Soil Compaction And Crop Response In A Potato Crop Rotation

F. B. Arnold and R. E. Sojka

The effects of soil compaction on certain soil properties and the growth of potatoes, sugarbeets, and wheat were observed in two years of a fallow-sugarbeet-potato-wheat-wheat rotation. Compaction resulted in higher soil moisture and soil strength, with the effect still observable in the second year. Potato growth and yield were reduced in the compacted treatments significantly in the first year. Potato yields were reduced in the second year also, but not significantly for that year. Compaction affected wheat growth inconsistently though wheat yield and quality were reduced in the second year. Damage to the sugarbeets by 2,4-D early in the season from adjacent production wheat fields confounded treatment effects both years, though interestingly 2,4-D damage was generally less severe in compacted plots, possibly due to greater water availability in the compacted treatment. Bulk densities immediately below the zone of fall tillage (6-12 in.) remained elevated over winter in the compacted treatment.

INTRODUCTION

Soil compaction refers to the reduction of porosity in soil. Several soil properties can be substantially altered when soil becomes compacted: 1) Bulk density or the weight of a given volume of soil increases, 2) Soil strength or hardness increases, 3) Soil-moisture properties are changed in a variety of ways depending on the initial soil condition, though generally the amount of water held at saturation is reduced, and 4) The amount of soil air held in the soil is limited, particularly in the presence of high moisture percentages. These changes in properties can have a variety of effects on plant response to soil compaction.

Various physiological responses of crops common to the Red River Valley have been observed as a result of soil compaction or related changes in the soil-root environment (1, 2, 3, 5, 7, 8, 9, 10). In addition to yield reduction, these responses include increased adventitious root development of grain crops, reduction in such quality components as size, shape, and specific gravity of potatoes, and sprangling and lower sugar content in sugarbeet.

Soil and plant properties as affected by soil compaction and crop sequence were studied for two years in a potato crop rotation with particular attention to the persistence of compaction effects in the second year. Studies were conducted at the Red River Valley Potato Research Farm near Grand Forks, ND on a Beardon silty clay loam soil. Studies were supported in part by grants from the Sugarbeet Research and Education Board of Minnesota and North Dakota and by the Red River Valley Potato Growers Association.

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PROCEDURES

Soil in compacted treatments was uniformly compacted by repeated passes of a loaded truck (gross wt. approx. 39,000 lbs) prior to planting in Spring 1977. Non-compacted treatments received no initial compaction. Five crop treatments were involved which consisted of a fallow-sugarbeet-potato-wheat-wheat rotation. Treatments were arranged in a split block design with five replications per treatment. Each individual plot measured 14 x 55 feet. Varieties used were American Crystal 2B (ACH-17) sugarbeet, Kitt wheat, and Norchip potato. Planting dates were April 29 for wheat and beets and May 14 for potatoes in 1977, and May 15 for wheat and potatoes and May 26 for beets in 1978. Fertilization was to soil test recommendation.

Soil moisture and soil strength were measured periodically throughout both growing seasons. Soil strength data were obtained using a portable recording penetrometer (6). Various growth parameters for each crop were also measured. The wheat, potato, and sugarbeet crops were harvested on August 9, September 15, and October 7, 1977, respectively, and August 17, September 29, and October 11, respectively, in 1978. Data collected were subjected to statistical analysis using analysis of variance and Duncan's multiple range test.

RESULTS - 1977

Soil water data for 1977 are given in Table 1. With the exception of the 24-36 inch depth on August 4, soil moisture was consistently higher at all depths in the compacted treatments. With compaction, small pores can be expected to increase resulting in greater capillarity in the compacted treatments. Root penetration and water use from the lower profile can be expected to decrease.

Table 1. Effect of Soil Compaction on Gravimetric Soil Moisture Per Cent for 1977.

Treatment	Date	Depth (in)				
		0-6	6-12	12-24	24-36	36-48
Noncompacted	7/20/77	18.21	21.48	16.59	15.39	18.89
Compacted	7/20/77	22.00	23.94	17.62	17.37	24.65
% Significance level		1	1	1	1	1
Noncompacted	8/4/77	16.14	17.60	14.62	18.89	17.27
Compacted	8/4/77	18.10	19.96	15.94	15.53	20.37
% Significance level		1	1	NS	1	1

Penetrometer data are presented in Table 2. Soil strength increased significantly to a depth of one foot in compacted treatments on both sampling dates. Soil strength on August 4 was substantially greater than on July 20 for both treatments due to decreased soil water with time (Table 1) since soil strength increases with decreasing water content.

Growth in 1977 of potatoes, sugarbeet, and wheat are given in Table 3. Plant counts and leaf area of the potatoes on June 7 were significantly higher on the noncompacted treatment. With the exception of the number of potatoes per hill on July 20, the remainder of the potato growth parameters were also higher on the noncompacted treatment, although not significantly. Although the number of potatoes were somewhat higher on the compacted treatment on July 20, tuber volume and dry weight were less, indicating potatoes were smaller in the compacted treatment.

Plant counts for sugarbeet were significantly higher on the compacted treatment on May 13. This is possibly due to the more favorable soil moisture conditions in the compacted treatment which enhanced germination, and is consistent with other observations of the effect of seedbed firmness on beet stand establishment (10, 11). On June 7, sugarbeet plant counts remained higher on the compacted treatments, though not significantly. At this date, substantial 2,4-D damage from an adjacent wheat field was evident. Interestingly the beets in the compacted treatments withstood the 2,4-D much better than those in the noncompacted treatment. This may be related to higher soil moisture availability to the beets on the compacted treatment, reducing the herbicide x water stress effect. Little difference in sugarbeet growth was evident up to this time between the treatments as shown by the June 7 measurements. After June 7, the 2,4-D significantly reduced the stand in the noncompacted treatment as shown by the plant counts after thinning on July 20. All other growth parameters were also adversely affected on the noncompacted treatments.

Plant counts for wheat were initially greater in the noncompacted treatment. As the season progressed, the wheat stand in the compacted treatments surpassed that of the noncompacted. Again, this may relate to higher soil moisture levels in the compacted treatments. On June 7, number of tillers, dry weight and leaf area were all significantly greater in the compacted treatment. By July 20, the situation reversed with number of tillers and dry weight greater in the noncompacted treatments. The earlier stand and more complete cover on the compacted treatments may have increased competition late in the season when atmospheric evaporative demand is greatest favoring growth parameters expressed on a per plant basis. When expressed as a function of row length, however, these differences diminish.

Potato harvest results are given in Table 4. In general, soil compaction resulted in a decrease in potato yield. Both yield and number of US No. 1 potatoes were reduced significantly by soil compaction. Specific gravity of the potatoes was significantly lower in the compacted treatments. Soil compaction increased the amount of culls. Although the differences were not statistically significant, the data illustrate a tendency for potatoes to be malformed and of reduced quality due to soil compaction.

Table 2. Effect of Soil Compaction on Soil Resistance. All data are in lb/in^2.

Treatment	Year	Date	Depth (in)					
			3	6	12	18	24	36
Compacted	1977	7/20	263[a]	298[a]	231[a]	239[a]	267[a]	298[a]
Noncompacted			82[b]	171[b]	216[a]	240[a]	242[a]	262[a]
Compacted		8/4	313[a]	375[a]	280[a]	265[a]	279[a]	314[a]
Noncompacted			179[b]	297[b]	318[a]	278[a]	270[a]	289[a]
Compacted	1978	7/10	25[a]	87[a]	138[a]	181[a]	384[a]	------
Noncompacted			28[a]	47[b]	124[a]	182[a]	401[a]	------
Compacted		7/28	112[a]	151[a]	180[b]	208[a]	206[a]	302[a]
Noncompacted			127[a]	139[a]	201[a]	223[a]	245[b]	283[a]

Means at the same depth and sampling date followed by the same letter indicate no significant difference at the 5% level.

Table 3. Effect of Soil Compaction on Growth of Potatoes, Sugarbeets and Wheat in 1977. Except for Plant Counts, All Data are Expressed on a Per Hill or Per Plant Basis.

Crop	Growth Parameter	Date	Treatment: Compacted	Treatment: Noncompacted	Level of Significance
Potato	Hills/100′	6/7	63	88	0.1
		7/20	74	81	NS
	No. of Vines	6/7	3.9	4.2	NS
	Dry wt., vines (gm)	6/7	2.0	3.3	Trend
	Leaf area (cm^2)	6/7	231	309	0.5
	No. of Vines	7/20	3.5	3.6	NS
	Dry wt., vines (gm)	7/20	62.2	74.3	Trend
	No. potatoes	7/20	9.38	8.00	NS
	Tuber volume (cm^3)	7/20	197.38	250.50	Trend
	Dry wt., potatoes (gm)	7/20	36.32	44.84	Trend
	Leaf area (cm^2)	7/20	6087	7757	Trend
Sugarbeet	Plants/100′	5/13	503	283	.01
		6/7	533	468	Trend
		7/20	98	48	.01
	Root volume (cm^3)	6/7	.24	.23	NS
	Dry wt., roots (gm)	6/7	.03	.03	NS
	Dry wt., tops (gm)	6/7	.37	.35	NS
	Leaf area (cm^2)	6/7	61.3	54.4	NS
	Root volume (cm^3)	7/20	65.7	40.0	Trend
	Dry wt., roots (gm)	7/20	11.1	6.1	Trend
	Dry wt., tops (gm)	7/20	15.75	13.23	NS
	Leaf area (cm^2)	7/20	2019	1736	NS
Wheat	Plants/100′	5/13	550	864	.01
		6/7	1080	1040	NS
		7/20	1240	960	.01
	No. tillers	6/7	5.2	4.1	.05
	Dry wt., (gm)	6/7	0.78	0.59	.05
	Leaf area (cm^2)	6/7	140.5	94.1	.01
	No. tillers	7/20	1.9	2.86	.01
	Dry wt., (gm)	7/20	3.97	5.48	.05

Table 4. Effect of Compaction on Potato Yield and Quality in 1977.

Grade	Yield (cwt/A): Compacted	Yield (cwt/A): Non-compacted	Stat. Sig.	No. Potatoes/A: Compacted	No. Potatoes/A: Non-compacted	Stat. Sig.
< 1½″	6.88	6.96	NS	10,488	10,746	NS
1½″-1 7/8″	14.53	20.72	Trend	11,090	15,044	Trend
1 7/8″-3½″ (US No. 1)	96.11	126.12	.01	29,917	39,890	0.5
> 3½″	1.38	0.77	NS	172	86	NS
Total Marketable	118.90	154.57	NS	51,667	65,766	NS
Culls						
Green	7.39	7.39	NS	4,556	3,439	Trend
Knobby	8.53	4.57	NS	3,525	2,149	NS
Cracked	9.11	7.57	NS	3,181	3,183	NS
Total Culls*	24.93	19.86	NS	11,262	8,771	NS
Overall Total	143.83	174.43	Trend	62,929	74,537	Trend
Specific Gravity	1.0888	1.0921	.05			

*Some culls are combinations of green, knobby and cracked potatoes.

Harvest results for sugarbeets and wheat are given in Table 5. Sugarbeet yield and percent sugar were significantly higher on the compacted treatments while the impurities were lower. The reduced yield and poor quality of the beets from the noncompacted treatment are attributed to the 2,4-D damage. Any treatment differences which might otherwise have been observed were obscured by the herbicide damage.

No significant differences were present in wheat yield or quality. The somewhat higher yield from the compacted treatment is likely due to higher soil moisture levels and greater stand.

RESULTS - 1978

In 1978 bulk density of peds in the zero to six inch and six to twelve inch depths was measured prior to planting. No significant differences in bulk density of surface peds occurred between the compacted and noncompacted treatments with bulk densities of 1.29 and 1.27 g/cc, respectively. The bulk density of peds taken at the six to twelve inch depth, however, was significantly higher in the compacted treatment, with a mean density of 1.38 g/cc compared to 1.27 for the noncompacted. No difference in bulk density of peds in the zero to six inch depth was expected as considerable breakdown of surface clods occurred overwinter. However, the higher bulk density of peds in the compacted treatment at the six to twelve inch depth indicates that the compaction imposed the previous season was still present below the surface. These results are similar to those observed elsewhete (4).

Soil water data for 1978 are in Table 6. Gravimetric soil water content was consistently higher in all depths at both samplings dates in the compacted treatment. As in 1977, this probably relates to decreased pore size and therefore greater capillarity in the compacted soil. These data also show a decrease in soil moisture with time. Additionally, seasonal precipitation for 1978 was more favorable late in the season in Grand Forks.

Table 6. Effect of Soil Compaction on Gravimetric Soil Moisture Per Cent for 1978.

Treatment	Date	Depth (in) 0-6	6-12	12-24	24-36
Compacted	7/10/78	24.91	28.13	22.21	24.61
Noncompacted	7/10/78	22.13	24.37	20.13	19.34
% Significance level		5	.01	1	5
Compacted	7/28/78	22.49	25.1	20.91	21.32
Noncompacted	7/28/78	20.24	22.04	18.84	18.03
% Significance level		5	.01	5	5

In both years (Table 2), soil strength increased significantly with time as soil water was depleted. Soil strength was lower on both dates in 1978 as compared to 1977. This is attributed primarily to higher soil moisture in 1978 than in 1977 resulting in lower soil strength. Compaction effects were still present in the upper twelve inches although differences between treatments were smaller than in the first year. Bulk density data indicate that higher soil moisture was the main contributing factor.

Growth of potatoes and sugarbeet are summarized in Table 7. Potato stand, dry weights, and leaf area early in the season were all significantly greater in the compacted treatment possibly due to a more favorable moisture regime. By midseason, growth had equalized with no significant differences remaining between treatments. Differences in growth of sugarbeets were not significant between treatments. Lack of differences in growth are attributed to the small soil strength differences and higher soil water in compacted treatments enabling the roots to overcome the minor differences in soil strength which were present.

Growth of wheat is summarized in Table 8. No significant differences due to compaction occurred. With the exception of plant counts, all growth parameters were

Table 5. Effect of Compaction on Yield and Quality of Sugarbeets and Wheat in 1977.

Crop	Parameter	Treatment: Compacted	Noncompacted	Level of Significance
Sugarbeet	Yield (T/A)	16.48	13.66	.01
	NO_3 (ppm)	88.14	521.04	.05
	Na (ppm)	277.2	446.6	.01
	Amino N (ppm)	426.7	583.6	.05
	K (ppm)	2139	2411	.05
	Conductivity	66.8	83.0	.01
	% Sugar	15.70	14.28	.01
	Impurity index	651.8	903.9	.01
	Sugar loss (T/A)	0.249	0.257	NS
	Extractable Sugar (T/A)	2.34	1.70	Trend
Wheat	Yield (bu/A)[1]	42.49	40.30	NS
	Test wt. (lb/bu)[1]	60.08	59.9	NS
	% protein[2]	14.20	14.38	NS

1 12% moisture basis.

2 14% moisture basis.

Table 7. Effect in 1978 of Soil Compaction on Growth of Potatoes and Sugarbeets. Except for plant counts, all data are expressed on a per plant basis.

