Influence of Subsurface Irrigation and Organic Additions on Top and Root Growth of Field Corn[1]

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ABSTRACT

Numerous attempts have been made to increase root proliferation by modifying soil profiles possessing undesirable chemical and physical properties.

Field and laboratory studies were conducted over a 5-year period on an Evesboro loamy sand (mesic, coated Typic Quartzipsamments) soil from Delaware to determine the effect of organic additions and type of irrigation on corn (*Zea mays* L.) grain yield, root distribution, and on selected soil properties. The study also sought to determine if organic additions would increase the effectiveness of subsurface irrigation. Organic additions, made only in the 1st year of the study, consisted of 10 × 40 cm chisel (C) openings at 76 cm intervals which were filled with solid waste (SW) and/or poultry manure (PM) at 65 metric tons/ha. No attempt was made to superimpose corn rows directly above the chisel openings. Irrigation types were subsurface (SSI), and trickle irrigation (TI). Grain yields were significantly higher in C + SSI than in C + TI treatments. Chiseling + SSI increased the average 5-year corn yield 4,300 kg/ha over C alone which demonstrated the pronounced effect that SSI had on yield. Organic additions had no signifciant effect on grain yields, although yields for the C + SW treatment were numerically higher than for the C + PM treatment each year of the study, and the former averaged 1,150 kg/ha higher over the 5-year period. The C + SW treatments also produced higher yields than the control (NC). Chiseling, without incorporation of organic materials (C) was no more effective than leaving the soil undisturbed (NC). Organic additions enhanced root growth more than yield of corn. The subsoil was essentially devoid of roots without chiseling or organic additions. The highest CEC and organic matter levels at the end of the 5-year study were found in the organic addition trench adjacent to the SSI lines. Corn roots proliferated in this region and in most cases enveloped the irrigation lines. Lateral as well as vertical movement of Ca, K, Mg, and P occurred with the lowest concentrations occurring in the plow layer. Movement of plant nutrients laterally from the organic addition trench into the surrounding subsoil probably contributed to root extension and could be significant in terms of nutrient utilization.

Additional index words: **Irrigation, Organic wastes, Atlantic Coastal Plain soils.**

MANY of the sandy-textured Ultisols of the Southeastern and Middle Atlantic States have a densely packed A2 horizon below the plow layer. The A2 horizon often restricts root penetration which reduces the storage capacity of plant available water and makes agricultural crops susceptible to drought (Reicosky et al., 1977).

Numerous attempts have been made to increase root proliferation by modifying soil profiles possessing undesirable chemical and physical properties. Methods used include deep subsoiling, slip plowing, deep plowing, double digging, trenching, and backhoe mixing (Mech et al., 1967; Robertson et al., 1966; Eck and Davis, 1971; Kaddah, 1976; Bradford and Blanchar, 1977). Cassell (1980) attempted to alter the water retention characteristics in two soils by deep and medium plowing. The deep plowing operations induced no direct increase in water-holding capacity in either soil. Deep plowing of a Norfolk lamy sand however, decreased the infiltration rate which increased run-off. Weatherly and Dane (1979) found that with conventional tillage, soil water movement and water uptake were less for non-subsoiled treatments than for other treatments. The two subsoiled treatments and the no-tillage-no-subsoiling treatment indicated root penetration and soil-water uptake below 50 cm. In-row subsoiling was shown by Bennett (1939) to encourage deeper rooting of cotton (*Gossypium hirsutum* L.) and soybeans (*Glycine max* L.) and yields were increased, especially during dry years. With plentiful soil moisture, soil strength decreased and root development was less inhibited by traffic and textural pans. Doty et al. (1975) grew millet (*Setaria italica* L.) and sweet corn (*Zea mays* L. var. Sacchareta) on a Varina sandy loam soil with a compact A2 horizon disrupted by chiseling to a depth of 38 cm. Chiseling increased millet dry matter and sweet corn yields significantly. The chiseled soil produced yields comparable with irrigated non-chiseled soil. More water was also available for plant use in the chiseled soil than in the non-chiseled soil. The authors also found that chiseling the soil to disrupt the compact A2 horizon will sustain millet and sweet corn production from 8 to 24 days longer under drought conditions than moldboard plowing or shallow disking and harrowing.

