Research Article

Turk J Agric For
34 (2010) 173-179
© TÜBİTAK
doi:10.3906/tar-0906-189

Changes in distribution patterns of soil penetration resistance within a silage-corn field following the use of heavy harvesting equipments

Ekrem Lütfi AKSAKAL, Taşkın ÖZTAŞ

Department of Soil Science, Faculty of Agriculture, Atatürk University, 25240 Erzurum - TURKEY

Received: 26.06.2009

Abstract: Soil compaction caused by heavy wheeling reduces water infiltration, root development, and yield, and increases bulk density and soil strength. The objective of this study was to determine changes in spatial variability patterns of soil penetration resistance before and after using the silage machine in a corn-growing field. Soil penetration resistance was measured in a 100 × 400 m field with 10 m intervals just before and after harvesting. Measurements were taken from the 20 cm top layer on rows and inter-rows throughout each transect. The mean penetration resistance of 1353 measurements before and after harvesting was 2097 and 3116 kPa, respectively. Average bulk density within the field increased from 1.14 g cm^{-3} to 1.46 g cm^{-3}, but wet aggregate stability decreased from 33.4% to 17.9% following harvesting. Punctual kriging analysis was performed to prepare distribution maps of soil penetration resistance with 1 m intervals within the field. The patterns of variation in soil penetration resistance following harvesting showed remarkable differences compared to pre-harvesting.

Key words: Aggregate stability, bulk density, kriging, penetration resistance, soil compaction, spatial variability

Ağır hasat ekipmanlarının kullanıldığı silajlık mısır tarlasında toprak penetrasyon direnci dağılım paternlerindeki değişimler

Özet: Yoğun tarla trafiği kaynaklı toprak sıkışması, suyun infiltrasyonunu, kök gelişimini ve ürün verimini azaltırken, toprağın hacim ağırlığı ve toprağa giriş direncini artırmaktadır. Bu çalışmanın amacı, mısır yetiştirilen bir tarlada silaj ekipmanlarının kullanılmasından önce ve sonra toprak penetrasyon direncinin yersel değişim paternlerindeki değişimleri belirlemektir. Toprak penetrasyon direnci 100 × 400 m'lik tarlada hasattan hemen önce ve sonra 10 m'lik aralıklarla ölçülmüştür. Ölçümler herbir transect boyunca sıra üzeri ve sıralar arasında üst 20 cm'lik toprak katmanında kaydedilmiştir. Hasattan önce ve sonra 1353 ölçümün ortalama penetrasyon direnci sırasıyla 2097 kPa ve 3116 kPa'dır. Hasat sonrası çalışma alanının ortalama hacim ağırlığı 1.14 g cm^{-3}'den 1.46 g cm^{-3}'e yükselirken, ıslak agregat stabilitesi % 33.4'den % 17.9'a düşmüştür. Çalışma alanında 1'er m aralıklarla toprak penetrasyon direnci dağılım haritalarını hazırlamak için nokta kriging analizi uygulanmıştır. Hasat sonrasında toprak penetrasyon direnci değişim paternleri hasat öncesi değişim paternlerinden önemli ölçüde farklılıklar göstermiştir.

Anahtar sözcükler: Agregat stabilitesi, hacim ağırlığı, kriging, penetrasyon direnci, toprak sıkışması, yersel değişkenlik

---

* E-mail: toztas@atauni.edu.tr

Introduction

Sustainable use of agricultural lands for an optimal plant production is closely related to agricultural practices. It is commonly known that many soil properties are affected more or less by soil management practices. Heavy agricultural machines and equipments cause physical degradation of soils that leads to poor water and air movement, limited root developments, and reduction in crop yield (Raghavan et al. 1979; Hakansson et al. 1987; Kirby et al. 1997; Rosolem et al. 2002).

With increasing soil compaction level, soil bulk density increases (Gomez et al. 2002), porosity decreases (Sutherland et al. 2001), O_2 diffusion and microbial activity reduces (Dexter 1997; Li et al. 2002), root development declines (Unger and Kaspar 1994), plant nutrient uptake, infiltration, and evaporation are negatively affected (Brais 2001), and finally yield and quality significantly decreases (Unger and Kaspar 1994; Hakansson and Medvedev 1995). Soil compaction causes drainage problem in footplains and encourages runoff in hilly lands (Barfield et al. 1988; Horn et al. 1995; Brais 2001). In addition, more energy is needed for soil tillage in compacted soils (Horn et al. 1995; Whalley et al. 1995).

One of the main causes of soil compaction is intensive field traffic. Soil tillage practices, especially the ones that are performed when the soil is wet, cause the most severe soil compaction (Hakansson et al. 1987), and result in significant increase in soil bulk density and soil penetration resistance within the upper soil layer. Voorhees and Nelson (1987) reported that wheel traffic caused compaction throughout 45 cm soil depth and increased soil bulk density up to 20%. Swinford and Boevey (1984) applied 3.7 and 5.7 t loads to soil and determined that soil bulk density increased about 5%, and the volume of macro pores decreased nearly 40%.

The objective of this study was to determine changes in distribution patterns of soil penetration resistance before and after using the silage machine within a corn field.

Materials and methods

The study area, located at the Atatürk University farmland, covers 4 ha area under corn production. Soil in the study area formed on alluvial parent material was classified as Fluvaquent. The field was transected with 10 m intervals and soil penetration resistance was measured at the top layer (20 cm) on rows and inter-rows throughout each transection.

General properties of the soil in the study area were determined using a Bouyoucos hydrometer for texture (Gee and Bauder 1986), pH-meter for soil reaction (McLean 1982), Scheibler calcimeter for $CaCO_3$ (Nelson 1982), Smith-Weldon for organic matter (Nelson and Sommers 1982), ammonium acetate method for cation exchange capacity (Rhoades 1982), and Yoder type wet sieving analysis for aggregate stability (Kemper and Rosenau 1986).

A New Holland TD 75D 3600 kg tractor, a TURKAY T-MSM 450 kg silage machine, and a trailer with an empty weight of 1500 kg and with a capacity of 4000 kg were used in silaging. However, the trailer was loaded about 650 to 800 kg cut corn depending on water contents of corn during field operations.

Penetration resistance measurements were taken on rows and both sides of inter-rows 1 day before and after silaging using an Eijkelkamp-type hand penetrometer (Herrick and Jones 2002). Penetration resistance measurements were recorded at 1353 points, and bulk density values were determined using undisturbed samples (Blake and Hartge 1986) taken before and after silaging at 15 points.

The average moisture contents of soil samples at the time of penetration resistance measurements were 15% and 9% for the first (before silaging) and the second measurement (after silaging), respectively. Penetration resistance measurements were standardized for moisture changes using the following relationship developed by Busscher and Bauer (2003):

$$Y_c = Y_o\, e^{((X - 0.1)/0.132)} \qquad (1)$$

where;

Y_c: Adjusted penetration resistance, (kPa)
Y_o: Measured penetration resistance, (kPa)
X : Moisture content during measurement, (kg kg^{-1})
0.1: Selected moisture content for standardization, (0.1 kg kg^{-1})

Semivariogram and punctual kriging analyses were performed for preparing the distribution patterns of spatial variability of penetration resistance within the study field using the GS+ geostatistical software (Gamma Design Software 2005).

The experimental semivariograms were produced using the following equation (Isaaks and Srivastava 1989):

$$\gamma(h) = \frac{1}{2} N(h) \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]^2 \qquad (2)$$

where γ(h) semivariance for internal distance class h, h is the lag interval, N(h) is the total number of sample pairs for the lag interval h, $Z(x_i)$ is the measured sample value at point i, $Z(x_i + h)$ is the measured sample value at point i + h.

The best fit models were chosen by considering the minimum RSS (residual sum of squares) and maximum r^2. The exponential and spherical semivariogram models were the best-fitted models to explain spatial variability in this study:

$$\gamma(h) = C_0 + C\,[1-\exp(-h/A_0)]$$

Exponential model (3)

$$\gamma(h) = C_0 + C\left[1.5\frac{h}{A_0} - 0.5\left(\frac{h}{A_0}\right)^3\right]$$

$$\text{if } h \le A_0 \quad \text{Spherical model} \qquad (4)$$

$$\gamma(h) = C_0 + C \quad \text{if } h > A_0 \qquad (5)$$

where γ(h) is the semivariance for internal distance class h, h is the lag interval, C_0 is nugget variance, C is the structural variance, A_0 is the range of influence.

Punctual kriging procedure was used to estimate spatial distribution of soil penetration resistance:

$$Z^*(x_0) = \sum_{i=1}^{N} \lambda_i Z(x_i) \qquad (6)$$

where $Z^*(x_0)$ is the penetration resistance at an unknown location, x_0; $Z(x_i)$ is the measured values from N sampled locations, and x_i and λ_i are the weights.

Results

Some physical and chemical properties of the soils studied are given in Table 1. The soil in the study field classified as Çiftlik series is loamy-textured, containing 1.2% organic matter and 1.1% $CaCO_3$. The average initial bulk density (BD_i) and wet aggregate stability (WAS_i) values of the soil before silaging were 1.14 g cm^{-3} and 33.4%, respectively.

Penetration resistance, bulk density, and aggregate stability values before and after silaging showed statistically significant differences based on the t-test results ($P < 0.01$). Soil bulk density increased from 1.14 g cm^{-3} to 1.46 g cm^{-3}, but soil wet aggregate

Table 1. Some physical and chemical properties of the soil in the experimental field.

Soil Properties	Min.	Max.	Mean	S.D.	CV
Sand (%)	43.0	45.4	44.3	0.92	2.1
Silt (%)	37.6	37.0	38.9	0.85	2.2
Clay (%)	15.2	18.3	16.8	1.21	7.2
Textural class			Loam		
Bulk density					
Initial (before silaging-BD_i) (g cm^{-3})	1.06	1.23	1.14	0.05	4.4
Final (after silaging-BD_f) (g cm^{-3})	1.36	1.52	1.46	0.04	2.7
Soil reaction (1:2.5 water)	7.0	7.5	7.3	0.24	3.3
Organic matter (%)	1.1	1.3	1.2	0.08	6.7
Electrical conductivity (dS cm^{-1})	304	330	315	10.55	3.4
$CaCO_3$ (%)	1.0	1.2	1.1	0.08	7.3
Cation exchange capacity (cmol kg^{-1})	16.9	19.4	18.2	1.01	5.6
Aggregate stability					
Initial (before silaging-WAS_i) (%)	28.5	39.2	33.4	4.68	14.0
Final (after silaging-WAS_f) (%)	15.5	21.4	17.9	2.54	14.2

stability decreased from 33.4% to 17.9% following silaging. While the rate of increase in bulk density was 28.1%, the rate of decrease in soil aggregate stability was 46.4% following silaging. These results indicated that mechanical forces operated on the field surface during silaging caused significant soil compaction and destructed soil aggregates.

The mean penetration resistance of 1353 measurement points was 2097 ± 136 kPa before silaging, but it increased up to 3116 ± 90 kPa after silaging (Table 2). In other words, the mean penetration resistance following silaging increased by 48.6%. The coefficient of variation (CV) in the measurements performed before silaging was 6.5%, but it was 2.9% for the measurement values after silaging. Although both CV values were not so high, a lower CV after silaging indicated that almost a homogeneous compaction was occurred within the field. It could also be clearly seen in the range of the values (928 for the first and 585 for the second measurement). Small differences in the penetration resistance measurements taken after silaging were expected because field operations during silaging removed variation sources due to differences in surface features. Following silaging, a significant level of compaction occurred in everywhere within the field and extreme values due to local changes disappeared, which resulted in low CV in penetration resistance values.

Geostatistical analyses

The experimental semivariograms were developed for different directions (0°, 45°, 90°, and 135°) for soil penetration resistance values to determine directional variability within the research field. There were no distinct differences among the structures of the directional semivariogram models. Therefore, isotropy was assumed and an omni-directional semivariogram was fitted for characterizing spatial variability (Figure 1). The best-fit models and model parameters, such as nugget variance, sill variance, and the range of influence, were presented in Table 3. The range of influence, which indicates the maximum distance for dependency between 2 sampling points, was 82 m for the PR data taken before silaging and 110 m for the data taken after silaging. This means that the degree of homogeneity in the penetration resistance measurements following silaging was higher compared to before silaging.

Punctual kriging procedure was applied for estimating penetration resistance values at the unsampled points with 1 m intervals using 8 to 16 measured values. The patterns of variation in soil penetration resistance following silaging showed remarkable differences compared to before silaging (Figures 2 and 3). The maximum values of penetration resistance measured before silaging localized at the central parts of the field in the north to south directions along with the inter-rows (Figure 2). However, in the area where the lowest penetration resistance values observed throughout the east side of the field, an irrigation channel exists. This was the main reason for low penetration resistance values because penetration resistance is strongly dependent on soil moisture content. Therefore, all measurements were adjusted for 10% moisture content. However, distribution patterns of the penetration resistance values taken after silaging did not show significant differences within the field except the southwest part of the field, where excessive loading was present because of the field road (Figure 3).

Table 2. Some descriptive statistics of penetration resistance before (PR_i) and after (PR_f) silaging.

Minimum	Maximum	Range	Mean	S.D.	CV	Skewness	Kurtosis
			PR_i				
1565	2493	928	2097	136	6.5	-0.27	3.0
			PR_f				
2804	3389	585	3116	90	2.9	-0.6	3.6

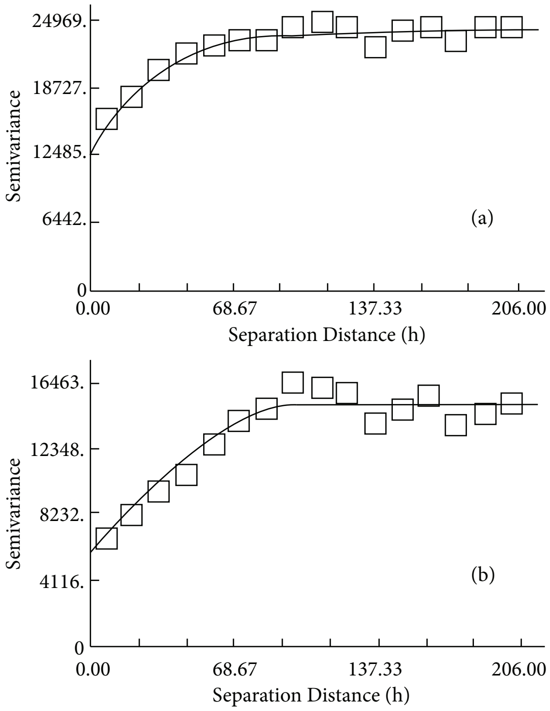

Figure 1. The best-fitted isotropic semivariogram models for the penetration resistance data before (a) and after (b) silaging.

Discussion and conclusion

The distribution patterns of penetration resistance values within the field following silaging did not show significant differences. The lowest penetration resistance measured after silaging was 2804 kPa, which was 12.5% higher than the maximum penetration resistance obtained before silaging. However, the range between the maximum and the minimum penetration resistance values decreased (37%) after silaging. There was no single point with a penetration resistance value lower than 2000 kPa following silaging. Gupta et al. (1990) emphasized that one of the most important criteria of excessive compaction in soil was to have penetration resistance greater than 2000 kPa. Moreover, penetration resistance was even higher than 3000 kPa in about 85% of the whole field. Busscher and Sojka (1987) pointed out that if penetration resistance was greater than 3000 kPa, root growth in soil was limited.

The results of this study indicated that the mean penetration resistance of loamy soil within the study field increased (48.6%) from 2097 kPa to 3116 kPa

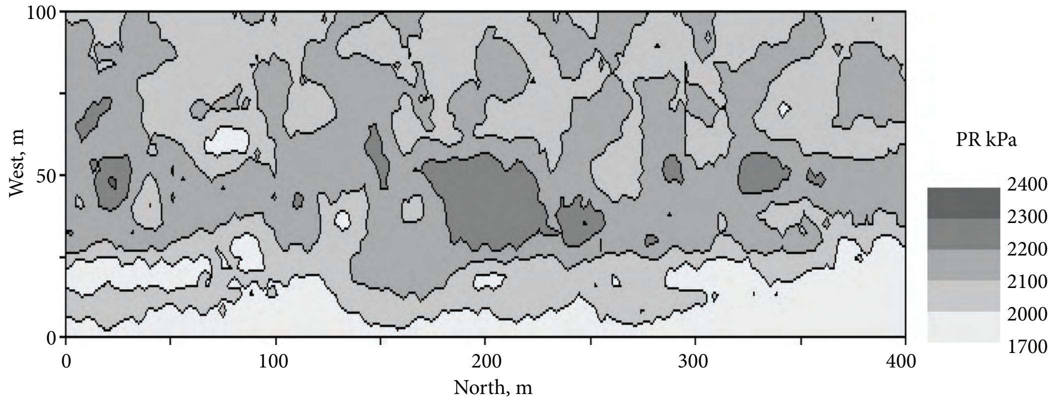

Figure 2. Distribution patterns of soil penetration resistance within a corn field before silaging.

Table 3. Best-fitted semivariogram models and model parameters for soil penetration resistance values before and after silaging.

Best-fit model	Nugget (C_0)	Sill ($C+C_0$)	$C_0/(C+C_0)$	Range of influence (A_0)	r^2
			Before silaging		
Exponential	11970	23950	0.50	82	0.928
			After silaging		
Spherical	5290	13850	0.38	110	0.923

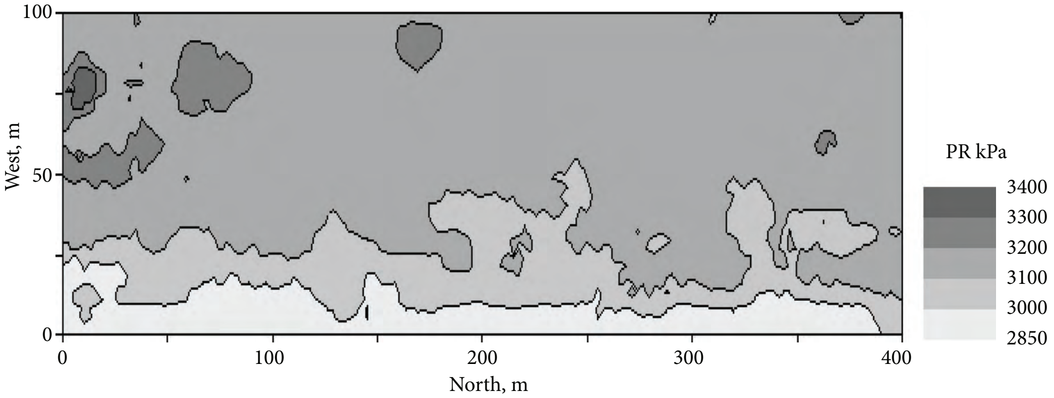

Figure 3. Distribution patterns of soil penetration resistance within a corn field after silaging.

following silaging. Similarly, the mean bulk density increased (28.1%) from 1.14 g cm^{-3} to 1.46 g cm^{-3}, but the mean wet aggregate stability decreased (46.4%) from 33.4% to 17.9%. Van Dijck and Van Asch (2002) studied the compaction of a loamy soil due to tractor traffic in vineyards and orchards and found that bulk density values were greater in wheel tracks (1.51 ± 0.18) than inter-rill areas (1.33 ± 0.14) in the top soil.

In conclusion, the distribution patterns and these results indicated that a significant compaction occurred within all over the study field after the use of heavy silaging machinery for corn harvesting.

References

Barfield BJ, Barnhisel RI, Hirschi MC, Moore ID (1988) Compaction effects on erosion of mine spoil and reconstructed topsoil. Trans of the ASAE 31: 447-452.

Blake GR, Hartge KH (1986) Bulk density. In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, 2nd ed (Ed. A Klute), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 363-375.

Brais S (2001) Persistance of soil compaction and effects on seedling growth in Northwestern Quebec. Soil Sci Soc Am J 65: 1263-1271.

Busscher WJ, Bauer PJ (2003) Soil strength, cotton root growth and lint yield in a southeastern USA coastal loamy sand. Soil and Tillage Research 74: 51-159.

Busscher WJ, Sojka RE (1987) Enhancement of subsoiling effect on soil strength by conservational tillage. Transactions of the ASAE 30: 888-892.

Dexter AR (1997) Physical properties of tilled soils. Soil and Tillage Res 43: 41-63.

Gamma Design Software (2005) GS+ Geostatistics for the Environmental Sciences. GS+ User's Guide, Ver 7, Plainwell, MI, USA.

