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TWELVE-YEAR TILLAGE AND CROP ROTATION EFFECTS ON YIELDS AND SOIL CHEMICAL PROPERTIES IN NORTHEAST IOWA[1]

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ABSTRACT: Long-term tillage and crop management studies may be useful for determining crop production practices that are conducive to securing a sustainable agriculture. Objectives of this field study were to evaluate the combined effects of crop rotation and tillage practices on yield and changes in soil chemical properties after 12 years of research on the Clyde-Kenyon-Floyd soil association in northeastern Iowa. Continuous corn (*Zea mays* L.) and a corn-soybean [*Glycine max* L. (Herr.)] rotation were grown using moldboard plowing, chisel plowing, ridge-tillage, or no-tillage methods. Tillage and crop rotation effects on soil pH, Bray P1, 1M NH_4OAc exchangeable K, Ca, and Mg, total C, and total N in the top 200 mm were evaluated. Profile NO_3-N concentrations were also measured in spring and autumn of 1988. Crop yields and N use efficiencies were used to assess sustainability. Bray P1 levels increased, but exchangeable K decreased for all cropping and tillage methods. Nutrient stratification was evident for no-tillage and ridge-tillage methods, while the moldboard plowing treatment had the most uniform soil test levels within the 200 mm management zone. Chisel plowing incorporated fertilizer to a depth of 100 mm. Soil pH was lower with continuous corn than with crop rotation because of greater and more frequent N applications. Profile NO_3-N concentrations were significantly different for sampling depth and among tillage methods in spring 1988. In autumn the concentrations were significantly different for sampling depth and for a rotation by tillage interaction. Estimated N use efficiencies were 40 and 50 kg grain per kg N for continuous corn, and 48 and 69 kg grain per kg N for rotated corn in 1988 and 1989, respectively. The results suggest that P fertilizer rates can be reduced, but K rates should probably be increased to maintain soil-test levels for this soil association. Crop rotation and reduced tillage methods such as ridge-tillage or chisel plowing appear to meet the criteria for sustainable agriculture on these soils.

INTRODUCTION

The Iowa Groundwater Protection Act of 1987 created the Aldo Leopold Center for Sustainable Agriculture and defined sustainable agriculture as "the appropriate use of crop and livestock systems and agricultural inputs supporting those activities which maintain economic and social viability while preserving the high productivity and quality of Iowa's land". This legislation has created opportunities and challenges for agricultural scientists to quantify sustainability.

One way to approach this task is to evaluate the longterm effects of various tillage and crop rotations on crop yields and soil chemical properties. This may help to provide answers to questions such as: (i) what long-term effects do crop rotations and various tillage methods have on soil NO_3-N concentrations, (ii) do these practices increase the potential for contaminating groundwater resources with N or pesticides, and (iii) how profitable are the alternate practices. These questions are justified because recent studies (12,13,17,20) have shown that current agricultural practices can significantly affect groundwater quality.

Use of conservation tillage (19) can reduce soil erosion (21), energy costs (22), and soil water loss (16). However, the methods used must be adapted from location to location to overcome restraints imposed by factors such as low soil temperature, runoff and erosion control, or soil compaction (19). Use of crop rotations must also be considered, especially on soils that are poorly drained (7,8,11).

The Clyde-Kenyon-Floyd soil association is formed in loamy sediments and in the underlying glacial till on nearly level to moderately sloping topography in the northern Corn Belt. The soils are moderately well- to poorly-drained, formed on moderately broad ridge crests with long slopes, and in broad natural drainageways. The drainageways form an integrated, dendritic pattern and frequently have low (<3%) gradients. Surface layers are typically 200 to 225 mm thick, black loam or silty clay loam. Corn and soybean are the primary crops because plant available water capacity is high (>0.2 mm/mm). Controlling water erosion, improving drainage, maintaining good tilth, and providing adequate soil fertility are the primary management concerns for these soils. By combining drainage tile, conservation tillage, and terraces, erosion can often be controlled and excessive wetness prevented.

Many conservation tillage studies are currently focused on quantifying attributes of sustainability and environmental acceptability (10) of various practices. This is consistent with conclusions reached by Dick and Daniel (9) who stated that, to fully comprehend the impacts of tillage on our environment, long-term chemical and biological changes that occur with those systems must be quantified. Quantifying the long-term tillage and crop rotation effects was also identified as important for understanding soil tilth (18), and the processes through which it can be changed.

Soil-test parameters that have been used to assess longt-erm effects of alternate tillage and crop rotations include total soil C and N concentrations (14), the C:N ratio (4), pH, and nutrient stratification. Measurements in Kentucky (5,6) showed that after 10 years, surface soil acidification as well as P and K stratification were potential problems associated with no-tillage methods. Conservation tillage studies in Iowa (10) showed that stratification was greatest during the first two years, but stratification did not appear to adversely affect corn or soybean yields. Detection of changes in soil chemical properties in the northern Corn Belt is possible, but annual changes in some parameters are often small and imperceptible under subhumid and semiarid dryland conditions (4).

The objective of this study was to evaluate soil chemical properties, associated with corn-soybean and continuous corn rotations grown in northeast Iowa using moldboard plowing, chisel plowing, ridge-tillage, or no-tillage methods, as attributes for evaluating potential sustainability of various agricultural production practices.

METHODS AND MATERIALS

A 15 ha conservation tillage experiment with 36, 0.4 ha plots was established near Nashua, IA in 1977. Soils at the site are Floyd (fine loamy, mixed, mesic Aquic Hapludolls) loam, Kenyon (fine-loamy, mixed, mesic Typic Hapludolls) loam, and Readlyn (fine-loamy, mixed, mesic Aquic Hapludolls) loam.

Crop rotation treatments included both the corn and soybean phase of a corn-soybean rotation and continuous corn. Tillage treatments included moldboard plow, chisel plow, ridge-tillage, and no-tillage methods. Crop rotation whole plots and tillage subplots were replicated three times in a split-plot experimental design.

Samples collected from each plot in autumn of 1977 were analyzed for pH, organic matter, Bray P1, and exchangeable K by the Iowa State University Soil Testing Laboratory. