in a nontrafficked plot in each replication. The depth of the depression resulting from traffic by each tractive device was measured relative to the undisturbed soil surface on either side of the path. The depression depth was obtained by averaging measurements of lug- and interlug-depression depths in the path.

TABLE 1. Specifications for tractive devices and tractors evaluated

	Tractive Device Configuration		
	Single Rear Wheels*	Dual Rear Wheels*	Tracks†
Static weight (kN)			
– Front	29.1	29.1	39.0
– Rear	46.9	49.4	39.0
Front tires			
Size designation	14.9R28	14.9R28	
Type	Radial	Radial	
Inflation (kPa)	181	181	
Rear tires			
Size designation	18.4R38	18.4R38	
Type	Radial	Radial	
Inflation (kPa)	162	162	
Dual tires			
Size designation		18.4R38	
Type		Radial	
Inflation (kPa)		131	
Track			
Size (mm)			540 × 2100
Type			Steel
Tread spacing (m)			
Tire, front	2.18	2.18	
Tire, rear	2.28	Inside 2.28 Outside 3.48	
Track			1.52

* White Model 160 with mechanical front wheel drive.
† Caterpillar Model D3B SA.

RESULTS AND DISCUSSION

A representative plot of the data collected from one test run for each tractor configuration is shown in figures 1, 2, 3, and 4. In all instances, soil was deformed by the tractive device, and some seemingly elastic rebound occurred after the load was removed. Figures 1 and 2 show that the rear wheel of the tractor created a small expansion of the transducer, which was exhibited by a decrease in strain, just before the wheel passed over the transducer. In plots trafficked by both the front and rear wheels (figs. 1 and 2), the front wheels produced most of the permanent deformation, with the rear wheels creating only a small amount of additional strain in the soil. Soil strain created by the track-type tractor continually increased as the track passed over the transducer (fig. 4). The small strain peaks are seemingly due to stress peaks beneath each of the six midwheels of the track.

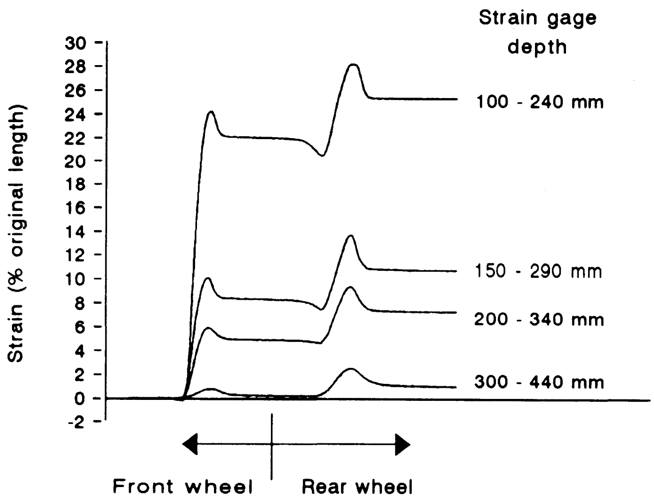

Figure 1–Representative plot of dynamic soil strain under front and rear tires of a moving tractor with single-rear wheels.

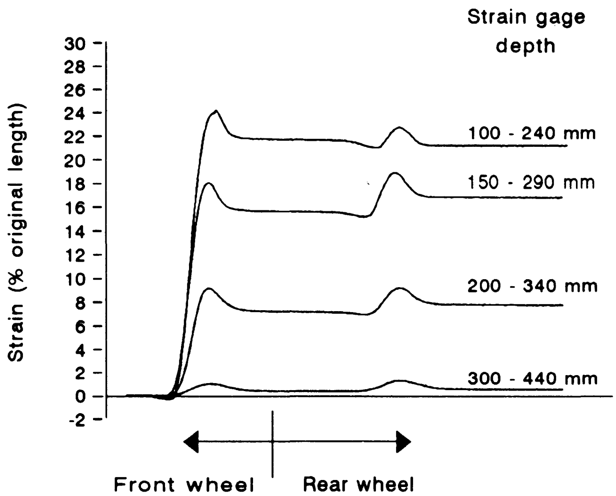

Figure 2–Representative plot of dynamic soil strain under the front and inside-rear tire of a moving tractor with dual-rear wheels.