Researchers have also attempted to mitigate the presence of pans by deep placement of lime, fertilizers, and organic materials (Bradford and Blanchar, 1977; Cassell, 1980). Cassell (1980) employed deep tillage, medium tillage, and conventional tillage techniques to add lime and P to some Atlantic Coastal Plain soils. With deep-tillage, soil pH and P levels were higher at the 38- to 51-cm depth than with conventional or medium-tillage systems.

Numerous researchers have sought to ameliorate undesirable soil chemical and physical properties by adding composts or by mulching. Hortenstine and Rothwell (1973) found that compost applications kept soil pH at the level of the control treatment; however, there was a drop in pH as the result of mineral fertilizer applications. Soil P was increased over the control with the two highest rates of compost. Soil K and Ca were increased with the 16-, 32-, and 64- metric tons/ha rates of the compost and the mineral fertilizer. The compost significantly increased the CEC and organic matter content of the soil when applied at the highest rate of 64 metric tons/ha.

Vitosh et al. (1973) found that organic matter and exchangeable Ca, K, and Mg increased with increasing rates of manure. Jackson et al. (1977) surface applied broiler litter at rates up to 134.4 metric tons/ha. They found that organic matter decreased from 1.7% in the check plots to 1.4% at the high rate of broiler litter. The net decrease in organic matter with increasing

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Table 1. Organic addition and irrigation treatments.†

1. No Chisel (NC) (Control)
2. Chisel (C)
3. Trickle Irrigation (TI)
4. Chisel + Trickle Irrigation (C + TI)
5. Chisel + Subsurface Irrigation (C + SSI)
6. Chisel + Solid Waste (C + SW)
7. Chisel + Solid Waste + Subsurface Irrigation (C + SW + SSI)
8. Chisel + Poultry Manure (C + PM)
9. Chisel + Poultry Manure + Subsurface Irrigation (C + PM + SSI)
10. Chisel + Solid Waste + Poultry Manure (C + SW + PM)
11. Chisel + Solid Waste + Poultry Manure + Subsurface Irrigation (C + SW + PM + SSI)
12. Chisel + Lime + Phosphorus + Subsurface Irrigation (C + L + P + SSI)
13. Chisel + Solid Waste + Poultry Manure 1 + Lime + Phosphorus + Subsurface Irrigation (C + SW + PM1 + L + P + SSI)
14. Chisel + Solid Waste + Poultry Manure 3 (C + SW + PM3)
15. Chisel + Solid Waste + Poultry Manure 3 + Subsurface Irrigation (C + SW + PM3 + SSI)
16. Chisel + Solid Waste + Poultry Manure 3 + Lime + Phosphorus + Subsurface Irrigation (C + SW + PM3 + L + P + SSI)

† PM = Poultry manure from one flock (wood shavings litter) moved directly from broiler to field.
PM1 = Stockpiled poultry manure from one flock (solid waste litter).
PM3 = Stockpiled poultry manure from three flocks (solid waste litter).
SW = Composted paper and food waste supplied by Fairfield Engineering, Altoona, Pa.

Table 2. Selected chemical and physical properties of Evesboro loamy sand.

Horizon	Particle size analysis Sand	Silt	Clay	Organic matter	pH	CEC	Exchangeable Ca	Mg	K
	%					meq/100 g			
Ap	85.2	9.8	5.0	1.0	5.8	3.5	0.85	0.32	0.08
B21t	80.0	10.0	10.0	0.5	5.5	3.7	1.29	0.76	0.09

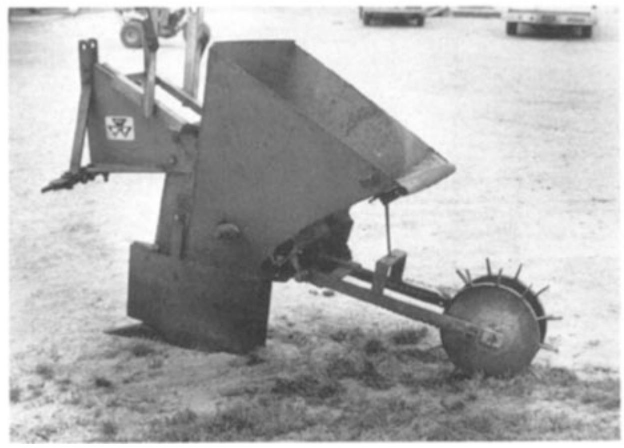

Fig. 1. Tapered bin and open-back hollow chisel used to place organic material into the soil.

rates of the litter was ascribed to increased microbial activity associated with the low C:N ratio of the broiler litter.

Mitchell (1981) subsurface irrigated field corn (*Zea mays* L.) on a Matapeake silt loam from Delaware with thin-walled plastic tubing placed at a depth of 36 cm. The tubing functioned for a period of 7 years and there was no evidence of the tubing failing to reinflate when the system was activated following shut-down for a period of weeks or even months. Root development adjacent to the lines was thought to stabilize the soil and to prevent collapse around the tubing. There are no reports of similar work on sandy soils.

The objectives of this study were to: (1) determine the effect of organic additions and type of irrigation on corn grain yield and on selected chemical properties in an Evesboro loamy sand soil; (2) determine if organic additions would increase the effectiveness of subsurface irrigation; and (3) to ascertain the effect of organic additions and type of irrigation on root distribution in an Evesboro loamy sand soil.

MATERIALS AND METHODS

Field Studies

Field corn studies, conducted on an Evesboro loamy sand (mesic, coated Typic Quartzipsamments) soil (Table 2) for 5 years, involved the organic addition and irrigation treatments shown in Table 1. The 4.6 × 15.2 m experimental plots were arranged in a randomized complete block design with three replications.

Organic addition treatments, made at the beginning of the experiment, consisted of 10 × 40 cm chisel openings at intervals of 76 cm which were filled with solid waste (SW) and/or poultry manure (PM) at 65 metric tons/ha (wet weight basis). Each of the organic additions contained ~30% moisture. These materials were discharged from a tractor-mounted tapered bin aided by agitation from a ground driven paddle wheel (Fig. 1). Gravity and paddle wheel agitation were sufficient to cause the waste products to move into the soil via an open-back hollow chisel. On a dry weight (70 C) basis the PM contained 2.5, 2.7, and 2.0% N, P, and K, respectively, while the SW contained 1.4, 0.5, and 0.7% N, P, and K, respectively.

In subsurface irrigation treatments (SSI) tubing constructed from spun-bonded olefin and functioning as a line emitter was mechanically placed 3 to 6 cm from the bottom of the chisel opening and covered by soil, PM, or SW in a single operation. Trickle irrigation (TI) treatments involved surface placement of irrigation lines at intervals of 76 cm. While TI lines were replaced annually, the subsurface lines remained functional for 5 years following initial installation. Lateral irrigation lines were connected to a 3.18 cm diam main feeder line. The system was operated at 0.34 bars with water from a 30 m well using a centrifugal pump and an electrical power source. Dolomitic limestone at 6.7 metric tons/ha and P at 241 kg/ha, as triple superphosphate, were applied to selected treatments as shown in Table 1. All plots received 112 kg P/ha as triple superphosphate, 112 kg K/ha as KCl, and 280 kg N/ha as NH_4NO_3. The N was sidedressed when the corn was about 15 cm high whereas P and K were broadcast before planting.

Corn 'Pioneer 3369A' was planted at 54,000 plants/ha. Conventional tillage with a rye (*Secale cereale* L.) cover crop was used from 1975 to 1977. In 1978 and 1979 corn was planted without tillage into a hairy vetch (*Vicia villosa* Roth.) cover crop using a no-tillage planter equipped with disc openers, fluted coulters, and ribbed press wheels. From 1975 to 1977, weed control was achieved by use of simazine [2-chloro-4,6-bis (ethylamino)-*s*-(triazine)] and atrazine [2-chloro-4-(ethylamino)-6-(isopropylamino)-*s*-triazine)] at 1.40 and 1.40 kg active ingredient (a.i.)/ha, respectively. During 1978 and 1979, paraquat (1,1′-dimethyl-4,4′-bipyridinium ion), at 0.56 kg a.i./ha, and a non-ionic wetting agent (Ortho X-77) were combined with simazine and atrazine for weed control in the no-tillage corn. Herbicides were applied as a tank mixture with water at 560 liters/ha and 2.1 kg/cm^2 pressure.

Table 3. Precipitation during growing season of corn at Georgetown Substation for 1975–1979.

Month	1975	1976	1977	1978	1979
	cm				
May	8.3	6.6	5.6	15.8	9.9
June	9.4	3.2	5.8	5.3	15.9
July	18.6	6.3	4.3	10.4	6.8
August	13.0	16.0	7.7	21.9	14.2
Total	49.3	32.1	23.4	53.4	46.8

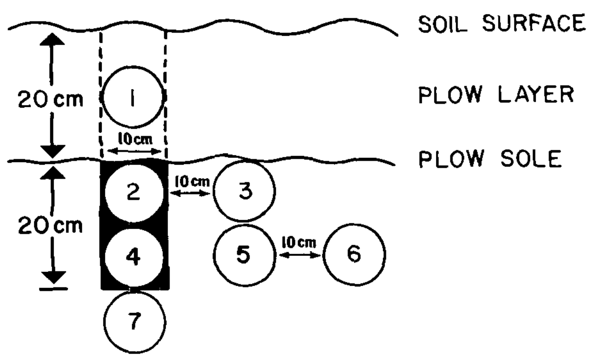

Fig. 2. Pattern of soil sampling of experimental plots in 1979.

Grain yields were determined from 6.1 m sections of two interior rows from each plot. These yields were adjusted to 15.5% moisture. Ear leaves from 10 plants in each plot were collected at the early silk stage, composited, oven dried (70 C), and ground to pass a 20-mesh screen. Subsamples of the tissue were analyzed for N using the Kjeldahl method and for B using the azomethine-H method (John et al., 1975). Other analyses were made after dry ashing 1.0-g subsamples of the tissue at 450 C and leaching with dilute HNO_3. Concentrations of Ca, K, and Zn were determined by atomic absorption spectrophotometry. Phosphorus in the earleaf tissue was measured using a vanadate colorimetric procedure.

Soil Analyses

Bulk soil samples collected in 1975 from the Ap and B21t horizons were air dried and crushed to pass a 2 mm sieve in preparation for characterization. Particle size was determined by the hydrometer method (Day, 1965); organic matter was determined by a modified Walkley-Black procedure (Allison, 1965); and cation exchange capacity (CEC) was determined by $MgCl_2$ saturation and subsequent displacement by $CaCl_2$ (Okazaki et al., 1963; Rich, 1962). Exchangeable Ca, Mg, and K were extracted with 1 N NH_4OAc (Jackson, 1958) and their concentrations determined by atomic absorption spectrophotometry. Soil pH was determined using a 1:1 soil/water ratio.

Detailed soil sampling of each experimental plot, as shown in Fig. 2, was conducted following the final corn harvest in October 1979. The soil profile was exposed to a depth of 50 cm, and 10 × 10 cm cores were removed by driving a hand-held coring device into the soil profile wall. The soil cores were air-dried, sieved, and analyzed for pH, organic matter, CEC, and exchangeable Ca, Mg, and K using the methodologies given previously.

Corn Root Growth

In September 1975, soil cores were removed from six locations in selected organic addition plots of an adjacent experiment to determine the influence of treatments on corn root growth. Soil cores (800 cm^3) were washed over a 2 mm screen and the recovered roots were oven dried at 70 C and weighed. The sample locations, with reference to the organic addition trench, are shown in Fig. 3.

Table 4. Effect of organic additions and irrigation on corn grain yield over a 5-year period on Evesboro loamy sand.

