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Effect of Plow Depth and Fertilizer Rate on Yields of Corn, Barley, Soybeans and Alfalfa and on Soil Tests

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INTRODUCTION

The potential for deeper plowing increases as tractors become more powerful. Deeper plowing, however, does not necessarily increase crop yields since incorporating subsurface soil into the plow layer may create less desirable physical conditions, dilute plant nutrients, and increase nutrient fixation. The response to deeper plowing depends on soil type and kind of crop.

Sugarbeet yields in Ontario increased by plowing deeper than 10 in. on fine-textured soils but yields did not increase on coarse-textured soils (1). Corn yields decreased from 40-31 bu/A as the plow depth increased from 4-10 in. in an experiment conducted at East Lansing from 1933-48 (8). Subsequent to this latter experiment, minimum tillage was generally adopted. Thus the question was raised as to whether or not the use of several tillage operations after plowing for seedbed preparation had obliterated any possible benefits from increased thickness of the plow layer. To answer these questions, an experiment was designed to use minimum tillage and to measure the effect of increased plow depth on yields with the same amount of fertilizer and with increasing amounts of fertilizer.

EXPERIMENTAL PROCEDURE

In 1956, a randomized block design experiment was established on the Soil Science Farm in East Lansing. The design consisted or 12 treatments with a 5-year crop sequence of corn-corn-soybeans-barley-alfalfa. Conover loam (Udollic Ochraqualfs) was the dominant "soil type." Other soils included Brookston loam (Typic Argiaquolls), Miami loam (Typic Hapludalfs) and Owosso sandy loam (Typic Hapludalfs). Plots were 14 x 100 ft. with four replications. The treatments are given in Table I, including the amount of phosphorus and potassium applied per rotation. Supplemental nitrogen was applied at 65 lb./A for corn following alfalfa, and 140 lb./A for corn following corn to eliminate a limiting factor. No fertilizer was applied for the alfalfa. All plots received 1 T of lime in 1958.

Crops were established with minimum tillage methods (usually plow-plant to establish crop and herbicide applications to control weeds and minimize cultivation). Satisfactory plowing conditions at planting for the 12-in. plow depth were sometimes too dry for the 4-in. depth. Fall plowing started in fall 1962 to create more uniform soil conditions for spring planting; crops were established with as little tillage as necessary. Plant population counts were obtained for corn in 1958 through 1962, and for soybeans in 1959 through 1963. Soil samples were collected on selected plots from 1958-61 and 1970.

Table 1. Plow depths and fertilizer treatments applied to corn 1956-1970 (a)

Treat-ment	Plow depth, in. (b)	Drilled at planting, lb/A					Broadcast and plowed under, lb/A (c)				Total P and K per rotation, lb/A			
		N	P_2O_5	P	K_2O	K	P_2O_5	P	K_2O	K	P_2O_5	P	K_2O	K
1	4	10	40	18	40	33	0	0	0	0	160	70	160	133
2	8	10	40	18	40	33	0	0	0	0	160	70	160	133
3	12	10	40	18	40	33	0	0	0	0	160	70	160	133
4	4	10	40	18	40	33	100	44	100	83	560	246	560	465
5	8	10	40	18	40	33	100	44	100	83	560	246	560	465
6	12	10	40	18	40	33	100	44	100	83	560	246	560	465
7	4	10	40	18	40	33	200	88	200	187	760	334	760	631
8	8	10	40	18	40	33	300	132	300	250	1,160	510	1,160	963
9	12	10	40	18	40	33	400	176	400	332	1,560	686	1,560	1,295
10	4	0	0	0	0	0	240	106	240	199	760	334	760	631
11	8	0	0	0	0	0	340	150	340	282	1,160	510	1,160	963
12	12	0	0	0	0	0	440	194	440	365	1,560	686	1,560	1,295

(a) The treatments were the same for barley and soybeans. However, treatments 7-12 received 40 lb/A less P_2O_5 and K_2O broadcast and plowed under. No fertilizer was applied to alfalfa.
(b) Treatment 12 was plowed 8 in. deep in 1956 and 1957.
(c) In 1956 and 1957 for treatments 4-12, some fertilizer was applied on the plow sole; some fertilizer was also applied with a chisel or subsoiler for treatments 10-12 in 1956. The subsoiler broke tile lines and the treatments were discontinued.

