Soil Compaction from Liquid Manure Tanker Traffic

J. L. B. Culley, N. K. Patni

ABSTRACT

LOADED commercial liquid manure tankers exert substantial axle loads on soils and thus may induce significant compaction. Changes in soil bulk density and water desorption characteristics of a maize-cropped Haplaquent were evaluated approximately midway through the growing season, under a range of manure application methods including: plowed under in the autumn. disked in the spring, and sidedressed with and without injection. Soil structure changes from the manure disposal practices varied from year to year. This seasonal effect may have been related to soil water content at application time. Moldboard plowing of manure in the autumn appeared to have no effect on soil porosity the following season while spring treatment of wet soil resulted in compaction, as indicated by a reduction in the volume of pores drained at high matric potentials (>-8 kPa).

INTRODUCTION

In recent years, concerns have developed over soil structure degradation resulting from traffic by ever larger and heavier farm machinery. Raghavan et al. (1977) observed that tire contact pressures, the number of passes, and soil water content affected near-surface soil bulk density values, while total axle load and soil strength appear to determine the depth to which compactive stresses are transmitted (Voorhees et al., 1986). Soane et al. (1980/81) indicated that for agricultural vehicles and implements, the greatest loads and tire pressures were associated with slurry tankers and bulk material spreaders.

Despite these compaction concerns, the agronomic benefits of manure, particularly in solid form, as a soil conditioner are well known. For example. Sommerfeldt and Chang (1985) measured decreasing densities and power requirements for tillage with increasing annual rates of manure application. Effects of liquid manure, particularly when applied with commercial-scale equipment, on soil physical properties have not been extensively documented. Pagliari et al. (1985) observed that annual applications of pig slurry increased total porosity of a silty clay but decreased the proportion of large pores. which were defined as those with equivalent cylindrical radii of 250 µm.

Article was submitted for publication in December, 1986; reviewed and approved for publication by the Power and Machinery Div. of ASAE in August, 1987.

Contribution 86-89 from Land Resource Research Center and 1442 from Animal Research Centre, Central Experimental Farm, Ottawa. Ontario. Canada.

The authors are: J.L.B. CULLEY, Physical Scientist. Land Resource Research Centre. and N.K. PATNI, Research Scientist, Animal Research Centre. Central Experimental Farm, Ottawa, Ontario. Canada.

Current Province of Ontario recommmendations (Ontario Ministry of Agriculture and Food, 1986) emphasize nitrogen (N) conservation. Consequently. spring application followed by immediate incorporation is recommended as most effectively conserving manure-N. However, injection of manure early in the growing season has been shown to inhibit corn growth under some circumstances in the US Corn Belt (Schmitt and Hoeft, 1986). In addition, injection is time consuming, and many operators who work large land holdings, experience scheduling difficulties during spring and early summer.

The objective of this study was to characterize growing-season soil water release characteristics and hence, pore size distributions, as they are affected by a range of liquid manure applicaiton methods and times using commercial equipment on relatively large experimental units.

MATERIALS AND METHODS

Liquid manure from dairy cattle was applied to a silage corn-cropped Typic Haplaquent soil having a loamy-textured A_p horizon and clay loam B and C horizons. Prior to the experiment the area was vegetated by alfalfa *(Medicago sativa)* heavily infested with quackgrass *(Agropyron repens).* Six land treatments. each with 4 replications, were imposed in a randomized complete block design (Fig. 1). Treatments were: (a) control; (b) N fertilizer applied through a bulk spreader; (c) manure, preplant incorporated; (d) manure sidedress-injected; (e) manure sidedress without incorporation; (f) manure autumn incorporated with a moldboard plow. Each plot measured 14.6 m in width by 67.1 m in length. The study commenced in May 1982 with manure and fertilizer being broadcast on the appropriate plots. The entire area was then plowed with a 5-furrow moldboard plow mounted on a John Deere 4240 tractor. The field was then sprayed with atrazine and disked twice. Spring-time commencement of the study meant that there was no autumn treatment in year 1 (Y_1), and that this autumnal treatment (6) had one less application of manure over the experimental period.