Treatment	1975	1976	1977	1978	1979	Avg.
	kg/ha					
NC (Control)	9,670	5,980	950	8,180	6,390	6,230
C	8,990	5,990	570	8,380	7,240	6,230
TI	10,270	7,930	9,310	10,200	7,870	9,120
C+TI	10,680	6,770	9,750	10,160	8,000	9,070
C+SSI	11,630	11,610	9,800	10,510	9,190	10,550
C+SW	9,580	7,420	1,920	8,740	7,060	7,060
C+SW+SSI	11,540	10,890	9,150	10,120	9,050	10,150
C+PM	8,150	5,870	640	8,100	6,820	5,910
C+PM+SSI	11,580	11,030	9,070	9,700	8,520	9,980
C+SW+PM	7,020	7,580	1,350	8,360	6,550	6,740
C+SW+PM+SSI	11,640	11,100	8,090	10,200	10,120	10,120
C+L+P+SSI	9,980	10,660	6,200	9,390	8,830	8,830
C+SW+PM1+ L+P+SSI	10,320	11,860	8,920	10,510	9,450	10,210
C+SW+PM3	7,620	5,740	930	8,590	7,050	5,980
C+SW+PM3+SSI	9,970	11,480	9,970	10,360	9,140	10,190
C+SW+PM3+L +P+SSI	10,760	11,040	9,980	10,190	8,870	10,170
L.S.D. (0.05)	3,200	2,680	3,360	2,400	2,200	1,350

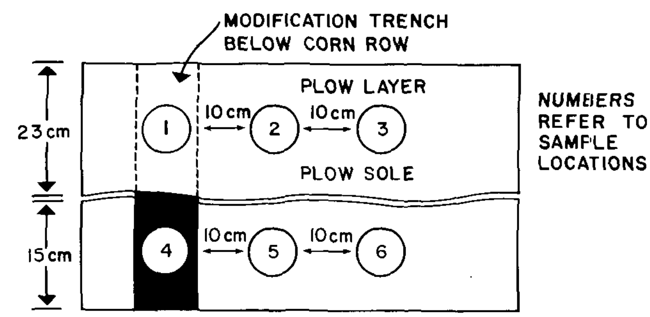

Fig. 3. Location of soil samples used for root growth measurements.

RESULTS AND DISCUSSION

Monthly and total rainfall during the growing season varied widely from 1975 to 1979 (Table 3). The strong positive relationship between grain yield of the control (NC) plots (Table 4) and precipitation in July (Fig. 4) illustrate the critical need for supplemental irrigation during periods of high evapotranspiration.

Irrigation and Corn Yield

The 5-year average corn yield (Table 4) was significantly increased by irrigation. Trickle irrigation (TI, C + TI) with emitter lines placed on the soil surface produced significantly lower yields than subsurface irrigation (C + SSI). Although small yield differences in favor of C + SSI over TI were noted each year, the poor performance of TI was especially striking in 1976. The latter could be explained by N deficiencies that were observed in corn leaves and confirmed by tissue analysis in 1976 (Table 5). Since the same amount of water was applied through the TI and SSI systems, the lower yield and lower leaf-N concentration with the former system may have resulted from N losses due to leaching and/or deni-

Table 5. Effect of organic additions and irrigation on nutrient concentration of corn ear leaf tissue on Evesboro loamy sand in 1976.

Treatment	N	P	Zn
	%		
NC	3.23	0.41	33.33
C	3.09	0.34	28.33
TI	2.28	0.28	16.33
C+TI	2.10	0.29	16.33
C+SSI	2.95	0.41	22.67
C+SW	3.05	0.37	33.67
C+SW+SSI	3.14	0.36	24.67
C+PM	3.17	0.46	31.33
C+PM+SSI	3.00	0.36	21.00
C+SW+PM	3.48	0.44	35.33
C+SW+PM+SSI	3.05	0.38	21.67
C+L+P+SSI	3.03	0.35	20.33
C+SW+PM1+L+P+SSI	3.06	0.40	23.33
C+SW+PM3	3.13	0.43	32.00
C+SW+PM3+SSI	3.11	0.38	21.33
C+SW+PM3+L+P+SSI	3.25	0.40	22.67
L.S.D. 0.05	0.44	0.07	4.69

