Chapter 27

Long-Term Tillage and Crop Residue Management Study at Akron, Colorado

A.D. Halvorson, M.F. Vigil, G.A. Peterson, and E.T. Elliott

CONTENTS

I. INTRODUCTION

Following the dust bowl years of the 1930s, summer fallow became a mechanism to conserve soil water for future crop production. Intensive tillage was used for weed control during the fallow period. Precipitation storage efficiency during the fallow period was relatively low with conventional tillage practices. Stubble mulch tillage practices were developed during the 1960s that improved precipitation storage efficiency by maintaining more crop residue on the soil surface during the fallow period. During the late 1980s, herbicides became available that could be used to control weed growth during the fallow period rather than using mechanical tillage. Use of chemicals for weed control and reduction in mechanical tillage during the fallow period had potential to increase precipitation storage efficiency. The long-term tillage study reported in this paper was initiated to evaluate the effects of various combinations of tillage and herbicides for weed control during the fallow period in a winter wheat-fallow farming system. This chapter reports comparative data for the conventional-till, reduced-till, and no-till systems from this study.

II. SITE DESCRIPTION

The site is at the Central Great Plains Research Station (40°9′N, 103°9′W, 1384 m a.m.s.l) located 6.4 km east of Akron, CO on Highway 34 (NW 1/4 of SE 1/4 of Sec. 12, T2N, R52W, Washington County). The climate is continental, characterized by warm summers (mean daily temperature in July is 23°C) and cold winters (mean temperature in January is –3.9°C), with large diurnal temperature differences associated with the high altitude and predominantly clear skies. Mean annual precipitation

0-8493-2802-0/97/$0.00+$.50

is 420 mm with about 70% occurring between April and August. Year to year variability is high with annual totals varying between 250 and 680 mm, since records began at the station (1908).

The soil is a Weld silt loam (Aridic Paleustoll) with a mean surface soil texture of about 30% sand, 40% silt, and 30% clay. The site has been under cultivation since 1907. From 1907 to 1954, most of the area was used to study numerous crop rotations.[1] During this time, most of the crop residues were removed from the site. In 1955, the entire area was cropped to grain sorghum. From 1956 to 1966 the area was uniformly cropped to winter wheat in a crop-fallow rotation. In 1967, a study was initiated on the area by Wally Greb and Darryl Smika (USDA-ARS) to evaluate the use of herbicides and tillage for weed control during fallow. There were two sets of plots established in separate blocks so that there was a cropped and fallowed plot for each treatment each year. Eight tillage and crop rotation treatments in all were established. Data from three of the tillage treatments are reported in this paper. Tillage treatments are

- *Conventional (stubble-mulch) till fallow.* Tillage is performed with sweeps and rodweeder operations during the 19-month fallow period as needed. Average number of operations is six, which incorporates about 55 to 65% of the previous crop residues by wheat planting time.
- *Reduced till fallow.* A combination of tillage, residual herbicide (Atrazine), and contact herbicides (Paraquat + 2,4-D) are used. When the residual herbicide no longer controls weeds (average 11 months after application), a sweep plow or rodweeder tillage is used as needed for weed control. Generally, two or three tillage operations, which incorporate 30 to 35% of the residue, are needed to control weeds.
- *No-till fallow.* Residual herbicide (atrazine) and contact herbicides (Paraquat + 2,4-D) are used. When residual herbicides no longer control weeds (average 11 months after application), contact herbicides are used as needed for weed control. Average estimated residue loss is 20% from natural causes (wind, etc.).

Details of the tillage operations and treatments are provided by Smika.[2] Figure 1 shows the physical layout of the plots in 1991, as modified in 1989. Five of the previous reduced till treatments were converted to other tillage and crop rotation systems in 1989. Plot numbers 102, 205, 304, and 407 correspond to the conventional till (CT) plots; 108, 206, 303, and 401 to the reduced till (RT) plots; and 105, 207, 301, and 403 to the no-till (NT) plots. These plot numbers correspond to the north set of plots (top of Figure 1). The south set of plots have the same plot numbers (plus 400) for each of the treatments mentioned above. In the data tables, only one set of numbers is used to identify the treatments in the north and south sets of plots. The north plots are 11 × 30 m in size and the south plots 7.3 × 30 m.

A native grass site is located adjacent to the tillage plot area. This area could be sampled as a reference site to document changes in soil quality caused by long-term crop production practices.