Corn *(Zea mays)* was planted at 65000 plants ha^{-1} using a 4-row planter. A small amount of mixed fertilizer was banded near the seed. Three applications of atrazine in year (Y,) were required to control quackgrass adequately, but one treatment (pre-plant, incorporated) was sufficient therafter. Sidedressings of manure were applied 4 to 5 weeks after planting. Subsequently, all plots were plowed in the autumn; spring manure and fertilizer applications were incorporated with a disk cultivator. All plots received two passes with a disk cultivator as secondary tillage. Three annual manure applications were made to treatments 3, 4 and 5, but just two were made to treatment 6 (autumn) plots. First year

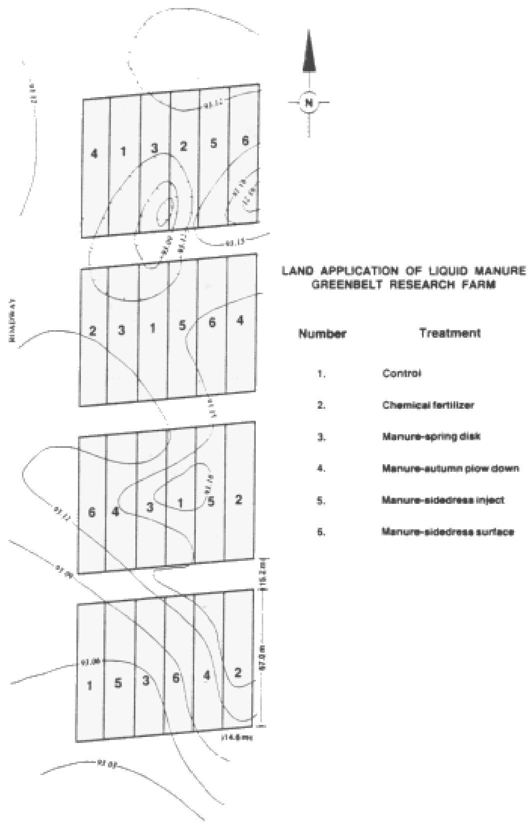

Fig. 1—General experimental plan showing plot layout and treatments. Contour elevations are in meters relative to an arbitrary benchmark.

residual (Y_{res}) effects were also monitored.

Manure was transported and applied from commercial pressurized tankers (Clay Equipment Corporation Honeywagons) with 8.21 m^3 capacity. A fully loaded tanker weighed 16060±410 kg; its weight empty was 9460±570 kg. Each tanker was supported by tandem axles on each of which two tires (size 16.5 L — 16.1 SL) were mounted. They were inflated to a pressure of 276 kPa. Spring- and autumn-applied manure was broadcast on the surface while that sidedressed was dispensed through injection knives located behind fluted coulters. For sidedress application, injection knives remained above the soil surface or were set to reach a depth of 0.15 to 0.20 m. All interrows of sidedress plots were trafficked during manure applications. Application rates were chosen to apply 250 kg ha^{-1} of total N which was estimated to supply the same amount of NH_4-N as the fertilizer N. This required average application rates of 90000 kg ha^{-1} of liquid manure on manured plots.

Soil water release characteristics were measured from undisturbed soil cores which were obtained 4 to 5 weeks after sidedressings, when the crop was in the tasseling-to silking stages. In year II (Y_{II}), cylindrical cores 25.4 mm in height and 76.2 mm in diameter were taken from interrow areas of all plots at depths of 0.10, 0.20 and 0.30 m. For the next 2 years of the study, cores were extracted from depths of 0.06. 0.16 and 0.26 m. Cores were taken from interrows untracked during planting. As all treatment plots received the same tillage and harvesting traffic, no attempt was made to monitor or control wheel traffic from these activities. Because of disturbance associated with sampling, each core was obtained from a new boring, and so soil depth was treated as a split plot treatment in the statistical analysis. Soil water desorption curves were determined using the method of Topp and Zebchuk (1979). Following equilibration on the tension media and weighing, soil cores were dried for several days at 105 ºC, thus allowing calculation of water contents and bulk densities. Subsamples of Y_{II} cores were sieved, packed in rings and saturated on ceramic plates. Gravimetric soil water contents of these subsamples were determined at pneumatic pressures of 400 and 1500 kPa. The ANOVA procedure (SAS Institute Inc. 1985) was applied to the data set. Treatment means were compared using the LSD procedure.