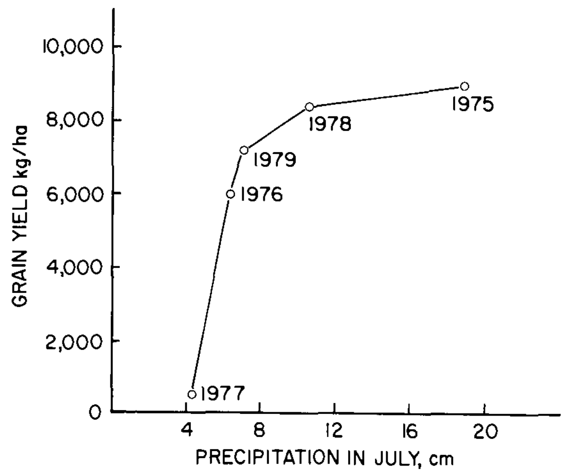

Fig. 4. Influence of July precipitation on corn production in control plots at Georgetown Substation from 1975 to 1979.

Table 6. Influence of organic addition treatments on the root growth of field corn in 1975 on Evesboro loamy sand.

Modification treatment†	Root growth, dry Sample location‡ 1	2	3	4	5	6	Avg.
	g/800 cm³ of soil						
NC	0.80	0.18	0.19	0.05	0.01	0.09	0.22
C	3.24	0.49	0.73	1.23	0.07	0.18	0.99
C+SW	2.45	1.08	0.38	2.17	0.11	0.08	1.04
C+PM1	3.05	0.93	0.28	2.17	0.15	0.04	1.10
C+SW+PM1	3.62	0.43	0.25	3.67	0.12	0.03	1.35
C+L+P	3.30	0.26	0.19	0.44	0.85	0.02	0.84
C+L+P+PM1	1.70	0.15	0.34	1.12	0.01	0.01	0.55
C+L+P+SW	5.43	0.44	0.43	2.39	0.51	0.09	1.55
C+L+P+PM1 +SW	3.31	0.40	0.19	1.62	0.99	0.12	1.10
C+L+P+SW +PM	1.82	1.31	0.17	0.62	0.76	0.07	0.79
Avg.	2.61	0.57	0.31	1.55	0.36	0.07	
L.S.D. 0.05 Sample Location				0.76			
L.S.D. 0.05 Modification treatment				0.98			

† Municipal solid waste (SW) and stockpiled broiler manure (PM1) were mixed in equal amounts on a volume basis. Broiler manure (PM) was removed directly from the broiler house, mixed with SW, and placed in the modification trench.
‡ See Fig. 3.

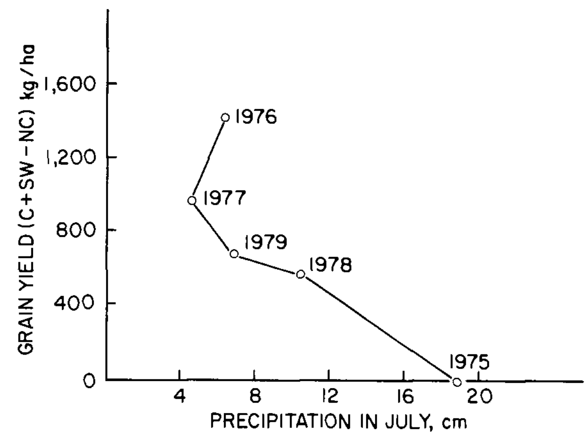

Fig. 5. Relationship between difference in yield of C + SW and NC treatments and precipitation in July, 1975–1979.

trification. The data suggest that a more favorable water and N irrigation pattern existed with the SSI system. Trickle irrigation treatments also gave the lowest ear leaf P and Zn concentrations.

Chiselling + SSI increased the average corn yields 4,300 kg/ha over C alone demonstrating the pronounced effect that SSI has on yield. Chiselling, to facilitate the placement of SSI tubing in the soil, provided an opening through which topsoil could enter with resulting modification of the subsoil adjacent to the tubing. Since some soil modification is inevitable when SSI tubing is installed, a yield response may not be solely a function of irrigation. Modification of the chisel opening with organic materials, however, did not increase the yield of irrigated corn (Table 4).