RESULTS AND DISCUSSION

Average Yields

Average annual yields and summer rainfall are given in Table 2. No irrigation was used and the low corn yields in 1965 are related to low summer rainfall. Average yields for the entire experiment by treatment show little response due to treatments (Table 3). Alfalfa yields were increased about ½ T/A by the fertilizer applied in treatments 4-12. Average yields of corn were generally slightly less on plots plowed 12 in. deep (treatments 3, 6, 9, 12) as compared to 4- and 8-in. depths.

Data for all 12 treatments were analyzed as a randomized block design. In 19 of 75 cases, yield difference among the 12 treatments was significant.

Plow Depth

Treatments 1-6 were analyzed separately as a 2 x 3 factorial with two fertilizer rates and three plow depths. Significant yield responses from plow depth occurred three times for corn and once for alfalfa, barley, and soybeans (8% of the cases.) In addition, the responses did not consistently favor shallow or deep plowing (Table 4). Subsurface soil material was incorporated into the plow layer as a result of 12-in. plowing during the early years of the experiment.

Fewer weeds and less vigorous plants were sometimes observed on the most deeply plowed plots early in the season. Weidemann and Millar (8) reported a 10-in. plow depth tends to cause surface soil crusting which adversely affects corn seedling emergence. Large reductions in corn stands and yields occurred by plowing 18 in. deep as compared to 9 in. on Conover loam in an earlier experiment (5).

Table 2. Average annual yields and summer rainfall (Data for 1957-62 was obtained from the Horticulture Farm, and for 1963-70 from the Soil Science Farm at East Lansing.)

Year	Monthly rainfall, in.					Bu/A		
	May	June	July	August	Total	Barley	Corn	Soybean
1956	6.3	2.8	2.5	5.2	16.8		70.4	
1957	6.0	2.6	8.4	1.4	18.4	35.5	76.0	24.3
1958	0.4	3.5	4.6	3.5	12.0	50.6	89.2	35.3
1959	2.7	2.2	5.6	4.5	15.0	56.6	103.1	38.5
1960	3.5	3.3	2.0	3.8	12.8	57.9	87.4	17.0
1961	1.0	2.2	2.7	4.0	9.9	82.4	94.8	34.9
1962	1.8	3.4	2.4	1.9	9.5	82.1	87.8	24.9
1963	2.4	3.8	2.8	3.0	12.0	65.8	95.0	30.3
1964	4.6	3.4	1.6	4.3	13.9	87.9	75.3	36.3
1965	0.1	2.5	0.4	3.9	6.9	73.9	42.3	24.1
1966	1.9	4.1	1.9	3.1	11.0	36.2	84.8	35.2
1967	1.0	5.5	1.6	3.4	11.5	44.9	95.1	31.9
1968	4.5	8.0	2.2	2.3	17.0	71.8	86.9	33.1
1969	3.2	4.0	6.5	0.4	14.1			35.4
1970	2.5	5.9	5.9	1.8	16.0	65.4		

Plant stands for corn were determined nine times in 5 years for treatments 1, 2, and 3 and six times during three of the 5 years for the remainder of the treatments (Table 5). Average plant populations for 8- and 12-in. plow depths were similar. There were about 1,100 plants more per acre than for the 4-in. plow depth. Thus, corn population cannot be used to support the thesis that increasing plow depth to 12 in. caused poor seedling emergence. The plant population data were collected before fall plowing began in 1962 and could reflect the drier soil conditions on plots plowed only 4 in. deep. This would explain the reduced germination and plant population. Although shallow plowing resulted in fewer plants per acre, it tended to produce higher yields than the 12-in. depth (Table 5). In 96 comparisons, the maximum corn yield occurred for the 4-, 8-, and 12-in. plow depths, 45, 37 and 14 times, respectively.

Tables 3 and 5 show consistently lower yields of corn for the 12-in. plow depth (which consumes more energy and costs more), compared to 4- and 8-in. plow depths.

Vitosh, *et. al.,* found no significant difference in plowing 7 or 12 in. for corn planted from 1963-70 where varying rates of phosphorus and potassium or manure were applied (7).

Soybean yields were significantly different for plow depth in 1961; however, yields and plant population were not related.

Fertilizer Rate

Sufficient supplemental nitrogen was applied to all treatments to eliminate nitrogen as a limiting factor. Any response to added fertilizer is attributed to phosphorus and potassium. There were significant yield differences due to fertilizer rate in 18 of 75 cases. The average yields from fertilizer are given in Table 6.

Fertilizer increased alfalfa yields 32% of the time, barley 46%, and corn 13%. For soybeans the yield was depressed by increased phosphorus and potassium. There is little or no evidence that rates of P and K higher than that of treatments 4, 5, and 6 increased yields of any crop (Table 3).

The limited response to added fertilizer was due to the generally high fertility level of the area which had been used for sugarbeet research and fertilizer rate experiments. Little if any fertilizer response is expected for many crops on loamy soils if the soil test exceeds 40 for P and 210 for K (2). Soil test data (Table 7) for treatments 1-3, where only starter fertilizer was used, help explain the limited response to fertilizer.

Table 3. Average yields as tons of hay or bushels of grain per acre

				Corn (a)		
Treatment	Plow depth, in.	Alfalfa (b)	Barley (c)	After alfalfa	After corn	Soybeans (c)
1	4	3.38	63.5	86.0	87.7	37.5
2	8	3.36	65.8	87.5	84.0	36.8
3	12	3.34	68.0	84.0	84.1	35.0
4	4	3.84	63.6	86.9	88.5	36.1
5	8	3.83	63.0	88.8	86.9	35.9
6	12	3.79	62.1	85.8	83.3	37.8
7	4	3.72	67.7	84.9	88.3	35.0
8	8	3.71	67.1	85.2	87.0	35.5
9	12	3.64	65.1	80.9	81.9	32.6
10	4	3.68	65.6	85.4	85.6	34.6
11	8	3.77	67.3	88.8	84.3	34.1
12	12	3.84	65.4	85.9	82.4	34.3

(b) 25 cuttings during 11 harvest years.
(c) 13-year average.
(a) 11-and 13-year averages, respectively, for corn after alfalfa and after corn.

Table 4. Yields when significant yield responses resulted from plow depth in tons of hay or bushels of grain among treatments 1-6

		Plow depth		
Crop	Year	4 in.	8 in.	12 in.
Alfalfa				
1st cutting	1961	2.22	2.04	1.65
Barley	1967	42.5	44.1	45.0
Corn				
after alfalfa	1960	82.6	105.9	86.4
after corn	1961	98.3	82.2	93.3
after corn	1963	99.4	99.5	89.1
Soybeans	1961	18.8	13.1	18.6

Table 5. Plants per acre, yields and plants per bushel for corn in selected years during the early years of the experiment, 1958-1962

Treatment	Plow depth, in.	Plants/A	Bu/A	Plants/bu	No. of observations
1	4	17,819	92.3	193	9
2	8	18,553	95.2	195	9
3	12	18,491	92.1	201	9
4	4	16,864	98.8	171	6
5	8	18,079	97.0	186	6
6	12	17,902	92.4	194	6
7	4	17,197	97.2	177	6
8	8	18,381	95.1	193	6
9	12	18,018	93.1	194	6
10	4	16,576	94.6	175	6
11	8	18,402	98.2	187	6
12	12	18,142	96.7	188	6

Table 6. Average yields when significant yield responses occurred from fertilizer among treatments 1-6

	Tons of Forage or Bushels of Grain Per Acre			
Treatments	Alfalfa (8) (32%) (a)	Barley (6) (46%)	Corn (3) (13%)	Soybeans (1) (8%)
1, 2, and 3	1.32	49.0	74.0	36.0
4, 5, and 6	1.57	54.6	59.8	32.7

(a) Eight times or 32% of the observations.