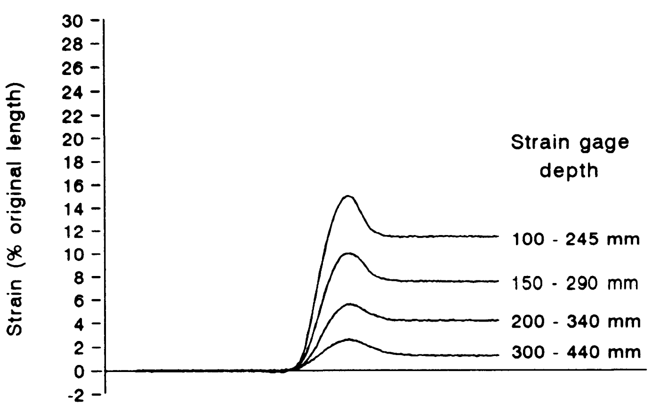

Figure 3–Representative plot of dynamic soil strain under the outside-rear tire of a moving tractor with dual-rear wheels.

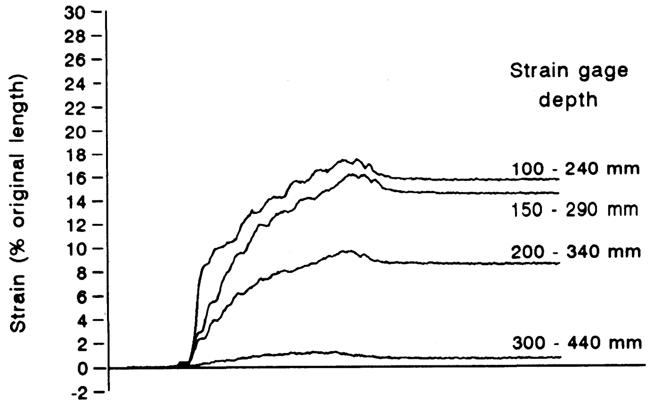

Figure 4–Representative plot of dynamic soil strain under track of a moving track-type tractor.

Table 2 shows average soil strain measured for each tractive device. The columns for maximum front and maximum rear strain list the average maximum dynamic soil strain created as the front and rear wheels, respectively, of the tractor passed over the transducers. Final strain values list the soil strain after the tractor had passed over the transducer and the soil had relaxed. Final strain increased in the order: dual-wheel outside, track, dual-wheel inside, and single wheel. The apparent significant difference in strain in the 100-240 mm deep soil

TABLE 2. Maximum dynamic soil strain and final static strain caused by traffic of tractors with different tractive devices

		Soil Strain			
		Front Wheel		Rear Wheel or Track	
Tractive Device	Depth of Soil Layer (mm)	Maximum Dynamic (%)	Final Static (%)	Maximum Dynamic (%)	Final Static (%)
Single rear wheel					
	100 - 240	15.2	12.8	19.0	16.0
	150 - 290	8.6	6.8	13.3	11.1
	200 - 340	4.4	3.2	7.5	5.8
	300 - 440	0.9	0.3	2.1	0.9
Dual rear wheels					
Inside wheels	100 - 240	11.2	8.7	12.6	10.2
	150 - 290	11.0	8.7	11.8	10.0
	200 - 340	5.6	4.1	6.7	5.3
	300 - 440	0.8	0.3	1.0	0.3
Outside wheels	100 - 240			9.7	7.3
	150 - 290			5.9	4.2
	200 - 340			4.6	3.3
	300 - 440			1.0	0.3
Track					
	100 - 240			11.1	9.4
	150 - 290			7.5	6.2
	200 - 340			5.1	6.2
	300 - 440			1.2	0.7

LSDs for final static strain:
Depth averages for same tractive device, 0.9%;
Tractive device averages at same or different depths, 1.3%.