D'Hollander (1979) observed that soil water desorption curves often resembled the cumulative normal distribution function, and hypothesized that the effective pore radii followed a log normal distribution. Estimates of the log-transformed effective pore radius mean, μ, and deviation, σ, for each treatment and depth in years Y_{II}, Y_{III} and (Y_{res}) were obtained from application of

$$pF(\theta)=\log_{10}(A)-\mu-\sigma\,\phi^{-1}\left[\frac{\theta-\theta_r}{\theta_s-\theta_r}\right]\quad\ldots\ldots\ldots\ldots\,[1]$$

which was given by Hill et al. (1985). In this equation pF(θ) is the $\log_{10}$ of the negative of the applied matric potential (ψ), A is a constant, ϕ^{-1} is the inverse standard cumulative normal distribution function with argument,$[(\theta - \theta_r)/(\theta_s - \theta_r)]$. θ_s and θ_r are the volumetric water contents at saturation and at air dryness, respectively. Air-dry θ is 0.034 m^3m^{-3} above 0.2 m and 0.054 m^3m^{-3} below. Estimates of μ and σ were obtained using a nonlinear estimation routine (SAS Institute Inc, 1985) with each observation weighted by the slope of the semi-log desorption curve ($\partial pF/\partial\theta$) as D'Hollander (1979) suggested.

RESULTS AND DISCUSSION

Bulk Density

Analysis of variance showed that soil density was not affected by land treatment either during treatment years or in Y_{res} (Table 1). Despite this nonsignificant result, certain treatment means were significantly different. The depth averaged spring-disk and sidedress densities were significantly greater ($p<0.05$) than those with fall-plowed or sidedress-injected manure in Y_{II} (Table 2). Also, the average density at 0.1 m depth was significantly less ($p<0.05$) than that at 0.2 m; while at 0.3 m, it was not significantly less ($p>0.10$) than that at 0.2 m. Different results were obtained in Y_{III} where the pooled density from all spring-applied plots was significantly greater than that for the control, fertilized and autumn-applied treatments ($p<0.05$). The depth effect was highly significant, with the near-surface layer much less dense than the two lower layers, whose average densities differed by just 0.01 Mg m^{-3}. The greatest difference

TABLE 1. SIGNIFICANCE LEVELS OF F VALUES CALCULATED FROM ANOVA PROCEDURE APPLIED TO SOIL CORE DENSITY AND WATER RELEASE DATA

Year*	Source of variation †	Bulk density	Saturation traction at specified matric potential. - kPa 0.5	1.0	2.0	4.0	6.0	8.0	10.0	15.0	22.5	35.0	30.0	400.0	1500.0
II	Land treatment	0.16	0.06	0.02	0.03	0.02	0.05	0.06	0.06	0.08	0.10	1.09	0.11	0.13	0.12
	Depth	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	Treatment X depth	0.26	0.03	<0.01	<0.01	0.01	0.09	0.15	0.18	0.28	0.31	0.27	0.34	0.84	0.76
III	Land treatment	0.19	0.12	0.02	<0.01	0.01	0.05	0.10	0.16	0.26	0.34	0.39	0.39	-	-
	Depth	<0.01	0.04	<0.01	<0.01	<0.01	0.01	0.01	0.02	0.03	0.04	0.05	0.07	-	-
	Treatment X depth	0.70	0.56	0.37	0.44	0.42	0.42	0.38	0.36	0.33	0.29	0.30	0.22	-	-
Residual	Land treatment	0.36	0.46	0.37	0.27	0.32	0.48	0.55	0.58	0.63	0.66	0.69	-	-	-
	Depth	<0.01	0.65	0.03	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	-	-	-
	Treatment	0.84	0.48	0.15	0.26	0.43	0.54	0.52	0.55	0.53	0.52	0.46	-	-	--

* Years 11 and III refer to samples collected during the 2nd and 3rd years of manure application: the residual year refers to cores taken the following season when no treatments were applied.