Crop	Growth Parameter	Date	Treatment: Compacted	Treatment: Noncompacted	Level of Significance
Potato	Hills/100′	6/26	96	80.0	1
	No. vines	6/26	5.75	5.97	NS
	Dry wt., vines (gm)	6/26	23.62	13.07	0.1
	Leaf area (cm^2)	6/26	3,582	1,983	1
	No. potatoes	8/8	17.8	20.4	NS
	Dry wt., leaves (gm)	8/8	62.54	65.11	NS
	Dry wt., stems (gm)	8/8	46.72	55.28	NS
	Dry wt., tops (gm)	8/8	109.27	120.39	NS
	Dry wt., potatoes (gm)	8/8	255.19	186.02	NS
	Leaf area (cm^2)	8/8	17,136	18,399	NS
Sugarbeets	Plants/100′	6/26	234.5	309.5	NS
	Dry wt., tops (gm)	6/26	0.42	0.36	NS
	Dry wt., roots (gm)	6/26	0.05	0.04	NS
	Leaf area (cm^2)	6/26	127	110	NS
	Dry wt., tops (gm)	8/8	23.03	26.07	NS
	Dry wt., roots (gm)	8/8	13.84	13.85	NS
	Leaf area (cm^2)	8/8	9,554	2,720	Trend

Table 8. Effect in 1978 of Soil Compaction and Rotation on Wheat Growth. Rotation 1 and 2 refer to wheat following potato and wheat following wheat respectively. All parameters are on a per plant basis except for plant count.

Growth Parameter	Date	Rotation	Treatment: Comp	Treatment: Non-Comp	Level of Significance: Treatment	Level of Significance: Rotation
Plants/100′	6/26	1	1400	1500	NS	NS
		2	1393	1380		
No. Tillers	6/26	1	3.3	3.6	NS	1
		2	2.6	2.7		
Dry wt. (gm)	6/26	1	0.91	0.92	NS	0.1
		2	0.60	0.62		
Leaf area (cm^2)	6/26	1	56	65	Trend	0.01
		2	31	35		
Plants/100′	8/8	1	1107	1047	NS	NS
		2	1113	1127		
No. Tillers	8/8	1	2.5	2.6	NS	0.1
		2	1.7	1.7		
Dry wt. (gm)	8/8	1	4.15	4.40	NS	0.01
		2	2.56	2.54		

significantly greater in the first rotation of wheat (wheat following potatoes) than the second rotation of wheat (wheat following wheat). This may best be attributed to the lower soil water present in the second rotation of wheat. Nitrogen availability may have been low as indicated by protein and yield in 1978 (Table 11).

The potato harvest results are given in Table 9. No significant treatment differences for any of the yield measurements were present at the 5% level of significance, though yield and numbers of potatoes decreased in compacted treatments as in 1977. Overall potato yields for 1978 were approximately double those of 1977 due in part to more favorable soil moisture conditions late in the season.

Sugarbeet harvest data are given in Table 10. Again, no statistically significant treatment differences occurred for yield or quality measurements. Overall yields were low as in 1977, again related to 2,4-D damage from surrounding wheat fields.

Table 9. Effect of Compaction on Potato Yield and Quality in 1978.

Grade	Yield (cwt/A) Compacted	Yield (cwt/A) Non-compacted	Stat. Sig.	No. Potatoes/A Compacted	No. Potatoes/A Non-compacted	Stat. Sig.
<1½"	16.91	18.07	NS	20,055	21,432	NS
1½"-1 7/8"	30.03	26.94	NS	22,754	20,110	NS
1 7/8"-3½" (US No. 1)	200.44	220.94	NS	63,581	70,303	NS
>3½"	3.75	3.14	NS	106,721	112,120	NS
Total Marketable	251.13	269.09	NS	106,721	112,120	NS
Culls						
Green	10.08	9.92	NS	6,446	6,336	NS
Knobby	8.59	8.62	NS	3,030	2,810	NS
Cracked	2.06	4.06	NS	689	1,157	NS
Total Culls*	20.73	22.60	NS	10,027	10,303	NS
Overall Total	271.86	291.69	NS	116,748	122,423	NS
Specific Gravity	1.0916	1.0904	NS			

*Some culls are combinations of green, knobby and cracked potatoes.

