EFFECTS OF TIRE CONTACT PRESSURE ON CORN YIELD

G.S.V. Raghavan[1], E. McKyes[1], G. Gendron[2], B.K. Borglum[1], and H.H. Le[1]

[1]*Department of Agricultural Engineering, and* [2]*Department of Plant Science, Macdonald College of McGill University, Ste. Anne de Bellevue, Quebec H0A 1C0*

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To link the damage caused to the soil structure by machinery wheels and its effect on corn yield, a 100-plot experiment was established. Tire contact pressures ranging from none to 61.8 kPa were used with 1, 5, 10 and 15 vehicle passes over the same tracks, either before or after the seeding of silage corn. The results indicated the damage caused by the before-seeding treatment to be somewhat higher than that of the after-seeding treatment. Plots with no traffic treatments produced a total average dry matter yield of 16,000 kg/ha which is 30% higher than the provincial hybrid test mean for that variety of corn. A reduction of 45-50% in production was observed for higher contact pressures operating over the maximum number of passes.

INTRODUCTION

When heavy machinery is used intensively in row crop production, the compaction of soil is expected to be considerable. Many researchers have measured density changes in different soil types as a function of applied load and soil moisture content (Söhne 1958; Soane 1970; Chancellor 1971). In addition, the number of passes of a machine and the wheelslip have been found to influence compaction (Davies et al. 1973; Raghavan et al. 1975, 1976). But the consequences of soil density changes with respect to crop yields comprise the primary consideration for agricultural production. And, while numerous studies have been made on compacted soil properties as they affect root penetration and air and water availability to plants (Weaver and Crist 1922; Lemon and Erickson 1952; Taubenhaus et al. 1961; Huck et al. 1975), very few experiments have combined the knowledge of soil mechanics and agronomy to describe the exact crop yields to be expected as a function of particular machinery sizes and traffic programs.

Several demonstrations have been carried out to show that density variations in topsoil do influence the growth of plants in the field. Phillips and Kirkham (1962) and Morris (1975), for example, reported on corn yield reductions of 10 and 22%, respectively, due to compaction. Saini and Lantagne (1974) measured reduced yields in potatoes of up to 22% with increases in soil density, and Feldman and Domier (1970) observed reduced wheat growth after increased machinery traffic.

The intent of this study was to describe the effects of varying levels of tire contact pressure and traffic intensity on the yields of silage corn, so as to be able to assess the agronomic and economic consequences of compaction on crop production over a considerable range. In the field experiment, three different tire contact pressures were used for various numbers of passes, from 0 to 15, before or after seeding, on a Ste. Rosalie clay plot of the Macdonald College research station.

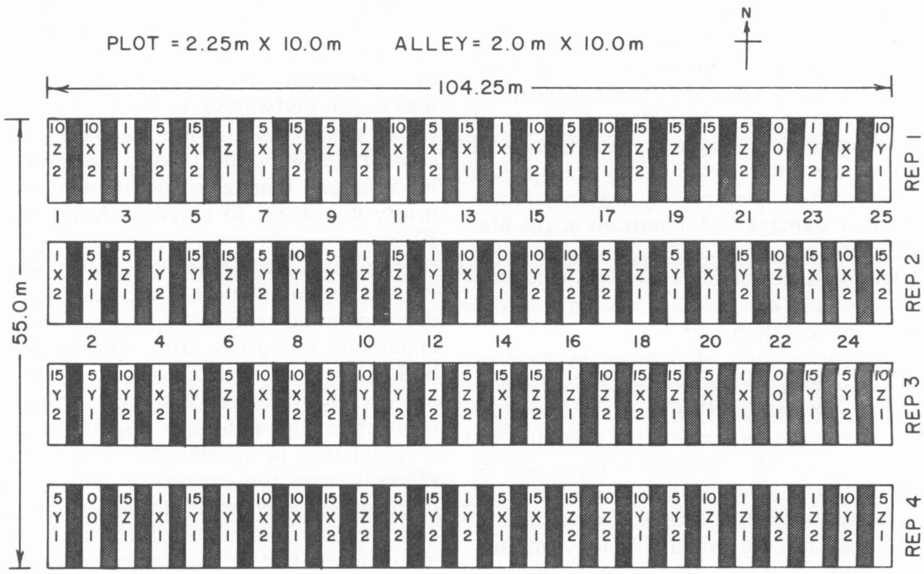

Figure 1. Randomly allotted treatments for each plot. The contact pressures *X*, *Y* and *Z* are respectively 61.8, 41.2 and 31.4 kPa.

EXPERIMENTAL METHODS

The experimental field was prepared by fall plowing in 1975, followed by rototilling in May of 1976 to a depth of approximately 25 cm, resulting in an average topsoil dry density of 0.84 g/cm^3. Subsequently, 100 plots of 2.25 X 10-m size were sectioned, and four replicates each of 25 different traffic treatments were executed on the plots in a randomized complete block design (Fig. 1). The weights of standard two-wheel drive tractors used in the treatments were 1,700, 3,515 and 4,420 kg and the resulting ground pressures, over the measured rear tire contact areas, were respectively 31.4, 41.2 and 61.8 kPa. Two traffic timings were employed, one before seeding in which the entire plot surface was covered by traffic, and the other consisting of machine passes between rows after plant emergence. The numbers of tractor passes selected were 1, 5, 10, 15 and a control of zero traffic.

Standard applications of herbicides and fertilizers were made on all the plots, including rates of 3 kg atrazine, 4.5 kg lasso, 450 kg 5-20-20 and 340 kg post-emergence ammonium nitrate per hectare. In order to preserve the soil structures after treatments, the seeding was done by hand without stepping on the plots and two seeds were sown in each hole, with subsequent thinning.

During the growing season, measurements of various crop growth and soil structural properties were made, in particular the soil densities to a depth of 20 cm. A gamma ray density probe was used for this purpose and several soundings were made at 5-cm depth intervals in each replicate treatment.

At season's end, harvesting of the two middle rows of each plot was done completely by hand, excluding the end plants in each row, which eliminated essentially all border effects. Firstly, every alternate plant was cut from the middle two rows to form fraction *A* of the plot and their combined weight was taken. In this group, a few plants were collected at random and chopped to obtain 1,000-g samples for total plant moisture determinations. Subsequently, the remaining plants of the middle two rows of the same plot were chopped at a height of 6-8 cm above the ground as before, and their total weight was

Figure 2. Plant heights measured after 10 wk. Plots with no traffic treatment and five passes of 41.2 kPa treatment (above); plots with no traffic treatment and fifteen passes of 41.2 kPa treatment (below).

TABLE I. CORRELATION COEFFICIENTS
P>R under HO: RHO = 0/N = 100

	Passes	Pressure
Plant moisture	0.2631	0.1844
	0.0082	0.0663
Ear moisture	0.4491	0.4189
	0.0001	0.0001
Yield	-0.6019	-0.4173
	0.0001	0.0001
Ear yield	-0.6369	-0.4316
	0.0001	0.0001
Percent shelling	-0.2427	-0.3427
	0.0150	0.0005
Grain yield	-0.6353	-0.4363
	0.0001	0.0001

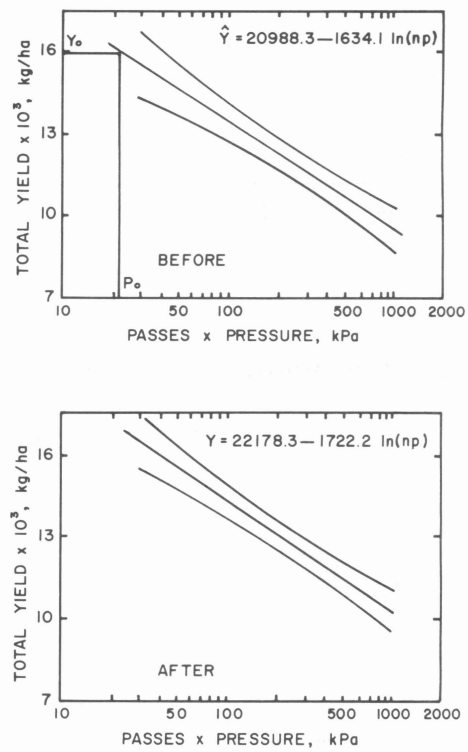

Figure 3. Total plant yields vs. traffic treatment for both before- and after-seeding categories.

recorded. This was called fraction *B*. All the ears of fraction *B* were separated and husked to determine the total weight and the number of ears. From this group, a few ears were picked at random and chopped to collect a 1,000-g sample for an ear moisture content determination. Also, 10 or more ears from each plot were stored for determining the dry matter grain yield. This procedure was repeated on all the 100 plots and data were reduced in terms of the required output variables: plant moisture, ear moisture, total yield, ear yield, shelling percentage, and grain yield. These data were then analyzed statistically to determine the effect of the traffic treatments.

RESULTS AND DISCUSSION

The measured values in each plot were used first to determine the treatment effect by the analyses of variance. The level of significance was 0.0001 associated with the total plant yield affected by the traffic treatments. The Duncan's multiple range test indicated 50% reduction in yield for severe treatments compared to the control, no traffic treatment. The analysis also revealed a marginally higher damage in the case of before-seeding treatments compared to the after-seeding. Differences in plant heights were observed throughout the growing season and a typical picture depicting this is shown in Fig. 2.

A correlation study was conducted to determine the relation of plant output variables to tire contact pressures and number of passes. The results are shown in Table I along with the probability values indicating the level of significance. The plant and ear moisture show an increase with contact pressure rise and increase in number of passes. Several forms of models were examined to determine the suitable prediction equations for the output variables and for the analyses, data for before and after seeding treatments being handled separately. The output variables were found to vary with the natural log of the product of pressure and passes, $\ln(np)$. Estimations of the intercept and the coefficient of $\ln(np)$ were made for each variable excluding the control plot data. These values are shown in Tables II and III for yield and grain yield respectively.

TABLE II. MODEL FOR YIELD PREDICTED FROM TREATMENTS

BEFORE SEEDING

	df	Sum of squares	Mean square	F	$P>F$
Regression	1	147,171,408	147,171,408	29.5	0.0001
Error	46	229,599,714	4,991,298		
Total	47	376,771,122			

	B value	Std. error	Type II SS	F	$P>F$	R value
Intercept	20,988.3					
1 n (np)	-1,634.1	300.94	147,171,408	29.5	0.0001	0.62

AFTER SEEDING

	df	Sum of squares	Mean squares	F	$P>F$
Regression	1	163,470,798	163,470,798	47.5	0.0001
Error	46	158,199,629	3,439,122		
Total	47	321,670,427			

	B value	Std. error	Type II SS	F	$P>F$	R value
Intercept	22,178.3					
1 n (np)	-1,722.2	249.8	163,470,798	47.5	0.0001	0.71

TABLE III. MODEL FOR GRAIN YIELD PREDICTED FROM TREATMENTS

BEFORE SEEDING

	df	Sum of squares	Mean square	F	$P>F$
Regression	1	52,850,236	52,850,236	40.0	0.0001
Error	46	60,738,642	1,320,405		
Total	47	113,588,878			

	B value	Std. error	Type II SS	F	$P>F$	R value
Intercept	11,231.2					
ln (np)	-979.3	154.8	52,850,236	40.0	0.0001	0.68

AFTER SEEDING

	df	Sum of squares	Mean square	F	$P>F$
Regression	1	30,195,617	30,195,617	48.2	0.0001
Error	46	28,847,739			
Total	47	59,043,356			

	B value	Std. error	Type II SS	F	$P>F$	R value
Intercept	10,314.9					
ln (np)	-740.2	106.7	30,195,617	48.2	0.0001	0.72

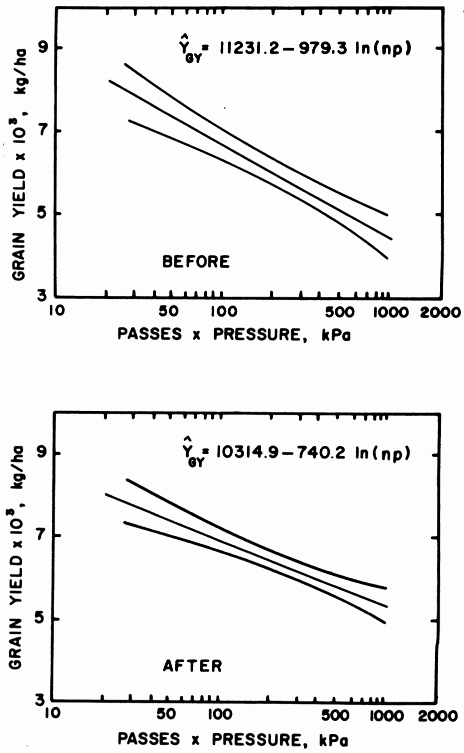

Figure 4. Grain yield vs. traffic treatment for both before- and after-seeding categories.

Referring to Table II, the prediction equation for yield can be given by:

$$Y = 20{,}988.3 - 1{,}634.1\ [1\, n\, (np)\,],\ \text{kg/ha} \quad (1)$$

Using the mean value of the control (Y_0 = 15,950.6) in this equation, an equivalent pre-consolidation pressure, $(np)_0$, can be estimated by the relation:

$$Y_o = 15{,}950.6 = 20{,}988.3 - 1{,}634.1\ [1\, n\, (np)_o] \quad (2)$$

where, Y is the output parameter of either yield or grain yield and B is the value of the coefficient shown in Table II or Table III. Another useful way of expressing the equation is in the form:

$$\triangle Y = Y_2 - Y_1 = B\ 1\, n \frac{(np)_2}{(np)_1} \quad (3)$$

where, $\triangle Y$ is the reduction in the output parameter caused by the increase in pressure or the number of passes from $(np)_1$ to $(np)_2$. B values can be obtained from Tables II and III for appropriate variables and conditions. Observing the relations, a straight line for the plot of output variables against pressure times passes on a semilog graph is expected. These plots are shown in Figs. 3 and 4 for yield and grain yield, respectively. The confidence-interval belt showing the upper and lower boundaries of all interval estimates at the 95% confidence level is also shown in each figure. These analyses provide a method to predict plant output variables in terms of the traffic performed in the field.

TABLE IV. MEAN VALUES OF YIELD, GRAIN YIELD AND SOIL DENSITY

Sl.no.	Treatment	Contact pressure (kPa)	No. of passes, *n*	Yield (kg/ha)	Grain yield (kg/ha)	Soil dry density, 0-20 cm (g/cm³)
1	No traffic	0	0	15,951	7,695	0.8915
2	Before	31.4	1	15,457	7,436	0.9586
3	Before	31.4	5	11,444	5,954	1,0050
4	Before	31.4	10	13,699	7,404	1.0660
5	Before	31.4	15	13,434	5,749	1.0352
6	Before	41.2	1	14,337	7,526	0.9720
7	Before	41.2	5	12,396	5,624	1.0220
8	Before	41.2	10	11,555	5,419	1.0357
9	Before	41.2	15	10,434	5,206	1.0726
10	Before	61.8	1	14,279	7,444	1.0018
11	Before	61.8	5	11,855	5,627	1.0397
12	Before	61.8	10	7,859	3,910	1.0420
13	Before	61.8	15	8,884	3,760	1.0272
14	After	31.4	1	15,830	7,282	0.9951
15	After	31.4	5	15,157	7,155	1.0484
16	After	31.4	10	13,763	7,281	1.0496
17	After	31.4	15	13,059	6,225	1.0365
18	After	41.2	1	14,563	7,653	1.0045
19	After	41.2	5	13,281	6,381	1.1137
20	After	41.2	10	11,243	5,721	1.1175
21	After	41.2	15	9,968	5,202	1.0301
22	After	61.8	1	15,030	6,953	1.0536
23	After	61.8	5	13,206	6,121	1.0654
24	After	61.8	10	9,122	4,810	1.0686
25	After	61.8	15	9,965	4,877	1.0648

Table IV shows the average results of total and grain yield for each treatment, together with soil dry densities between 0 and 20 cm.

In this experiment, a yield reduction of 50% was observed between the control and the heavily treated plots. The average yield obtained in the control plots was 15,951 kg/ha, which is about 30% more than the recommended average value reported by the Quebec Ministry of Agriculture for the same variety of corn. That is to say that the field operation performed in the latter case is apparently equivalent to a plot with a treatment of 196.1 kPa for the variable *np*. This could be translated to a traffic pattern of five passes with 39.2 kPa pressure, for example, a tractor weighing 3,515 kg.

SUMMARY AND CONCLUSIONS

The corn-growing experiment was based on a randomized block design with 25 treatments and four blocks. The average value of yield in the control plots showed a 30% higher production than that measured by the Quebec Ministry of Agriculture in hybrid tests. Mathematical models were obtained for the output variables in terms of traffic treatments along with an expression for reduction in yield predictions. A lower output of the corn plants in some heavily treated plots can be attributed to moisture stresses, reduction in nutrient uptake and higher root penetration resistance of the soil.

The reduction in plant yields obtained was over 50% for plots with 41.2 and 61.8 kPa contact pressures and over 10 passes. Lower contact pressures, such as 31.4 kPa, cause less damage even at a higher number of passes.

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