† Sources of variation include method of manure application, fertilizer from bulk spreader or nothing, soil depth, and their interaction.

between Y_{II} and Y_{III} occurred under sidedress-injection. In Y_{III}, cultivation associated with injection induced compaction. while the opposite was the case in Y_{II}. These seasonal differences may have been related to soil water content. For the 2-day period prior to Y_{II} spring applications, potential evapotranspiration (PE, estimated by an equation given by Baier (1971) exceeded rainfall by 1 and 10 mm for the disk and sidedressing treatments, respectively, indicating relatively dry soil conditions in the near-surface zone. For the same period in Y_{III}, however, rainfall exceeded PE by 15 and 13 mm for disk and sidedressing, respectively. In Y_{res} there was no significant treatment effect ($p<0.05$) within any soil layer. The effect of depth differed in $Y_{res.}$ The near-surface layer density was not significantly different from that at 0.16 m, but was 0.09 Mg m^{-3} lower ($p<0.01$) than that at 0.26 m; densities for the two layers differed from each other at $p<0.05$.

Overall, the coefficients of variation (CV) for density ranged from 5.9 in Y_{III} to 12.0% in Y_{II}. Such variations in density are similar to those observed by others (Warwick and Neilsen, 1980).

Soil Water Desorption

Soil water desorption curves were analysed statistically using both volumetric water content (θ) and saturation fraction *(θ/θ_S)* as dependent variables. Land treatment effects were discernible with θ/θ_S, but not with θ. Land treatments affected θ/θ_S at all matric potentials (t.p)>-35 and -8 kPa in Y_{II} and Y_{III}, respectively (Table 1). Not surprisingly, most of these differences occurred in the near-surface zone; depth was highly significant ($p<0.01$) at all ψ in Y_{II} (Fig. 2). Cultivation associated with the sidedress-injection decreased θ/θ_S at all depths in Y_{II}; wheel-tracking due to sidedressing slurry at this time increased θ/θ_S above 0.2 m. As with density, different results were observed in Y_{III},; spring-amended plots exhibited similar desorption behavior having increased θ/θ_S, above 0.16 m relative to the other land treatments (Fig. 3). There was no land treatment effect in $Y_{res,}$ indicating that compactive effects from slurry disposal, as estimated by density and water desorption characteristics,

TABLE 2. EFFECT OF LAND TREATMENT AND DEPTH ON SOIL BULK DENSITY

Soil depth	Land treatment: Control	Fertilizer	Manure application method: Fall plow	Spring disk	Sidedress Inject	Sidedress Surface
m			Mg m^{-3}			
			Year II			
0.10	1.28	1.39	1.17	1.44	1.06	1.44
0.20	1.38	1.40	1.45	1.37	1.32	1.44
0.30	1.38	1.31	1.18	1.39	1.33	1.35
*$S\bar{x}$ = 0.12						
			Year Ill			
0.06	1.24	1.29	1.28	1.34	1.39	1.43
0.16	1.39	1.43	1.36	1.47	1.52	1.45
0.26	1.41	1.36	1.40	1.47	1.45	1.48
$S\bar{x}$ = 0.05						
			Residual Year			
0.06	1.22	1.19	1.13	1.11	1.18	1.25
0.16	1.27	1.17	1.17	1.11	1.27	1.27
0.26	1.30	1.24	1.25	1.27	1.30	1.27
$S\bar{x}$ = 0.08						

* refers to standard error for comparisons between any two treatment means.

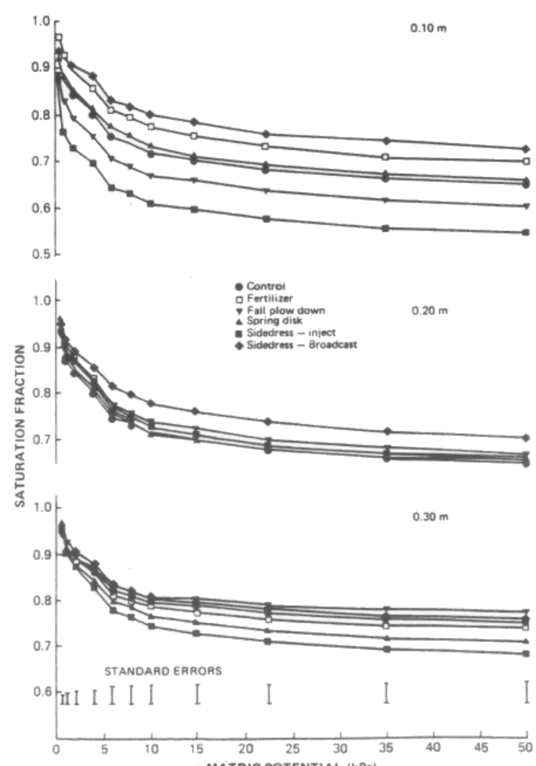

Fig. 2-Soil water desorption curves in year II.

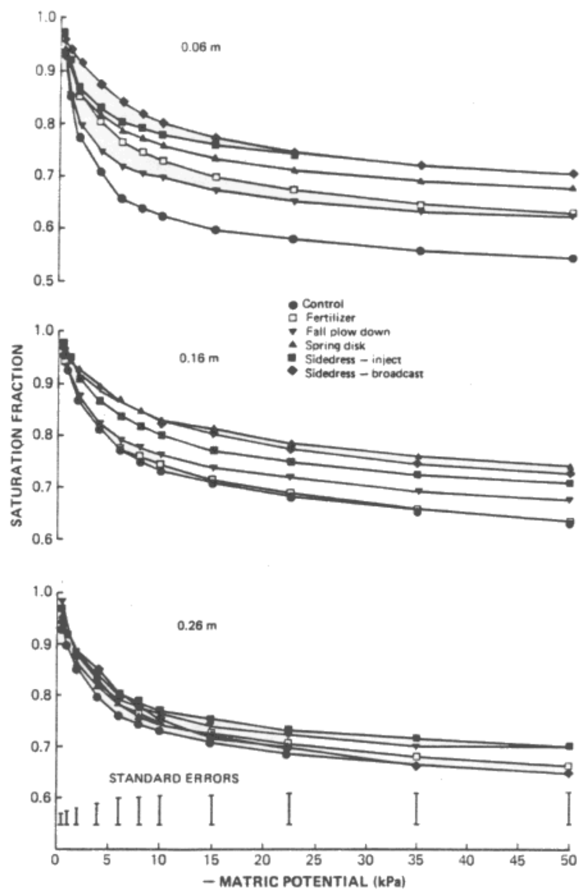

Fig. 3- Soil water desorption curves in year III.

did not persist for more than 1 year on termination of the applications. Coefficients of variation for θ/θ_S, in undisturbed soil cores ranged from about 3% at ψ = -0.5 kPa to 10% at ψ = -50 kPa. Repacked-soil CVs for θ/θ_S, were substantially greater than those observed for undisturbed soil, being 30% at ψ = -1500 kPa.

Grable and Siemer (1968) suggested that optimum corn root elongation required air filled porosity of 0.12-0.15. In Y_{II} all soil layers of all treatments had air filled porosities of 0.15 at ψ of -5 kPa. which may be a reasonable estimate of the in-situ gravitationally drained ψ ("field capacity") for this soil. This was not the case in Y_{III} however, when spring-treated soil had air filled pore values less than 0.15 at ψ = -5 kPa at the 0.16 m depth.