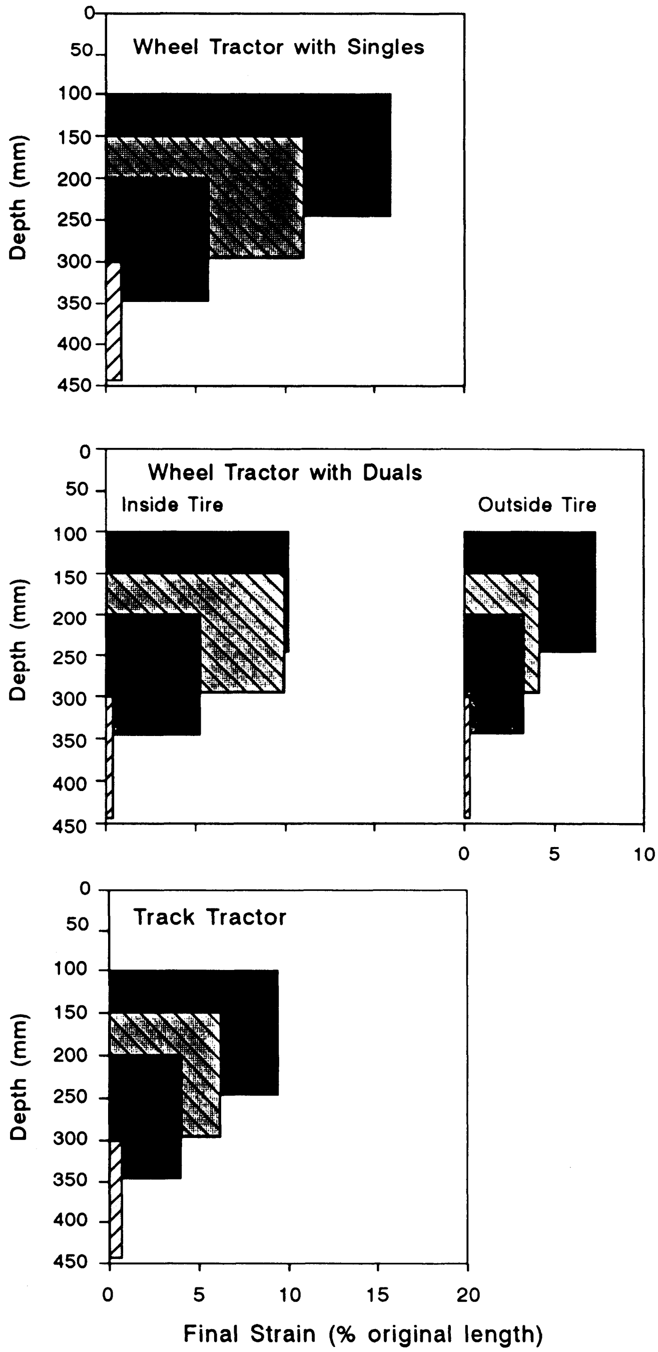

Figure 5–Average final strain with respect to depth for each tractor. Bar location represents initial location of transducer with respect to soil surface.

layer caused by front wheels of single- and dual-rear wheeled tractors is not explained.

Figure 5 shows average final soil strain for each tractive device and each soil depth. In the 100 to 240-mm soil layer, the tractor with single-rear wheels caused 55% more final soil strain than did the inside dual-rear wheel and 70% more strain than did the track. The outside wheel of the wheel tractor with dual wheels produced the least amount of soil strain. This lower strain is probably due to the lower inflation pressure of that tire which caused the inside-rear wheel to carry the majority of the tractor weight.

TABLE 3. Soil profile water content at time of trafficking by tractors with different tractive devices and the bulk density and penetration resistance after trafficking

Tractive Device	Depth (mm)	Water Content (m^3/m^3)	Bulk Density (Mg/m^3)	Penetration Resistance (kPa)
Single rear wheel	25	0.23	1.17	410
	75	0.41	1.51	230
	125	0.40	1.45	270
	175	0.40	1.43	350
	225	0.38	1.44	390
	275	0.37	1.47	410
	Average	0.36	1.41	340
Dual rear wheels				
Inside wheel	25	0.25	1.30	420
	75	0.39	1.46	250
	125	0.39	1.40	230
	175	0.39	1.39	310
	225	0.39	1.42	390
	275	0.36	1.40	440
	Average	0.36	1.39	340
Outside	25	0.24	1.24	240
	75	0.36	1.34	240
	125	0.40	1.41	260
	175	0.37	1.23	300
	225	0.40	1.39	380
	275	0.39	1.37	490
	Average	0.36	1.33	320
Track	25	0.23	1.20	270
	75	0.39	1.37	260
	125	0.39	1.39	320
	175	0.40	1.40	340
	225	0.42	1.48	380
	275	0.39	1.51	440
	Average	0.37	1.39	330
Non-trafficked	25	0.21	1.08	130
	75	0.39	1.22	180
	125	0.39	1.34	200
	175	0.39	1.32	190
	225	0.42	1.41	260
	275	0.40	1.45	410
	Average	0.37	1.30	230

LSD for tractive device averages: Water content, 0.02 m^3/m^3; Bulk density, 0.06 Mg/m^3; Penetration resistance, 33 kPa.

LSD for depths of same tractive device: Water content, 0.05 m^3/m^3; Bulk density, 0.16 Mg/m^3; Penetration resistance, 82 kPa.

LSD for tractive device averages at same or different depths: Water content, 0.05 m^3/m^3; Bulk density, 0.16 Mg/m^3; Penetration resistance, 103 kPa.

In all instances, some soil strain was measured in the 300 to 440-mm depth layer. Strains of about 1% occurred in a soil layer extending from about one and one-half to two times the depth to which the field was tilled with the moldboard plow. Hardpans, often said to develop in soil, might be related to this permanent deformation which occurs each time the soil is trafficked.