III. RESULTS

A. GRAIN AND STRAW YIELDS

Semi-dwarf wheats were grown during the time period reported here. "Vona" winter wheat was grown from 1979 to 1988 and "TAM 107" from 1989 to 1991. A hoe-type drill with a 30-cm row spacing was used to plant the wheat until 1989, then a disk drill with a 18-cm row spacing was used through 1991. Grain yields for each of the treatments are reported in Table 1 for 1979 through 1991 for the north and south sets of plots. Grain yields were determined using field and plot combines to harvest a minimum of 45 m^2 from each plot. Grain yields were corrected to 12% moisture content. Grain and straw yields were not measured in 1985 because the crop was harvested as forage in early June and removed from the plot area because of a heavy infestation of jointed goatgrass (*Aegilops cyclindrica* Host.). Grain yields were generally not significantly affected by tillage system at the 0.05 probability level in any year. Grain yields varied from year to year depending on amount and distribution of precipitation during growing season. The average grain yield over all years was 2954, 2844, and 2788 kg/ha for the CT, RT, and NT tillage treatments, respectively, excluding 1985. The nearly identical yields between tillage systems is probably not surprising when one considers the fact that, after a fallow period, the root zone is at field capacity regardless of tillage system used.

Straw yields are reported in Table 2 for 1979 through 1991 for the north and south sets of plots. Straw yields were determined by harvesting a small area (1 to 2 m^2) of the plot at grain harvest for total biomass production (straw + grain), then subtracting the grain yield as determined by combine to get estimated straw yield. In 1985, the reported 560 kg/ha of straw stubble was only a visual estimate after the wheat crop was harvested as a forage. In 1988, straw yield was not measured. Tillage system did not have a significant affect on straw yield in any of the years reported, except for 1979. In 1979, straw yields of the CT system were significantly greater than those for the RT and NT systems. Straw yields, like grain yields, varied greatly from year to year depending on amount and distribution of precipitation

LONG TERM TILLAGE (AKRON) YEAR 1991

101	CC	201	CFW	301	NT	401	RT
102	CT	202	PLOW	302	CFW	402	WC
103	FWC	203	FWC	303	RT	403	NT
104	WCF	204	WCF	304	CT	404	PLOW
105	NT	205	CT	305	FWC	405	CFW
106	PLOW	206	RT	306	CC	406	WCF
107	CFW	207	NT	307	PLOW	407	CT
108	RT	208	CC	308	WCF	408	CC

501	CC	701	NT
502	CT	702	CFW
503	FCW	703	RT
504	WCF	704	CT
505	NT	705	FCW
506	PLOW	706	CC
507	CFW	707	PLOW
508	RT	708	WCF
601	CFW	801	RT
602	PLOW	802	FWC
603	FWC	803	NT
604	WCF	804	PLOW
605	CT	805	CFW
606	RT	806	WCF
607	NT	807	CT
608	CC	808	CC

TREATMENTS

CT=CONVENTIONAL TILLAGE ONLY

RT=RESIDUAL HERBICIDE, TILLAGE

NT=NO TILL, HERBICIDES ONLY

PLOW=PLOW, CONVENTIONAL TILLAGE

FWC=FALLOW-WHEAT-CORN

CFW=CORN-FALLOW-WHEAT

WCF=WHEAT-CORN-FALLOW

CC=CONTINUOUS CORN

NORTH

WEST **EAST**

SOUTH

Figure 1 Plot diagram of the long-term tillage study at Akron, CO.

during the growing season. The average straw yields over all years were 7373, 7269, and 7206 kg/ha for the CT, RT, and NT tillage systems, respectively, excluding 1985 and 1988.

Straw-to-grain ratios (straw yield/grain yield) for each year are reported in Table 3. Since straw yields were not measured in 1988, we were not able to calculate a straw-to-grain ratio for 1988. Straw-to-grain ratios varied from year to year, but were not significantly affected by tillage system in any given year. Straw-to-grain ratios averaged 2.57, 2.69, and 2.75 for the CT, RT, and NT systems, respectively.