Means, deviations and confidence intervals of the log-transformed pore size distributions for pooled spring and autumn/control Y_{III} , desorption data are presented in Table 3. Of note is the great range of pore sizes. Pores with radii in the order of 1-10 nm are associated with clay platelets and their electrical double layers, while those measuring 1-2 mm in diameter are probably derived from biological activity or wetting and drying cycles. In Y_{III}, the greatest differences in pore size distribution were observed in the cultivated zone, where the transformed mean radii of the autumn/control treatments were five-six fold greater than those receiving manure in the spring. Substantially greater dispersion of pore sizes was observed in the deepest layer. This may be related to the finer texture at this depth compared with that of the overlying plow layer (clay loam and loam. respectively). Predicted pF values from equation [1] were well correlated with those applied (Fig. 4). Correlation coefficients for the 3 layers ranged from 0.97 to 0.99 for the 0.06 and 0.16 m depths, respectively. Inclusion of the disturbed soil

TABLE 3. PORE SIZE DISTRIBUTION PARAMETERS FOR POOLED GROWING SEASON AND AUTUMN/FERTILIZER/CONTROL MANURE TREATMENTS IN YEAR III.

Manure treatment	Depth	Base 10 logarithmic pore radii †		Mean*	Probability interval	
		Mean	Standard Deviation		Lower 2.5%	Upper 97.5%
					µm	
Autumn/None	0.06	0.576	1.393	648	0.007	2028
		(0.001) ‡	(0.049)$			
Growing Season	0.06	0.309	1.208	98	0.009	475
		(0.042)	(0.048)			
Autumn/None	0.16	0.315	1.347	253	0.005	902
		(0.001)	(0.026)			
Growing Season	0.16	0.153	1.162	51	0.008	269
		(0.028)	(0.030)			
Autumn/None	0.26	0.097	1.668	1989	0.001	2324
		(0.001)	(0.039)			
Growing Season	0.26	0.202	1.509	667	0.002	1444
		(0.001)	(0.031)			

* mean radius of log normally distributed pores
† refers to estimates of μ and *a*, measured µm, obtained from equation [1] .
‡ refers to asymptotic standard errors as calculated by the SAS Nonlinear estimation (NLIN) alogrithm.

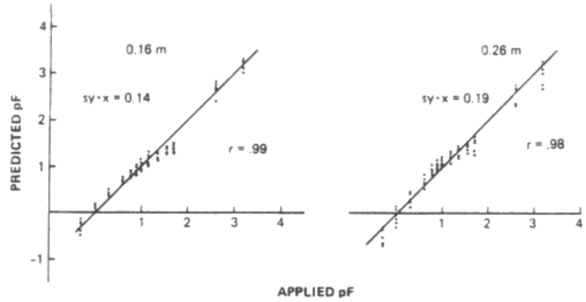

Fig. 4- Predicted and applied pF values for 0.16 and 0.26 m layer soil water desorption data from year III. Solid lines denote 1:1 relationship.

desorption data (applied pFs of 2.60 and 3.18) did not affect regression coefficients. Slopes of the best-fits varied from 0.93 to 0.99; none were significantly different from 1.00 at p = 0.01. Fig. 5 indicates that the value of the pore size density function for the Y_{II} near-surface zone of the sidedress-injected soil was 41% greater than that without incorporation at ψ = -5 kPa (equivalent radius of 30 μm).

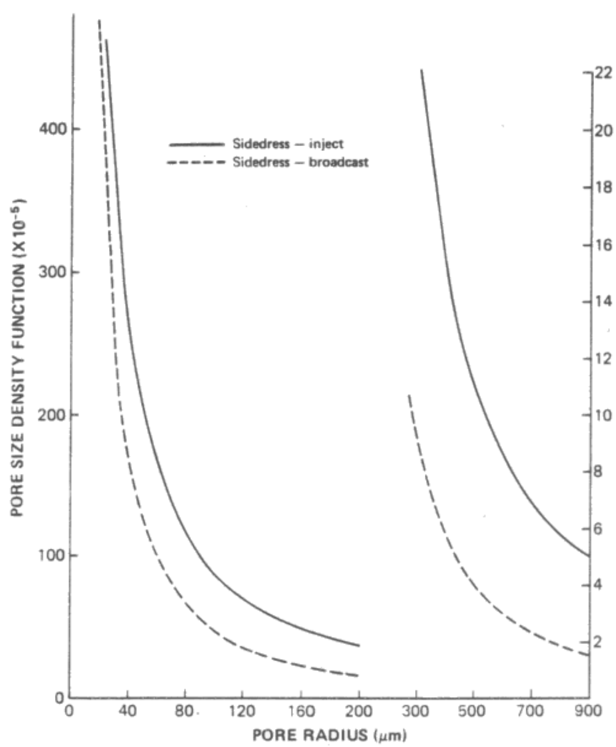

Fig. 5- Pore size density functions at 0.10 m depth of side-dress-inject and surface-broadcast treatments in year II.