Organic Additions

Organic addition treatments had no significant effect ($P \leq 0.05$) on grain yields (Table 4), although yields for the C + SW treatment were numerically higher than for the C + PM treatment each year of the study, and the former averaged 1,150 kg/ha higher over the 5-year test period. With the exception of 1975 which had relatively high rainfall (Table 3), the C + SW treatment also produced higher yields than the control (NC). The yield response relationship between July precipitation and soil modification treatments (C + SW - NC) (Fig. 5) is similar to that reported by Bennett (1939) who found higher yields for subsoiling treatments in dry years.

Grain yields were not significantly affected by chiseling alone, compared to leaving the soil undisturbed (NC). Manure additions without SSI in 1975–1978 caused a numerical, although insignificant ($P \leq 0.05$) reduction in grain yield when compared with the NC treatment (Table 4). Shortall and Liebhardt (1975) attributed a similar yield suppression to high salt concentrations since higher corn yields were obtained when manure applications were made well in advance of corn planting.

Organic addition treatments had a more general effect on root growth (Table 6) than on yield of grain (Table 4). Root proliferation in the subsoil at sample locations 4 and 5 (Fig. 3) was of special interest since

Table 7. Influence of soil sample location on soil parameters at end of 5-year study.

Sample location†	pH	O.M.	CEC	P	K	Ca	Mg
		%	meq/ 100 g	ppm/dm³			
1	6.2	0.70	3.50	57	46	339	61
2	6.2	0.94	3.81	103	59	491	65
3	6.3	0.92	3.55	156	69	707	80
4	6.3	1.17	4.20	186	66	1,008	94
5	6.3	0.79	3.61	172	58	752	84
6	6.3	0.71	4.19	133	74	569	86
7	6.3	0.82	3.64	176	57	725	82
L.S.D. (0.05)	*0.1*	*0.20*	*0.59*	*39*	*8*	*183*	*15*

† Sample location—See Fig. 2.

without chiseling or organic additions it was essentially devoid of root growth (Table 6). Roots were concentrated in the organic addition trench where the soil had been amended with PMI and SW with the latter treatment being more effective. The use of L + P, except where combined with PMI, appeared to stimulate root development at sample location 5 which was located about 10 cm horizontally from the organic addition trench. Increased earthworm activity was also observed at location 5 where the L + P treatment was used alone or in combination with SW and PM. At the end of the 5-year test, organic material in the modification trenches remained essentially intact although it was somewhat modified by the annual accumulation of corn roots. Based on these observations, it seems likely that the organic addition treatments will have a long lasting effect—a point of economic as well as agronomic significance.

Effect of Treatments on Soil Properties

At the end of the 5-year study, soil samples were taken at seven different locations in the soil profile of each treatment (Fig. 2). Although significant main effects as well as organic addition treatment times sample location interactions were found, of greater interest was the nutrient migration patterns that developed. Organic addition treatment values were averaged to show the influence of sample location on several soil parameters (Table 7). Soil acidity was slightly higher at locations 1 and 2 than at other points in the profile which may reflect surface N applications. The highest organic matter level was found in the organic addition trench adjacent to the SSI lines (sample location 4). Corn roots proliferated in this region and in most cases enveloped the irrigation lines. In earlier work, Mitchell (1981) found highest organic matter levels adjacent to irrigation lines and attributed this to recycling of annual root growth. An increase in CEC at location 4 is consistent with the higher organic matter level at this sample location. Lateral as well as vertical movement of Ca, K, Mg, and P occurred with the lowest levels found in the plow layer and at sample location 2. The P level was higher at location 3 than at 2 with similar levels at locations 4, 5, and 7. The significant drop in the P level at location 6 shows that P migration involved a distance of less than 20 cm. Calcium also appeared to move laterally from 10 to 20 cm. Potassium levels were higher at location 6 than at 7 but Mg appeared to move more uniformly throughout the sampled area. Movement of plant nutrients laterally from the organic addition trench into the surrounding subsoil probably contributed to root extension and may be significant in terms of nutrient utilization.

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