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Axle load and tillage effects on crop yield for two soils in central Ohio

R. Lal*, M. Ahmadi

School of Natural Resources, The Ohio State University, Columbus, OH 43210, USA

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Abstract

A load of 5–20 Mg on a single axle cart is a common practice for spreading manure and harvesting grains in the US Corn Belt. Yet, effects of such a load used for a long time of 5–10 years on crop yield are not known for predominant soils of the region. Further, axle load effects on crop yield may depend on tillage methods. Thus, effects of axle load and tillage methods on corn (*Zea mays* L.) grain yield were studied for Wooster silt loam an Orthic Luvisol (at Wooster) and Crosby silt loam a Gleyic Luvisol (at South Charleston) in Ohio. Experiments were conducted for 11 consecutive growing seasons (1988 through 1998) at Wooster and 6 seasons (1991–1994, 1997–1998) at South Charleston. Three axle load treatments at Wooster consisted of: (1) regular machine traffic (RMT), (2) 7.5 Mg axle load as guided or controlled traffic (CT), and (3) 7.5 Mg axle load covering the entire plot (CEP). There were three tillage methods at Wooster: (1) no till (NT), (2) chisel plowing (CP), and (3) moldboard plowing (MP). Three axle load treatments at South Charleston were: (1) control, (2) 10 Mg axle load, and (3) 20 Mg axle load. Two tillage methods used at South Charleston were NT and MP. There were no significant differences in soil bulk density and penetration resistance of Wooster silt loam soil measured after 11 seasons of harvest traffic. Harvest traffic treatments at Wooster significantly affected corn grain yield only in 1988 and 1998, for 2 out of 11 seasons. In 1988, corn grain yield was reduced by 14% by 7.5 Mg axle load treatments. In 1998, the reduction in grain yield was 5% by the CT and 15% by the CEP axle load treatments. Mean corn grain yield for 11 years was 6.6 Mg ha^{-1} for RMT, 6.3 Mg ha^{-1} for 7.5 Mg axle load with CT (reduction of 5%), and 6.0 Mg ha^{-1} for 7.5 Mg axle load with CEP (reduction of 9%). The mean grain yield reduction for the 11-year period for the CEP treatment was 10%. There were no consistent trends in grain yield from year to year with regard to tillage methods. The CP treatment out-yielded the other tillage treatments in 4 out of 11 years. Mean corn grain yield in CP was 7% more than that of NT and 13% more than that of MP. Neither axle load nor tillage treatment had any effect on corn grain yield at South Charleston, and mean corn grain yield was 7.5 Mg ha^{-1} for control, 7.6 Mg ha^{-1} for 10 Mg axle load, and 7.3 Mg ha^{-1} for 20 Mg axle load. The mean corn grain yield was 7.0 Mg ha^{-1} for NT and 7.8 Mg ha^{-1} for MP treatment. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Axle load; Soil compaction; Conservation tillage; Corn production; No till

1. Introduction

The harvest traffic and manure application in autumn, and tillage and sowing operations in the

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*Corresponding author. Tel.: +1-614-292-9069; fax: +1-614-292-7432.
E-mail address: Lal.1@osu.edu (R. Lal).

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spring can reduce crop growth and yield through soil compaction and other adverse effects on soil structure. Soil compaction thus caused can also increase fuel costs for tillage, and decrease fertilizer and water use efficiencies (Raghavan et al., 1978, 1990; Lavoie et al., 1991). Outside the snow-free belt in the southern USA, Gill (1971) estimated that crop yield was reduced by about 10% by soil compaction. The severity of adverse effects of axle load on crop yield may depend on soil moisture, soil texture, and tillage methods (Salire et al., 1994; Soane and Van Ouwerkerk, 1994).

The severity of soil compaction caused by the axle load depend on the antecedent soil moisture content and texture (McCormak, 1987). That is why some researchers have proposed that the susceptibility of soil to compaction may be assessed using soil and climatic data bases (Voorhees, 1987). In Ohio, Van Doren (1959) observed that the magnitude of the compaction effect on yield depended upon water content of soil at the time compaction was imposed. Corn (*Zea mays* L.) yield on a soil subject to harvest traffic in a high soil-water treatment was 71% of that in a low soil-water treatment. Soil compaction experiments conducted in Minnesota demonstrated that effects on crop yields depended on the interaction between moisture regime and axle load. Under relatively dry growing conditions, for example, corn yield fell by 8% and it took 3–4 years for yields to attain the control level. Under wetter conditions, yield losses were 25% and crop yields could not be fully recovered even after 4 years (Voorhees, 1986). In Scotland, Dickson and Campbell (1990) reported that soil compaction by wheels depressed the plant population of barley (*Hordeum vulgare* L.) sown by direct drilling in wet autumns. In Wisconsin, Lowery and Schuler (1991) observed that compaction by 8 and 12.5 Mg axle load treatments decreased corn grain yield 14–43% on Kewaunee (fine, mixed, mesic Typic Hapludalf) and 4–14% on Rozetta (fine-silty, mixed, mesic Typic Hapludalf) soil.

In general, heavy textured soils are more prone to compaction than light-textured soils (McCormak, 1987). In Quebec, Canada, reductions in corn yields of up to 50% were observed on clayey soils (Raghavan et al., 1978). Experiments in Sweden showed that the mean loss in crop yield due to compaction increased with increase in clay content (Håkansson, 1985; Arvidsson and Håkansson, 1996). Clay content (greater than 40%) also interfered with the amelioration process (Alakukku, 1996). Based on a series of experiments conducted in Europe and North America, Håkansson et al. (1987) concluded that occasional use of axle load of 10 Mg does not have a major effect on grain yield. The effects of heavy axle loads (20 Mg per axle) can, however, be severe especially on clayey soils with impaired drainage. Gameda et al. (1987) conducted a 3-year study to evaluate the effects on a clayey soil of annual compaction by loads of 10 and 20 Mg per axle. They observed a marginal increase in yield with a load of 10 Mg per axle, and a slight decrease with a load of 20 Mg per axle. The data of 259 location-years from 21 long-term experiments in Sweden showed that compaction treatment caused a yield loss of 11% (Arvidsson and Håkansson, 1996). In Finland, Alakukku and Elonen (1994, 1995a, b) observed that soil compaction reduced yield of barley by 5% and nitrogen uptake by 7%. For a heavy textured lakebed soil in Northwestern Ohio, Lal (1996) observed severe reduction in crop yields due to the harvest traffic, and reported that adverse effects of compaction on crop yield persisted for 7 years after termination of the compaction treatment. In general, persistence of the compaction effects lasts longer on clayey than on light-textured soils.

There is also a strong interaction between soil compaction by vehicular traffic and tillage methods. For a North Carolina Coastal plain fine sandy loam soil, Wagger and Denton (1989) observed that bulk density was 1.74 Mg m^{-3} in trafficked compared with 1.52 Mg m^{-3} in untrafficked zone of the no till plot. Total porosity in the trafficked position was 21% lower than that of the untrafficked position. On acid subsoils with compacted tillage pans in Auburn, Alabama, Reeves et al. (1990) observed that slit tillage was as effective as subsoiling on plant growth and grain yield responses. Low spring temperatures are a major constraint on compacted soils with conservation tillage and residue mulch (Cox et al., 1990).

It is apparent from a review of the literature that effects of axle load on crop yield depend on soil moisture content at the time of traffic, soil texture and tillage methods. While the effects of vehicle and wheel factors on soil properties may be predictable (Håkansson et al., 1988), effects on crop growth and yield are hard to predict. Site-specific data on a long-term basis are important to develop best management for sustainable management of soil and water resources. Thus, long-term experiments were initiated to assess the effects of annual harvest traffic on growth and yield of corn on two soils in Ohio.

2. Materials and methods

Field studies were conducted at two locations: the Ohio Agricultural Research and Development Center (OARDC) in Wooster, Ohio (45°52′ N, 81°55′ W), and the western branch of the OARDC at South Charleston, Ohio (39°45′ N, 83°36′ W). The experiment at Wooster was initiated in 1988 and continued for 11 consecutive growing seasons (1988–1998). The experiment at South Charleston was also initiated in 1988 but continued until 1994, and was reinitiated in 1997. The soil at the Wooster experimental site is classified as Wooster silt loam (30% sand, 48% silt and 22% clay) which belongs to the family of Typic Fragiudalf (Orthic Luvisol). The soil at South Charleston is classified as Crosby silt loam (25% sand, 60% silt and 15% clay), which belongs to the family of Aeric Ochraqualfs (Gleyic Luvisol).

At Wooster, a completely randomized block design (CRBD) with three replications was used. The field layout was arranged as a factorial combination of three compaction levels (i.e., regular machine traffic (RMT), 7.5 Mg controlled traffic or CT, and 7.5 Mg covering the entire plot or CEP) and three tillage treatments: no till (NT), chisel plow (CP), and moldboard plow (MP) treatments. The CT treatment implies that wheel tracks were confined to the same location every year, and the entire plot was not covered by the wheel rut. The depth of plowing was 20–30 cm with both chisel and moldboard plow. The vehicular traffic treatments were applied every year for 11 consecutive years at Wooster. Each plot size was 0.007 ha (6.1 m×10.7 m). The harvest traffic treatments were done by a liquid manure spreader that was pulled by a tractor. The specifications were as follows: in 1992 the tractor weight was 5.2 Mg, manure spreader weight was 7.5 Mg, tractor front tire size was 31.5 cm×61.0 cm and rear tire size was 46.7 cm ×61.0 cm, and the manure spreader tire size was 41.9 cm×57.2 cm. In 1995, CT treatment involved tire traffic at 3 m interval. With one exception (in 1997), the harvest traffic treatment was done in the autumn (October/November) prior to the ground freezing. The harvest traffic treatment in 1997 was done in spring just before the sowing.

The experimental design at South Charleston has been described elsewhere (Lal and Tanaka, 1991), and was also CRBD with three replications. Plot size was 0.004 ha (4.5 m×9.0 m). The field layout was a strip plot arrangement. The treatments were three harvest traffic levels (i.e., control, 10, and 20 Mg single axle loads). A cart with two axles was created by using a grain cart partly loaded (10 Mg) and fully loaded (20 Mg). The two tillage treatments were NT and MP. In both the 10 and 20 Mg treatments the entire plot surface was covered by wheel tracks. Grain carts were not used in the control treatments. Maximum axle load on the control plots was less than 4 Mg.

The harvest traffic treatment was done soon after harvesting the corn in October/November. Both MP and CP treatments involved plowing to about 20 cm depth. Soil water content for the surface 7.5 cm layer was measured at the time of performing the harvest traffic by using a 2.5 cm diameter soil sampling tube. Soil water content in 1993 at the time of applying harvest traffic for Wooster soil was 248 g kg^{-1} for NT, 243 g kg^{-1} for CP, and 223 g kg^{-1} for MP, respectively (LSD$_{0.05}$=90). Soil bulk density at Wooster was measured for 0–10 cm depth in summer 1999 using the core method (Blake and Hartge, 1986). The penetration resistance of the soil surface was measured using the blunt-tip pocket penetrometer. Soil bulk density at South Charleston was measured in 1997 using a strata gage that uses ^{137}Cs involving the backscattering principle (Campbell and Henshall, 1991).

Tillage treatments were performed soon after the harvest traffic treatment was done. At Wooster, corn (Pioneer 3527) was sown in spring at the rate of 68 000 kernels per hectare. Fertilizer was applied at the rate of 170 kg nitrogen (N) per hectare as ammonium nitrate, and 27 kg phosphorus (P) per hectare and 100 kg potassium (K) per hectare as compound fertilizer (0–8–30). Weed control at Wooster was achieved by applying the following herbicides: (1) flumetsulam+metolachlor, (2) 2.2 l ha^{-1} atrazine, and (3) 1.7 l ha^{-1} glyphosate. At South Charleston, corn (Country Mark 982) was sown at the rate of 64 000 kernels per hectare, with the same fertilizer treatment as Wooster. The weed control at South Charleston was achieved by applying the following herbicides: (1) 1.7 kg ha^{-1} cyanazine, (2) 1.7 kg ha^{-1} atrazine, (3) 1.3 l ha^{-1} metolachlor, and (4) 1.1 l ha^{-1} glyphosate. Weed biomass was measured in 1994 at the initial silk stage in terms of the above-ground dry matter per unit area. Plant height (up to the top of the tassel) and crop stand were measured at harvest for selected years (1992 and 1993 at Wooster). Grain and stover yields were measured at maturity, and the harvest index (ratio of grain to above ground biomass yield) was calculated. Corn grain yield was measured by harvesting the middle rows and adjusting the yield to grain moisture content of 15.5%. All variables were statistically analyzed for computing the analysis of variance and least significant difference (Steele et al., 1997).

3. Results and discussion

3.1. Precipitation

The precipitation data for all cropping seasons at the two locations with long-term means are shown in Tables 1 and 2. These data show below the long-term average rainfall for all but 2 years at Wooster when compared with the long-term annual averages (Table 1). The rainfall in 1990 and 1996 was above the long-term mean. The rainfall was less than 75% of the long-term mean in 1988, 1991 and 1997. The rainfall at South Charleston was also below the long-term average rainfall for all but 2 years. The rainfall in 1992 and 1996 was equal to or slightly more than the long-term mean. The rainfall at South Charleston was less than 75% of the long-term mean in 1991, 1994 and 1998.

3.2. Soil physical properties

Mean soil water content at the time of applying the harvest traffic at Wooster site was 288 g kg^{-1} in 1994, 195 g kg^{-1} in 1995 and 262 g kg^{-1} in 1997. There were no differences in soil water content among the axle load treatments (Table 3). Soil water content in 1997 was significantly more in NT than MP treatments. The axle load treatments for 11 consecutive years had no effect on soil bulk density or the penetration resistance of the soil surface. The mean values were 1.28 Mg m^{-3} for soil bulk density and 2.10 kg cm^{-2} for the penetration resistance. In contrast, tillage methods had a significant effect on soil bulk density and the penetration resistance. The highest soil bulk density was measured for the MP treatment and the highest penetration resistance for the NT

Table 1
Average monthly rainfall at Wooster in different years (mm)[a]

Month	Year											30-years mean
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
January	21	37	41	41	32	74	59	103	70	42	56	77
February	59	40	105	22	28	34	20	23	40	50	53	58
March	48	77	22	56	70	70	56	33	62	85	52	88
April	56	45	64	76	57	98	116	79	124	44	101	85
May	32	114	125	83	51	37	47	115	114	145	50	99
June	13	183	62	42	55	107	109	77	127	78	157	100
July	162	42	164	22	211	57	53	91	96	48	41	104
August	86	23	114	78	102	15	127	83	46	70	120	93
September	75	112	115	67	87	101	32	27	129	35	20	80
October	36	65	116	27	45	75	15	121	62	34	94	60
November	94	39	37	45	108	96	58	57	69	41	49	70
December	35	26	156	53	28	44	57	23	110	38	45	73
Total year	717	803	1121	612	874	808	749	832	1049	710	837	987
April–September	424	519	644	368	563	415	484	472	636	420	489	561

[a] From the joint publication of the Department of Agricultural Engineering, OARDC; Statistics Lab, OARDC; Department of Geography, Miami University.

Table 2
Average monthly rainfall at South Charleston in different years (mm)[a]

Month	Year							30-year mean
	1991	1992	1993	1994	1996	1997	1998	
January	41	62	103	71	59	50	55	74
February	50	18	34	34	39	36	35	62
March	99	80	72	45	80	107	40	88
April	90	68	84	77	180	32	131	101
May	83	56	20	42	176	135	91	117
June	42	55	90	61	97	114	88	106
July	35	180	197	97	106	77	54	104
August	65	46	22	82	21	87	36	89
September	74	44	84	34	119	26	17	77
October	34	43	64	23	51	29	64	58
November	31	12	115	75	81	53	38	85
December	74	27	46	57	82	47	68	76
Total year	718	1036	931	698	1091	793	717	1037
April–September	389	449	497	393	699	471	417	594

[a] From the joint publication of the Department of Agricultural Engineering, OARDC; Statistics Lab, OARDC; Department of Geography, Miami University.

treatment (Table 4). Neither the axle load nor tillage treatments had a significant effect on soil bulk density of the South Charleston site. The mean soil bulk density was 1.45 Mg m^{-3} at the mean field moisture content of 184 g kg^{-1} (Table 5).

3.3. Crop response

Weed biomass measured at Wooster in 1991 did not differ among axle load and tillage treatments (data not shown). The average weed biomass (dry weight) was 1.7 Mg ha^{-1}.

3.3.1. Plant height and crop stand

Neither plant height nor crop stand at Wooster were affected by the axle load treatments (data not shown). However, plant height differed among tillage treatments for 1992 and 1993 and plant population for 1992 (Table 6). Corn height was the lowest for NT

Table 3
Soil water content at 7.5 cm depth at the time of axle load treatment for the Wooster site in 1994, 1995 and 1997

Treatments	Soil water content in the fall of (g kg^{-1})		
	1994	1995	1997
Compaction			
RMT	–	–	265
7.5 Mg CT	287	194	250
7.5 Mg CEP	289	196	270
LSD (0.05)	NS	NS	NS
Tillage			
NT	288	197	274
CP	296	194	266
MP	281	195	241
LSD (0.05)	NS	NS	17

Table 4
Axle load and tillage effects on soil bulk density, penetration resistance and soil moisture content of 0–10 cm depth measured in summer 1999

Treatments	Bulk density	Penetration resistance (Mg m^{-3})	Soil moisture content (g kg^{-1})
(A) *Axle load*			
Control	1.27	2.12	105
7.5 Mg-CT	1.28	1.98	95
7.5 Mg-CEP	1.30	2.10	108
LSD	NS	NS	NS
(B) *Tillage methods*			
NT	1.29	3.41	101
CP	1.25	1.44	102
MP	1.31	1.31	105
LSD	0.05*	0.38**	NS

Table 5
Antecedent soil water content (7.5 cm depth) and bulk density measurements at South Charleston in 1997

Treatment	Soil moisture (g kg^{-1})	Bulk density (Mg m^{-3})
Control	172	1.44
10 Mg	189	1.47
20 Mg	191	1.44
LSD (0.05)	NS	NS
Tillage		
NT	186	1.44
MP	181	1.46
LSD (0.05)	NS	NS

Table 6
Tillage effects on corn height in 1992 and 1993 and plant population in 1992 at Wooster

Tillage methods	Plant height (cm)		Plant population in 1992 (10^3 plants per hectare)
	1992	1993	
NT	284	320	42.6
CP	309	307	50.0
MP	307	288	53.7
LSD (0.05)	20	13	8.3

treatment in 1992 and the highest in 1993. Plant population was significantly lower in NT compared with the other two treatments. Total seasonal rainfall was lower in 1992 than in 1993 and tillage-induced differences in plant height and stand may be due to differences in soil moisture content.

3.3.2. Stover and cob yields, grain:cob ratio, and harvest index

The axle load treatments had no effect on stover and cob yields, and grain:cob ratio (data not shown). The mean stover yield for Wooster was 6.2 Mg ha^{-1} in 1989, 9.5 Mg ha^{-1} in 1993, and 12.6 Mg ha^{-1} in 1996. Neither axle load nor tillage treatments had any impact on the harvest index. The mean harvest index at Wooster was 47.0% in 1993 and 49.3% in 1994.

3.3.3. Grain yield

The axle load treatments had significant effect on corn grain yield only for 1988 and 1998 for the Wooster site (Table 7). Corn grain yield in 1988 was significantly lower for both 7.5 Mg axle load treatments. In comparison with the control, the reduction in corn grain yield in 1988 was 14% for the axle load treatments. Corn grain yield in 1998 was reduced by 5% in the 7.5 Mg CT treatment and 15% in 7.5 Mg CEP treatment. Mean corn grain yield for other years ranged from a low of 3.9 Mg ha^{-1} in 1991 to a high of 11.4 Mg ha^{-1} in 1994. Mean corn grain yield for 11 years (average of all seasons) was 6.6 Mg ha^{-1} for RMT, 6.3 Mg ha^{-1} for 7.5 Mg/ha with CT, and 6.0 Mg ha^{-1} for 7.5 Mg axle CEP treatment. In contrast to axle load, tillage treatments affected corn grain yield in 7 out of 11 years (Table 8). However, there were no consistent trends in grain yield with regard to tillage methods. For a total of 5 years comprising 1988, 1990, 1992, 1995 and 1997, corn grain yield in NT treatment was lower than those in CP and MP treatments. For other years, NT out-yielded the other tillage treatments. Neither axle load nor tillage treatments had any effect on corn grain yield at South Charleston for either of the 4 years (Tables 9 and 10). Mean corn grain yield (average of all years) was 7.5 Mg ha^{-1} for control, 7.6 Mg ha^{-1} for 10 Mg axle load, and 7.4 Mg ha^{-1} for 20 Mg axle load treatments.

Table 7
Effects of axle load treatments on corn grain yield at Wooster in different years[a]

Compaction level	Corn grain yield for different years (Mg ha^{-1})											Mean
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
RMT	5.8	5.3	5.1	4.1	4.3	8.6	11.9	6.2	6.5	6.1	8.6	6.6
7.5 Mg CT	5.0	4.9	5.3	3.7	4.3	8.5	11.4	6.2	5.9	5.4	8.2	6.3
7.5 Mg CEP	5.0	4.0	4.6	4.0	4.2	7.9	10.8	6.8	6.0	5.4	7.3	6.0
LSD (0.05)	0.8	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.9	

[a] Grain yield at 15.5% water content. RMT=regular machine traffic; 20 Mg CT=20 Mg controlled traffic; 20 Mg EPT=20 Mg entire plot traffic.

Table 8
Effects of soil tillage on corn grain yield at Wooster in different years[a]

Tillage level	Corn grain yield for different years (Mg ha^{-1})											Mean
	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
NT	3.6	5.3	3.0	5.6	3.7	9.3	11.9	6.1	6.2	5.5	9.0	6.3
CP	6.0	5.4	5.5	3.7	4.6	8.7	11.8	7.8	6.0	6.3	8.9	6.8
MP	5.8	4.0	6.5	2.5	4.5	7.8	10.8	5.7	6.1	5.1	6.3	5.9
LSD (0.05)	0.8	NS	1.0	0.7	0.5	NS	NS	1.0	NS	0.9	0.8	

[a] Grain yield at 15.5% water content. NT=No till; CP=Chisel plow; MP=moldboard plow.

Table 9
Effects of axle load treatments on corn grain yield at South Charleston in different years

Compaction level	Corn grain yield for different years (Mg ha^{-1})						Mean
	1991	1992	1993	1994	1997	1998	
Control	10.3	7.4	5.5	6.8	6.8	7.9	7.5
10 Mg EPT	8.0	7.6	8.8	6.5	6.9	7.3	7.6
20 Mg EPT	9.5	7.6	6.9	6.9	6.1	6.9	7.3
LSD (0.05)	NS	NS	NS	NS	NS	NS	

Table 10
Effects of soil tillage on corn grain yield at South Charleston in different years

Tillage level	Corn grain yield for different years (Mg ha^{-1})						Mean
	1991	1992	1993	1994	1997	1998	
NT	9.3	6.2	6.6	6.3	6.6	6.7	7.0
MP	9.1	8.8	7.5	7.1	6.5	8.0	7.8
LSD (0.05)	NS	NS	NS	NS	NS	NS	

Similarly, mean corn grain yield was 7.0 Mg ha^{-1} for NT and 7.8 Mg ha^{-1} for MP treatments (Table 10).

The data for 11 consecutive years from Wooster show yield reduction of 5% for the CT treatment and 9% for the CEP treatment. The maximum yield reduction of 15% was observed in 1998. It is likely that yield reductions may have been more drastic for the higher load of 10–20 Mg on a single axle. The lack of response of corn to axle load treatments for South Charleston site is in accord with the published literature for the same soil (Lal and Tanaka, 1991) and similar soils and ecoregions (Fausey and Dylla, 1984). In contrast to the silt loam soils of Wooster and South Charleston, adverse effects of axle load on crop yields are generally severe on heavy textured and poorly drained soils (Lal, 1996).

4. General discussion and conclusion

Corn grain yield at Wooster was significantly reduced by the harvest traffic in 2 out of 11 seasons, in 1988 and 1998. The rainfall in both seasons was below the long-term mean, by 27% in 1988 and 15% in 1998. The yield reduction by 7.5 Mg CEP treatment was 14% in 1988 and 15% in 1998. The soil water content at the time of compaction in the fall of 1997 was high ranging from 250 to 270 g kg^{-1} (Table 3). The mean yield reduction over the 11-year period was 10%. The CP treatment produced significantly more corn grain yield than other tillage methods in 5 out of 11 years. The mean grain yield in CP exceeded by 7% than that of NT and by 13% than that of MP. The high grain yield in CP was also obtained in years with

Table 11
Rainfall effects on corn grain yield for different axle load treatments

Location	Axle load treatment	Regression equation[a]	Correlation coefficient (*r*)
Wooster	RMT	$Y=-26.3+0.13X-1.3\times10^{-4}x^2$	0.45
	20 Mg CT	$Y=-26.1+0.13X-1.3\times10^{-4}x^2$	0.43
	20 Mg CEP	$Y=-20.1+0.11X-1.1\times10^{-4}x^2$	0.40
South Charleston	Control	$Y=19.2-0.03X$	0.73
	10 Mg	$Y=3.73+8.7\times10^{-3}X$	0.47
	20 Mg	$Y=13.7-0.015X$	0.56

[a] Y in Mg ha^{-1}; X in mm.

below average rains. The yield increase in CP over MP in years with below average rains was 3% in 1988, 37% in 1995, 24% in 1997 and 41% in 1998. The mean increase in yield by CP over MP was 15%. The data in Table 11 shows regression equations relating corn grain yield to the axle load treatment. Regression equations were similar among the axle load treatments at Wooster. There were no consistent trends in regression equations relating grain yield to rainfall at South Charleston.

In comparison with heavy texture and poor drainage of soils at Hoytville where axle load treatments cause severe yield reductions (Lal, 1996), soils of the Wooster and South Charleston sites are silt loam in texture and are well-drained. Furthermore, these soils undergo 5–10 freeze-thaw cycles during the winter which may alleviate soil compaction. Conservation tillage system, based on crop residue mulch and chiselling in the row zone, are appropriate tillage methods for well-drained soils in North America (Nyborg and Malhi, 1989; Tessier et al., 1990; Dick et al., 1991; Lal et al., 1994; Dick et al., 1998). Any residual compactive effect can be alleviated by chiselling in the row zone, and through the ameliorative effect of crop residue mulch (Unger, 1984).

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