B. SOIL ANALYSES

Elliott et al.[3] analyzed soil samples collected in 1982 from the 0- to 2.5, 2.5- to 5, 5- to 10-, and 10- to 20-cm depths from the CT and NT treatments (Table 4). Bulk densities tended to be greater for NT than for CT at all depths. Total inorganic and organic C, total N, total P, total inorganic P, and total organic P on the same samples used for bulk density are reported in Table 5. Little, if any, inorganic carbon was found in the top 20 cm of soil at this site. Most of the carbon was in the organic form. When averaging the north and south sites, the general trends were for the NT to have a higher organic carbon level in the 0- to 2.5-cm depth than CT. At deeper depths, soil organic carbon was similar for both tillage treatments. Total soil N tended to be higher for NT than CT in the 0- to 2.5-cm depth and nearly identical at deeper soil depths. Inorganic P was greater for NT than CT in the 0-2.5 cm depth. At other depths, inorganic and organic P levels were similar between tillage treatments.

Table 1 Winter Wheat Grain Yields (12% Moisture Content) for the North and South Rotations of the CT, RT, and NT Treatments

		Grain Yield at North Site (kg ha^{-1})							Grain Yield at South Site (kg ha^{-1})					
	Plot	**1991**	**1989**	**1987**	**1985**	**1983**	**1981**	**1979**	**1990**	**1988**	**1986**	**1984**	**1982**	**1980**
CT	102	4154	1925	3147	n.d.[a]	1256	3194	4270	2720	2479	2920	3014	2806	3341
	205	4482	2534	3722	n.d.	1156	3561	4223	1892	1951	4223	3140	2960	4029
	304	3222	1446	3294	n.d.	1931	3194	4043	1685	1964	4069	2619	3040	3495
	407	3369	1892	2826	n.d.	1537	2472	3421	1994	2907	4664	3341	3274	2993
RT	108	4194	2311	3267	n.d.	1363	2873	3949	1840	1470	3434	2913	2699	3869
	206	5567	2094	3581	n.d.	1229	3561	3882	1746	2045	3461	2913	2786	3976
	303	3592	2174	3040	n.d.	1330	3167	3568	2096	2125	4430	2927	2225	3181
	401	2814	1595	2853	n.d.	1290	2780	3221	1449	1944	4063	2753	3154	3708
NT	105	4412	2519	4223	n.d.	1163	3354	3221	2064	2158	4363	2699	3949	3495
	207	3913	2938	3769	n.d.	1617	2606	3622	2228	2172	2626	2967	3020	3815
	301	3924	1834	2826	n.d.	1624	2125	3936	2406	2118	2125	1644	2760	3815
	403	3226	1843	2693	n.d.	1229	2432	4330	1821	2459	2011	2132	2245	3341
Mean		3906	2092	3270	n.d.	1394	2943	3807	1995	2149	3532	2755	2910	3588
CT		3807	1949	3247	n.d.	1470	3105	3989	2073	2325	3969	3029	3020	3465
RT		4042	2044	3186	n.d.	1303	3095	3655	1783	1896	3847	2877	2716	3683
NT		3869	2283	3378	n.d.	1408	2629	3777	2130	2227	2781	2360	2993	3617
$LSD_{.05}$		n.s.	n.s.	n.s.	n.d.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
C.V. (%)		13.8	15.3	10.9	n.d.	16.6	13.5	12.5	16.9	15.1	28.0	12.6	18.5	8.3

[a] Not harvested, due to jointed goatgrass infestation.

Table 2 Estimated Straw Quantities Remaining on Each Plot after Harvest for Each Crop Year for the North and South Rotations of the CT, RT, and NT Treatments

Table 2 Estimated Straw Quantities Remaining on Each Plot after Harvest for Each Crop Year for the North and South Rotations of the CT, RT, and NT Treatments

		Straw Yield at North Site (kg ha^{-1})							Straw Yield at South Site (kg ha^{-1})					
	Plot	**1991**	**1989**	**1987**	**1985**	**1983**	**1981**	**1979**	**1990**	**1988**	**1986**	**1984**	**1982**	**1980**
CT	102	6256	1932	7076	560[a]	6031	9451	7282	9953	n.d.[b]	13222	14455	5820	5234
	205	7141	2894	7039	560	7115	10571	6816	7996	n.d.	14060	11445	7130	7551
	304	3560	1429	8180	560	6582	8706	6994	4728	n.d.	14641	2470	9016	7172
	407	6345	2311	6320	560	5749	5706	5756	7140	n.d.	12527	5221	9671	7718
RT	108	4581	3930	6955	560	6252	8284	6517	5754	n.d.	11340	11960	6147	7279
	206	5517	1074	8653	560	7288	9453	6582	7703	n.d.	13514	14661	6885	6522
	303	4667	1339	8751	560	5466	10594	5725	8514	n.d.	10704	4630	5901	5757
	401	4499	1069	7556	560	7144	9122	5032	5847	n.d.	12854	14403	7130	6294
NT	105	10058	2946	9575	560	10305	10034	6078	6668	n.d.	12570	9054	10081	7688
	207	5474	1723	8186	560	5996	13766	6563	8586	n.d.	9625	12294	5737	5900
	301	6980	2677	9993	560	4842	9781	6229	8389	n.d.	4799	3730	10163	8021
	403	5653	2522	4648	560	4993	7981	5464	7478	n.d.	5708	5505	6393	6204
Mean		5894	2154	7744	560	6480	9454	6253	7396	n.d.	11297	9152	7506	6778
CT		5825	2142	7154	560	6369	8608	6712	7454	n.d.	13612	8398	7909	6919
RT		4816	1853	7979	560	6537	9363	5964	6955	n.d.	12103	11414	6516	6463
NT		7041	2467	8100	560	6534	10391	6084	7780	n.d.	8175	7646	8093	6953
$LSD_{.05}$		n.s.	n.s.	n.s.	n.d.	n.s.	n.s.	534	n.s.	n.d.	n.s.	n.s.	n.s.	n.s.
C.V. (%)		27.2	43.6	16.3	n.d.	25.5	15.6	4.9	24.4	n.d.	20.5	30.0	25.5	17.4

[a] Estimated standing stubble, most of biomass removed.

[b] Not determined.

Table 3 Straw-to-Grain Ratios for the CT, RT, and NT Treatments from the North and South Rotations

		Straw/Grain Ratio at North Site							Straw/Grain Ratio at South Site					
	Plot	**1991**	**1989**	**1987**	**1985**	**1983**	**1981**	**1979**	**1990**	**1988**	**1986**	**1984**	**1982**	**1980**
CT	102	1.51	1.00	2.25	n.d.[a]	4.80	2.96	1.71	3.66	n.d.	4.53	4.80	2.07	1.57
	205	1.59	1.14	1.89	n.d.	6.16	2.97	1.61	4.23	n.d.	3.33	3.64	2.41	1.87
	304	1.10	0.99	2.48	n.d.	3.41	2.73	1.73	2.81	n.d.	3.60	0.94	2.97	2.05
	407	1.88	1.22	2.24	n.d.	3.74	2.31	1.68	3.58	n.d.	2.69	1.56	2.95	2.58
RT	108	1.09	1.70	2.13	n.d.	4.59	2.88	1.65	3.13	n.d.	3.30	4.11	2.28	1.88
	206	0.99	0.51	2.42	n.d.	5.93	2.65	1.70	4.41	n.d.	3.90	5.03	2.47	1.64
	303	1.30	0.62	2.88	n.d.	4.11	3.34	1.60	4.06	n.d.	2.42	1.58	2.65	1.81
	401	1.60	0.67	2.65	n.d.	5.54	3.28	1.56	4.04	n.d.	3.16	5.23	2.26	1.70
NT	105	2.28	1.17	2.27	n.d.	8.86	2.99	1.89	3.23	n.d.	2.88	3.35	2.55	2.20
	207	1.40	0.59	2.17	n.d.	3.71	5.28	1.81	3.85	n.d.	3.67	4.14	1.90	1.55
	301	1.78	1.46	3.54	n.d.	2.98	4.60	1.58	3.49	n.d.	2.26	2.27	3.68	2.10
	403	1.75	1.37	1.73	n.d.	4.06	3.28	1.26	4.11	n.d.	2.84	2.58	2.85	1.86
Mean		1.52	1.04	2.39	n.d.	4.82	3.27	1.65	3.72	n.d.	3.21	3.27	2.59	1.90
CT		1.52	1.09	2.21	n.d.	4.53	2.74	1.68	3.57	n.d.	3.54	2.74	2.60	2.02
RT		1.25	0.87	2.52	n.d.	5.04	3.04	1.63	3.91	n.d.	3.20	3.99	2.42	1.76
NT		1.80	1.15	2.43	n.d.	4.90	4.04	1.64	3.67	n.d.	2.91	3.09	2.75	1.93
$LSD_{.05}$		n.s.	n.s.	n.s.	n.d.	n.s.	n.s.	n.s.	n.s.	n.d.	n.s.	n.s.	n.s.	n.s.
C.V. (%)		20.3	38.7	16.7	n.d.	35.1	21.7	9.6	11.1	n.d.	18.1	32.4	15.2	16.7

[a] n.d. = not determined.

Table 4 Soil Bulk Density Levels for the CT and NT Treatments from the North and South Rotations

Tillage	Depth (cm)	North Site Soil Bulk Density (g cm^{-3}) 9-13-82	10-4-82	5-9-83	Average	South Site Soil Bulk Density (g cm^{-3}) 9-13-82	10-4-82	5-9-83	Average
CT	0–2.5	0.99	0.97	1.24	1.07	0.95	1.02	1.27	1.08
	2.5–5	1.05	1.11	1.24	1.13	1.08	1.08	1.41	1.19
	5–10	1.11	1.38	1.51	1.33	1.31	1.16	1.44	1.30
	10–20	1.35	1.44	1.54	1.44	1.36	1.44	1.58	1.46
NT	0–2.5	0.97	1.18	1.27	1.14	1.14	1.00	1.15	1.10
	2.5–5	1.29	1.41	1.47	1.39	1.35	1.35	1.30	1.33
	5–10	1.45	1.50	1.47	1.47	1.41	1.54	1.54	1.50
	10–20	1.40	1.53	1.59	1.51	1.43	1.48	1.57	1.49

Note: Each soil bulk density value is the average of three replicated plots for each date.

Table 5 Total Soil Inorganic and Organic Carbon, Total P, Total Inorganic P, and Total Organic P in 1982

Tillage	Depth (cm)	Inorganic C (g kg^{-1})	Organic C (g kg^{-1})	Total N (g kg^{-1})	Total P (mg kg^{-1})	Inorganic P (mg kg^{-1})	Organic P (mg kg^{-1})
				North Site			
CT	0–2.5	0.024 (0.024)[a]	8.81 (0.3)	0.95 (0.04)	349 (24.4)	233 (16.2)	117 (29.2)
	2.5–10	0.000 (0)	8.14 (0.54)	0.93 (0.05)	368 (24.3)	243 (16.9)	125 (7.8)
	5–10	0.000 (0)	7.97 (0.41)	0.93 (0.08)	367 (24.0)	238 (18.6)	129 (6.1)
	10–20	0.000 (0)	6.76 (0.36)	0.76 (0.03)	359 (27.3)	234 (16.6)	125 (10.8)
NT	0–2.5	0.000 (0)	9.85 (0.89)	1.01 (0.09)	368 (25.0)	250 (16.9)	118 (9.5)
	2.5–10	0.000 (0)	8.38 (0.45)	0.89 (0.05)	361 (23.2)	244 (16.5)	118 (7.0)
	5–10	0.015 (0.015)	6.96 (0.55)	0.79 (0.06)	354 (28.2)	235 (21.9)	119 (7.1)
	10–20	0.005 (0.005)	6.33 (0.55)	0.72 (0.04)	350 (26.4)	234 (21.9)	116 (5.2)
				South Site			
CT	0–2.5	0.000 (0)	7.44 (0.38)	0.88 (0.13)	345 (4.3)	239 (3.3)	105 (1.3)
	2.5–10	0.000 (0)	7.19 (0.30)	0.78 (0.03)	345 (1.5)	234 (3.3)	110 (1.9)
	5–10	0.007 (0.007)	6.49 (0.12)	0.68 (0.06)	335 (1.5)	229 (1.5)	106 (1.7)
	10–20	0.000 (0)	5.57 (0.19)	0.82 (0.09)	329 (4.0)	217 (4.8)	112 (1.3)
NT	0–2.5	0.042 (0.042)	8.60 (0.33)	0.95 (0.03)	370 (32.9)	248 (12.0)	122 (9.5)
	2.5–10	0.000 (0)	7.43 (0.47)	0.81 (0.04)	359 (13.2)	248 (15.6)	111 (3.4)
	5–10	0.003 (0.003)	6.31 (0.55)	0.74 (0.03)	353 (13.8)	240 (11.7)	113 (2.2)
	10–20	0.003 (0.003)	5.86 (0.22)	0.74 (0.07)	342 (11.9)	226 (10.7)	116 (1.2)

[a] Each number is an average of three plots. Numbers in parentheses are standard errors.

Table 6 Total Soil Organic Carbon, Nitrogen, and Phosphorus for the South Site in 1982 with Soil Depth

Tillage	Depth (cm)	Total C (g kg^{-1})	Total N (g kg^{-1})	Inorganic P (mg kg^{-1})	Organic P (mg kg^{-1})
CT	0–20	6.19 (0.03)[a]	0.75 (0.018)	249 (13.1)	127 (5.6)
	20–40	5.25 (0.37)	0.70 (0.041)	460 (4.0)	131 (6.8)
	40–60	2.76 (0.40)	0.37 (0.057)	433 (10.3)	79 (7.5)
	60–90	1.66 (0.17)	0.25 (0.002)	448 (14.1)	42 (6.0)
	90–120	1.45 (0.16)	0.21 (0.006)	456 (3.1)	38 (2.9)
	120–150	1.25 (0.02)	0.19 (0.024)	466 (4.7)	32 (4.6)
	150–180	1.27 (0.26)	0.17 (0.009)	440 (7.7)	35 (4.5)
	180–210	0.97 (0.24)	0.13 (0.017)	344 (34.1)	17 (3.8)
	210–240	0.76 (0.22)	0.10 (0.013)	307 (51.0)	20 (2.3)
	240–270	0.49 (0.13)	0.10 (0.004)	274 (58.5)	20 (1.4)
	270–300	0.49 (0.12)	0.09 (0.003)	242 (50.9)	27 (4.8)
NT	0–20	6.70 (0.12)	0.75 (0.017)	250 (6.5)	120 (3.3)
	20–40	5.00 (0.10)	0.70 (0.016)	417 (76.4)	123 (3.7)
	40–60	3.44 (0.88)	0.44 (0.103)	459 (10.8)	76 (18.6)
	60–90	1.80 (0.19)	0.28 (0.048)	449 (5.0)	61 (9.8)
	90–120	1.32 (0.11)	0.22 (0.041)	450 (5.2)	34 (7.2)
	120–150	0.99 (0.28)	0.19 (0.034)	462 (3.2)	36 (5.2)
	150–180	0.99 (0.06)	0.17 (0.021)	444 (4.4)	28 (0.6)
	180–210	0.75 (0.05)	0.11 (0.014)	361 (31.1)	26 (1.8)
	210–240	0.38 (0.09)	0.09 (0.012)	265 (36.3)	36 (15.1)
	240–270	0.32 (0.06)	0.09 (0.011)	303 (31.9)	23 (8.5)
	270–300	0.24 (0.07)	0.09 (0.008)	305 (21.6)	33 (5.4)

[a] Each number is an average of three plots. Numbers in parentheses are standard errors.

Total soil organic C, N, inorganic P, and organic P was also determined on the south site for depths up to 2.8 m (Table 6). The trends were for the total soil organic carbon, total soil N, and total soil organic P to decrease with increasing depth in the soil profile for both tillage treatments. Total inorganic P tended to be higher in the 30- to 195-cm depth than at shallower or deeper soil depth for both tillage treatments.

Soil was sampled for the 0- to 20-cm soil depth in the CT, RT, and NT treatments of both sites in April 1989 (Halvorson and Vigil, unpublished). The trend was for the NT treatment to have a higher total soil C and N than the CT and RT tillage systems at the 0- to 5-cm soil depth (Table 7). There was little difference in total soil C and N between tillage treatments below 5 cm.

Soil NO_3-N levels, to 180-cm depth, for each of the CT, RT, and NT treatments are shown in Table 8 for the north and south rotation. The north rotation tended to have a higher level of residual soil NO_3-N than the south rotation for all tillage systems. When averaged over north and south rotations, the soil profile (0- to 180-cm depth) contained 167, 197, and 173 kg N/ha for the CT, RT, and NT tillage systems, respectively. Little or no difference in soil NO_3-N existed between tillage systems.