Table 7. Soil tests of phosphorus and potassium for selected plots

Treatment	Sampling depth, in.	P: 800, 1000 E 1958	P: 800, 1000 E 1959	P: 800FG 1960	P: 800HI 1961	P: 800, 1000 E 1970	K: 800, 1000 E 1958	K: 800, 1000 E 1959	K: 800FG	K: 800HI	K: 800, 1000 E 1970
1	0-4	43	36	105	76	59	99	121	94	191	124
	4-8	40	32	94	76	34	79	92	22	138	88
	8-12	24	29	68	55	11	55	89	14	128	82
	12-16			86	25	7			44	142	96
2	0-4	40	42	78	77	49	64	97	83	175	101
	4-8	40	36	88	75	47	62	36	43	126	71
	8-12	33	30	74	61	18	64	91	10	142	69
	12-16			81	26	8			17	134	86
3	0-4	33	31	64	74	41	57	114	114	202	115
	4-8	24	23	54	71	37	57	66	40	172	94
	8-12	24	32	58	70	22	71	81	45	194	80
	12-16			70	64	11			44	195	92
4	0-4	82	67	110	122	140	175	125	140	283	187
	4-8	100	47	116	101	117	218	142	60	212	129
	8-12	25	18	77	70	22	76	92	24	187	103
	12-16			77	46	13			22	189	117
5	0-4	47	50	104	90	97	98	168	188	226	159
	4-8	76	52	96	84	120	129	111	127	164	120
	8-12	79	75	88	73	96	124	87	66	192	96
	12-16			78	46	15			52	169	101
6	0-4	49	48	100	83	67	88	139	108	240	148
	4-8	38	33	123	84	73	83	99	120	191	105
	8-12	42	40	104	92	64	95	81	75	212	95
	12-16			133	81	35			34	211	97
7	0-4	61	105	134	94	200	160	175	121	259	263
	4-8	130	92	104	92	171	197	125	72	186	165
	8-12	40	33	66	70	42	76	76	30	182	117
	12-16			70	42	16			15	257	97
8	0-4	113	93	98	94	181	187	176	221	208	275
	4-8	153	109	106	103	210	211	165	124	145	200
	8-12	63	60	93	96	90	153	145	63	152	183
	12-16			74	36	19			32	175	140
9	0-4	94	91	155	103	218	173	257	260	356	364
	4-8	116	91	154	106	262	199	159	111	286	289
	8-12	64	73	164	105	231	202	158	122	312	274
	12-16			117	92	78			78	316	202
10	0-4	102	84	148	102	163	144	166	201	356	237
	4-8	121	49	133	98	150	175	96	68	228	149
	8-12	36	40	83	82	41	103	86	44	222	113
	12-16			93	62	15			17	231	105
11	0-4	129	90	145	94	178	134	176	212	235	261
	4-8	165	82	129	108	223	201	139	124	157	187
	8-12	71	49	110	73	100	146	129	86	141	175
	12-16			80	47	21			34	158	147
12	0-4	102	88	164	121	177	172	252	303	312	383
	4-8	84	99	158	121	231	154	161	163	201	318
	8-12	79	83	120	118	200	196	133	130	255	288
	12-16			102	88	46			96	253	190

Treatments 7-12 were designed to test whether an increase in plow depth, accompanied by an increase in fertilizer, would increase yields. These treatments were designed to overcome any adverse effect of nutrient dilution with deeper plowing. In spite of the higher amount of fertilizer, average yields for 12-in. plowing depth tended to be slightly less than the 4- or 8-in. plowing depths for corn. The higher fertilizer amount was not effective on the other crops (Table 3).

Fertilizer Rate and Plow Depth vs. Soil Tests

Soil tests results are given in Table 7. The tests represent one complete sampling for one crop in five different years. Tests for 1958, 1959, and 1970 were from the same plots. Increasing plow depth produced more uniform soil tests within the upper 16 in. of soil. The soil test for both P and K was increased in the 12-to 16-in. soil layer as a result of plowing 12 in. deep. For treatments 1-3 and for 4-6, the same amount of fertilizer was applied and plowing 12 in. deep compared to 4 in. reduced the available P and K in the top 4 in. of soil. This was probably due to increased fixation and nutrient dilution.

Brace roots of corn develop rapidly after tasseling (4) and branch profusely after entering the soil surface (Fig. 1). Brace roots can be very important for nutrient uptake if the top several inches of soil are occasionally rewetted by later summer rains. The uptake of P by corn brace roots is equal to 1-37% of the P derived from fertilizer and related to the amount of P added and number of brace roots (6). The trend for the lowest corn yields with 12 in. plowing could likely be due to reduced uptake of nutrients by brace roots caused by a slightly lower fertility level in the upper few inches of soil.

Fig. 1. Brace roots of corn showing unbranched main roots above ground and profusely branched main roots below ground level.

Changes in Soil Tests Over Time

Soil tests for 1958, 1959 and 1970 were for the same plots, permitting a comparison of changes in soil tests over time. The sampled plots were fertilized and planted to barley in 1958 and not fertilized and planted to alfalfa in 1959. Prior to 1959, the plots had been fertilized three times. They were fertilized nine times between 1959 and the time of sampling in fall 1970. Generally, there were small increases in soil P and K with time where only starter fertilizer had been applied (Table 7).

The highest amounts of fertilizer produced very high soil test values, in excess of 200 for P and nearly 400 for K. White and Doll (9) reported that 2-5 lb. of fertilizer P and 2-4.5 lb. of fertilizer K are required to increase soil tests 1 lb/A. This study (Table 8) verifies their findings for P where amounts in excess of starter fertilizer were used (treatments 4-12). The pounds of fertilizer K required to increase soil tests 1 lb/A were great by comparison.

Treatments 4, 5, and 6 received 1,046 lb of fertilizer K between 1959-70 and required from 12-52 lb of fertilizer K to increase soil tests 1 lb/A. This indicates soils in this study had greater K fixing capacity when compared to the soils in White and Doll's study.

High K fixation in Conover and Brookston soils in Michigan was found by Cummings (3). Reduced amounts of fertilizer K were required for the highest fertilizer rate. This suggests that the K fixing capacity of the soils was being satisfied. The increases of soil test K were associated with decreases in the exchangeable Mg/K ratio (Table 8).

Table 8. Pounds of P and K added as fertilizer to increase soil test values 1 lb/A from 1959-70 (a) and exchangeable Mg/K ratios in 1970 in upper 16 in. of soil

Treatment	P	K	Mg/K Ratio
1	40	—	4.6
2	20	23	4.6
3	11	10	4.5
4	4	12	3.1
5	4	52	3.5
6	5	29	3.8
7	4	8	2.0
8	5	10	2.1
9	3	6	1.1
10	4	9	2.2
11	4	9	1.9
12	4	5	1.3

(a) Assumed soil test value for 12-16 in. layer in 1959 was 10 for P and 90 for K.

SUMMARY AND CONCLUSIONS

An experiment was begun in 1956 to study effect of plow depth on crop yields when minimum tillage was used. Results did not justify plowing deeper than 4-8 in. for a corn-corn-soybeans-barley-alfalfa rotation using minimum tillage and no irrigation. In fact, caution should be exercised in plowing deeper than 8 in. because small but consistently lower yields of corn resulted from 12 in. plowing depth. This finding is particularly relevant with the current energy shortage.

Plowing 12 in. deep, compared to 4 or 8 in., created a more uniform distribution of P and K in the upper 16 in. of soil. Plowing 4 in. deep, compared to 12 in., resulted in higher soil test values for P and K in the top 4 in. of soil. This may be the result of greater nutrient dilution and fixation with 12 in. plow depth. As a result, the corn brace root system probably absorbs more nutrients with 4-in. plowing and, thus, yields more as compared to 12-in. plowing. This effect was not observed for soybeans, barley or alfalfa.

Adding large amounts of P and K fertilizer between 1959 and 1970 resulted in large increases in soil test P and K so that additional P and K fertilizer will not likely increase yields. The largest amount of fertilizer K reduced the exchangeable Mg/K ratio from about 4.5 to 1.2 between 1959 and 1970. This latter might reduce the magnesium content of crops sufficiently to lower their quality as animal feed.

Results of this study confirm those of two other studies conducted on the Soil Science Farm at East Lansing, namely, that plowing 10 or 12 in. as compared to 4 or 7 or 8 in. does not increase corn yields. A "deep, dark-colored topsoil" has been associated with high yields and productive soil, but trying to create one using fertilizer and plowing deeper in the loamy forested soils of southern Michigan appears unwise. Unless loamy soils of Michigan have root inhibiting layers, plowing only deep enough to do a good job of establishing crops appears sufficient. This does not negate the possibility that sugarbeet yields on fine-textured soils will be increased by plowing 10 or 12 in. deep rather than 8 in.

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