Based on these distributions, 50% of pores at 0.10 m depth in the injected plots were empty at ψ = -19 kPa; a six-fold lower ψ (-119 kPa) was required to drain 50% of the pores at the same depth under the broadcast treatment. No such differences were detected the following year when applications took place under much wetter conditions. Thus, soil loosening associated with injection appears to be strongly affected by soil moisture conditions at trafficking.

SUMMARY

The near-surface interrow zone of a loam soil exhibited a higher bulk density and fewer macropores (pores drained at matric potentials >-8 kPa) when corn was sidedressed with liquid manure. Injection of the manure with knives alleviated this compaction in one year. but not the following year. This may have been the result of different soil water contents during trafficking. Surface-soil water contents during sidedressing were substantially greater the second year. Moldboard plowing of manure in the autumn appeared to have no effect on soil porosity the following growing season, while spring applications under wet soil conditions induced significant reductions in the volume of larger pores during the growing season.

References

1. Baler. W. 1971. Evaluation of latent evaporation estimates and their conversion to potential evaporation. Can. J. Plant Sci. 51:255-266.
2. D'Hollander. E. H. 1979. Estimation of the pore size distribution from the moisture characteristic. Water Resour. Res. 15:107-112.
3. Grable, A. R. and E. G. Siemer. 1968. Effects of bulk density, aggregate size, and soil water suction on oxygen diffusion, redox potentials, and elongation of corn roots. Soil Sci. Soc. Amer. Proc. 32:180-186.
4. Hill. R. L., R. Horton and R. M. Cruse. 1985. Tillage effects on soil water retention and pore size distribution of two mollisols. Soil Sci. Soc. Am. J. 49:1264-1270.
5. Ontario Ministry of Agriculture and Food. 1986. Publication 296, Field Crop Recommendations. Queen's Printer for Ontario. Toronto, Canada. pp 52-54.
6. Pagliari, M., M. LaMarca and G. Lucamante. 1985. Relationships between soil structure and time of landspreading of pig slurry. p. 45-56. In: Long term effects of sewage sludge and farm slurries applications. EEC seminar in Pisa. Sept. 1984. J. H. Williams, G. Guidi and P. L'Hermite (ed), Elsevier Applied Science Publishers, London. England.
7. Raghavan, G. S. V., E. McKyes and B. Beaulieu. 1977. Prediction of clay soil compaction. Journal of Terramechanics 14:31-38.
8. SAS Institute Inc. 1985. SAS User's Guide: Statistics. Version 5 Edition, Cary, NC.
9. Schmitt. M. A. and R. G. Hoeft. 1986. Manure injection can sometimes injure corn crop. Crops and Soils 38(8):19-22.
10. Soane, B. D.. P. S. Blackwell, J. W. Dickson and D. J. Painter. 1980/81. Compaction by agricultural vehicles: A review II. Compaction under tyres and other running gear. Soil and Tillage Research 1:373-400.
11. Sommerfeldt. T. G. and C. Chang. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci. Soc. Am. J. 49:983-987.
12. Topp, G. C. and W. Zebchuk. 1979. The determination of soil water desorption curves for soil cores. Can. J. Soil Sci. 59:19-26.
13. Voorhees, W. B., W. W. Nelson, and G. W. Randall. 1986. Extent and persistence of subsoil compaction caused by heavy axle loads. Soil Sci. Soc. Am. J. 50:428-433.
14. Warwick. A. W. and D. R. Nielsen. 1980. Spatial variability of soil physical properties in the field. In: Applications of soil physics. D. Hillel (ed.) Academic Press, New York, NY.