Table 10. Effect of Compaction on Sugarbeet Yield and Quality in 1978.

Parameter	Treatment: Compacted	Treatment: Non-Compacted	Statistical Significance
Net yield (T/A)	9.80	9.65	NS
% sugar	15.92	15.90	NS
NO_3	65.25	71.75	NS
Na (ppm)	763.90	943.90	NS
Amino Nitrogen (ppm)	888.09	909.08	NS
K (ppm)	2692.61	2433.17	NS
Impurity Index	1163.94	1167.57	NS
Sugar loss (T/A)	0.27	0.27	NS
Extractable sugar (T/A)	1.29	1.25	NS

Wheat harvest results are shown in Table 11. In 1978, soil compaction significantly lowered both test weight and yield of the wheat. Per cent protein, test weight and yield were significantly higher in the first rotation of wheat as compared to the second rotation. These results are consistent with the wheat growth parameters shown in Table 8.

In summary, wheat yield was significantly lowered by compaction in 1978. Compaction effects were not evident statistically in the yield or quality of either potatoes or sugarbeets in 1978, though results paralleled the 1977 data. Soil compaction persisted as shown by the higher six to twelve inch bulk density of the compacted treatment. Bulk density gave a truer picture of the presence of compaction than did soil strength when strength data was not corrected to account for soil water. However, uncorrected soil strength data gave a good indication of crop performance in relation to soil strength. The higher soil water levels present in 1978 lowered soil strength thereby decreasing the effects of compaction on plant growth.

Table 11. Effect of Compaction on Wheat Yield and Quality in 1978.

Parameter	Rotation 1 Comp.	Rotation 1 Non-Comp	Rotation 2 Comp.	Rotation 2 Non-Comp.	Statistical Significance Treat	Statistical Significance Rotation
% Protein	15.78	14.72	13.58	13.3	Trend	1%
Test Weight (lb/bu)*	59.13	60.36	60.63	61.03	5%	1%
Yield (bu/A)*	36.58	40.63	19.17	20.54	5%	.01%

*12% moisture basis

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supported by the Agricultural Experiment Station enroll in graduate level biochemistry courses. The information and skills learned in these courses are used in the research conducted in their respective departments. For many years the Biochemistry Department has conducted an active research program on the biochemistry of oilseeds, especially flax and, more recently, sunflowers. This effort has been a cooperative one with the USDA which has supported one or two scientists located within the department. Another major effort is concerned with animal biochemistry with two studies underway–one concerned with the control of the metabolism of carbohydrates and another with the biosynthesis of thyroid hormone.

The emphasis on the safe use of chemical pesticides brought about the development of a special program for the study of pesticide residues. This program has two objectives: (a) determination of chemical residues in crops following the use of pesticides; (b) determination of changes the pesticide undergoes when applied to crops or soils. The information from these studies is being used by the Environmental Protection Agency in granting label clearance for the safe use of pesticides.

At the present time the department is actively involved in a program to develop alternative fuels for agriculture. The energy "crunch" has made the use of agriculturally derived liquid fuels more attractive. Our work is part of an interdisciplinary effort to identify those alternative fuels which have the greatest promise of success for this geographical region.

The material contributions of biochemistry to the general welfare have been notable and will probably continue and be greater. The identification of the vitamins, amino acids and other essential nutrients have made major impacts on our well-being. However, the real contributions of biochemistry will lie in providing an understanding of the chemistry of life. This is what biochemistry is all about.

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