The location of tire or track lugs relative to the position of buried transducers was not controlled. Therefore, some variability in the measured results may be due to nonuniform loading of the soil caused by lugs of the tractive devices. Spatial variability of soil properties, such as aggregation, also contributes to variability of measured values of soil strain. With this measurement technique, only soil motion in line with the axis of the strain gage is measured. The gages were inserted vertically and changes in gage orientation during the test were not measured. However, when excavated following the tests, the gages were found to have maintained a near vertical orientation.

Average bulk density, volumetric water content, and cone-penetration resistance of the soil after trafficking are given in Table 3. Generally, bulk density and cone-penetration resistance increased in the following order: control, dual-wheel outside, track, dual-wheel inside, and single wheel. Magnitudes of changes in bulk density were similar to those of vertical soil strain. However, it would be expected that lateral soil motion would occur and, as a result, changes in bulk density would be somewhat less than predicted from vertical strain alone.

The depth of the depression created by each of the tractor-tractive devices is given in Table 4. The tractor with single-rear wheels created the deepest depression and the tractor with steel tracks made the shallowest depression.

TABLE 4. Depth of soil surface depression caused by traffic with each tractive device

Tractive Device	Depression Depth		
	Lug (mm)	Inter-lug (mm)	Average (mm)
Single rear wheels	51.5	18.3	34.9
Dual rear wheels			
Inside wheel	30.8	5.8	18.3
Outside wheel	30.0	5.0	17.5
Track	28.3	– 2.0	13.2
Average	35.2	6.8	21.0
Tractive device LSD (P=0.05)	14.9	15.5	14.4

CONCLUSION

A tractor with single-rear wheels produced more strain in the 100- to 440-mm soil layer than did equal-mass tractors with dual-rear wheels or with steel tracks. Magnitudes of strain and differences among tractive devices were greatest in the 100- to 240-mm layer. Traffic by tractors with masses of about 8 Mg caused measurable soil strain in the 300- to 440-mm deep soil layer.

Soil bulk density and soil penetration resistance tend to increase as soil strain increases.

ACKNOWLEDGMENTS. The authors express appreciation to the National Science Foundation for support of the Agricultural Engineering Undergraduate Research Program, to Arlyn Wilcox for assistance with instrumentation and data collection, and to Kent Heikens for assistance in conducting the research.

REFERENCES

Bashford, L. B., A. J. Jones and L. N. Mielke. 1988. Comparison of bulk density beneath a belt track and tire. *Applied Engineering in Agriculture* 4(2):122-125.

Brixius, W. W. and F. M. Zoz. 1976. Tires and tracks in agriculture. *Transactions of the SAE* 85(3):2034-2044.

Buchele, W. F. 1961. A power sampler of undisturbed soils. *Transactions of the ASAE* 4(2):185-191.

Erbach, D. C. 1988. Farm equipment and soil compaction. *Transactions of the SAE* 95(3):1085-1089.

Erbach, D. C. and A. E. Abo-Abda. 1987. Strain gage to measure soil compaction. ASAE Paper No. 87-1012. St. Joseph, MI: ASAE.

Erbach, D. C., G. R. Kinney, A. P. Wilcox and A. E. Abo-Abda. 1991. Strain gage to measure soil compaction. *Transactions of the ASAE* 34(6):2345-2348.

Erbach, D. C., S. W. Melvin and R.M. Cruse. 1988. Effects of tractor tracks during secondary tillage on corn production. ASAE Paper No. 88-1614. St. Joseph, MI: ASAE.

Gassman, P. W., D. C. Erbach and S. W. Melvin. 1989. Analysis of track and wheel soil compaction. *Transactions of the ASAE* 32(1):23-29.

Gaultney, L., G. W. Kurtz, G. C. Steinhardt and J. B. Liljedahl. 1982. Effects of subsoil compaction on corn yields. *Transactions of the ASAE* 25(3):563-575.

Raghavan, G. S. V., E. McKyes and M. Chase. 1976. Soil compaction patterns used by off-road vehicles in eastern Canadian agricultural soils. *J. Terramechanics* 13:107-115.

Raper, R. L. and D. C. Erbach. 1988. Core sampling evaluation using the finite element method. *Transactions of the ASAE* 31(2):331-336.

Reaves, C. A. and A. W. Cooper. 1960. Stress distribution in soils under tractor loads. *Agricultural Engineering* 41:20-21.

Soehne, W. H. 1958. Fundamentals of pressure distribution and soil compaction under tractor tires. *Agricultural Engineering* 39(5):276-281, 290.

Taylor, J. H. and E. C. Burt. 1975. Track and tire performance in agricultural soils. *Transactions of the ASAE* 18(4):3-6.