Gee GW, Bauder JW (1986) Particle-size analysis. In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, 2nd ed (Ed. A Klute), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 383-411.

Gomez A, Powers RF, Singer MJ, Horwath WR (2002) Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. Soil Sci Soc Am J 66: 1334-1343.

Gupta SC, Hadas A, Voorhees WB, Wolf D, Larson WE, Sharma PP (1990) Development of guides on the susceptibility of soils to excessive compaction. University of Minnesota, BARD Report, St Paul.

Hakansson I, Medvedev VW (1995) Protection of soils from mechanical overloading by establishing limits for stresses caused by heavy vehicles. Soil and Tillage Res 35: 85-97.

Hakansson I, Voorhees WB, Elonen P, Raghavan GNS, Lowery B, van Wijk ALM, Rasmussen K, Riley H (1987) Effect of high axle-load traffic on subsoil compaction and crop yield in humid regions with annual freezing. Soil and Tillage Res 10: 259-268.

Herrick JE, Jones TL (2002) A dynamic cone penetrometer for measuring soil penetration resistance. Soil Sci Soc Am J 66: 1320-1324.

Horn R, Domzal H, Jurkiewicz AS, Ouwerkerk CV (1995) Soil compaction processes and their effects on the structure of arable soils and the environment. Soil and Tillage Res 35: 23-36.

Isaaks EH, Srivastava RM (1989) An Introduction to Applied Geostatistics. Oxford University Press, New York.

Kemper WD, Rosenau RC (1986) Aggregate stability and size distribution. In: Methods of Soil Analysis, Part 1, Physical and Mineralogical Methods, 2nd ed (Ed. A Klute), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 425-442.

Kirby JM, Blunden BG, Trein CR (1997) Simulating soil deformation using a critical-state model:II. Soil compaction beneath tyres and tracks. European J Soil Sci 48: 59-70.

Li CH, Ma BL, Zhang TQ (2002) Soil bulk density effects on soil microbial populations and enzyme activities during the growth of corn (*Zea mays L.*) planted in large pots under field exposure. Canadian J Plant Sci 82: 147-154.

McLean EO (1982) Soil pH and lime requirement. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed (Ed. AL Page), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 199-224.

Nelson DW, Sommers LE (1982) Total carbon, organic carbon, and organic matter. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed (Ed. AL Page), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 539-579.

Nelson RE (1982) Carbonate and gypsum. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed (Ed. AL Page), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 181-197.

Raghavan GSV, McKyes E, Taylor F, Richard P, Watson A (1979) The relationship between machinery traffic and corn yield reduction in successive years. Trans ASAE 22: 1256-1259.

Rhoades JD (1982) Cation exchange capacity. In: Methods of Soil Analysis, Part 2, Chemical and Microbiological Properties, 2nd ed (Ed. AL Page), American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, pp. 149-157.

Rosolem CA, Foloni JSS, Tiritan CS (2002) Root growth and nutrition accumulation in cover crops as affected by soil compaction. Soil Tillage Res 65: 109-115.

Sutherland RA, Bussen JO, Plondke DL, Evans BM, Ziegler AD (2001) Hydrophysical degradation associated with hiking-trail use: a case study of Hawai'Iloa ridge trail, O'Ahu, Hawai'i. Land Degradation and Development 12: 71-86.

Swinford JM, Boevey TMC (1984) The effects of soil compaction due to infield transport on ratoon cane yields and soil physical characteristics. In: Proceedings South African Sugar Technologists, Association No: 58, pp. 198-203.

Unger PW, Kaspar TC (1994) Soil compaction and root growth: a review. Agron J 86: 759-766.

Van Dijck SJE, Van Asch TWJ (2002) Compaction of loamy soils due to tractor traffic in vineyards and orchards and its effect on infiltration in southern France. Soil and Tillage Research 63: 141-153.

Voorhees WB, Nelson WW (1987) Compaction and soil structure modification by wheel traffic in the Northern Corn Belt. Soil Sci Soc Am J 42: 344-347.

Whalley WR, Dumitru E, Dexter AR (1995) Biological effects of soil compaction. Soil and Tillage Res 35: 53-68.