Table 7 Total Soil Carbon and Nitrogen on April 1989 Samples by Carlo Erba N-C-S Analyzer

Site	Tillage	Depth (cm)	Total C (g kg^{-1})	Total N (g kg^{-1})
North	CT	0–5	9.52 (0.72)*	0.93 (0.07)
		5–10	8.41 (0.65)	0.79 (0.07)
		10–20	7.26 (0.46)	0.72 (0.04)
	NT	0–5	10.17 (0.87)	0.98 (0.08)
		5–10	7.79 (0.75)	0.77 (0.07)
		10–20	7.14 (0.45)	0.70 (0.03)
	RT	0–5	9.74 (1.08)	0.91 (0.09)
		5–10	7.79 (0.80)	0.75 (0.06)
		10–20	6.78 (0.46)	0.66 (0.03)
South	CT	0–5	9.01 (0.41)	0.72 (0.01)
		5–10	7.18 (0.15)	0.62 (0.02)
		10–20	6.13 (0.08)	0.61 (0.01)
	NT	0–5	10.10 (0.20)	0.99 (0.16)
		5–10	7.35 (0.24)	0.60 (0.02)
		10–20	6.47 (0.21)	0.58 (0.01)
	RT	0–5	9.25 (0.77)	0.73 (0.05)
		5–10	7.19 (0.40)	0.61 (0.02)
		10–20	6.29 (0.21)	0.56 (0.01)

[a] Each number is an average of three plots. Numbers in parentheses are standard errors.

Table 8 Soil NO_3-N Levels in the Root Zone of Winter Wheat at Planting Time for the North Rotation (September 19, 1990) and South Rotation (September 6, 1989)

Tillage	Plot	Soil Depth (cm) 0–15	15–30	30–60	60–90	90–120	120–180	Profile Total
		Soil NO_3-N (kg ha^{-1})						
North Site								
CT	102	12.5	10.1	50.0	53.5	32.5	39.6	198.2
	205	38.6	10.4	22.0	19.7	11.0	38.4	140.1
	304	26.7	8.8	24.3	38.5	20.5	22.9	141.7
	407	15.6	18.1	116.2	52.6	30.2	43.9	276.6
RT	108	15.3	16.0	52.3	69.3	35.1	39.1	227.0
	206	15.9	24.3	68.8	80.7	46.9	40.6	277.2
	303	59.6	18.2	69.6	32.2	21.1	33.3	233.9
	401	22.5	22.3	52.0	38.3	43.6	29.1	207.8
NT	105	41.2	22.4	42.0	52.1	24.4	32.9	215.1
	207	120.9	21.3	42.8	54.6	27.5	57.7	324.8
	301	9.3	14.0	48.2	41.5	29.3	28.8	171.2
	403	13.5	27.6	73.8	30.2	15.7	26.4	187.2
South Site								
CT	102	22.6	26.4	65.9	16.7	10.7	31.9	174.1
	205	18.4	14.4	32.4	15.7	3.6	16.1	100.6
	304	34.7	18.7	27.1	24.8	14.0	57.2	176.4
	407	36.8	14.8	27.3	12.7	11.0	23.1	125.6
RT	108	4.4	6.2	27.5	9.4	4.4	8.7	60.6
	206	58.2	28.6	58.0	26.8	8.8	77.3	257.5
	303	23.4	23.9	46.1	24.9	14.5	16.3	149.1
	401	25.5	18.2	50.5	26.9	9.9	32.7	163.8
NT	105	21.2	16.0	35.6	25.1	11.7	18.4	128.0
	207	28.6	14.2	37.1	3.6	9.8	19.3	112.7
	301	17.1	15.1	36.8	36.5	8.1	8.2	122.0
	403	37.1	14.1	24.2	22.3	8.7	17.3	123.8

REFERENCES

1. Brandon, J.F. and Mathews, O.R., Dry Land Rotation and Tillage Experiments at the Akron (Colorado) Field Station, USDA Circular no. 700, Washington, DC, 1944.
2. Smika, D.E., Fallow management practices for wheat production in the Central Great Plains, *Agron. J.*, 82, 319, 1990.
3. Elliott, E.T., Horton, K., Moore, J.C., Coleman, D.C., and Cole, C.V., Mineralization dynamics in fallow dryland wheat plots, Colorado, *Plant Soil*, 76, 149, 1984.
4. Schepers J.S., Francis, D.D., and Thompson, M.T., Simultaneous determination of total C, total N, and ^{15}N on soil and plant material, *Commun. Soil Sci. Plant Anal.*, 20, 949, 1989.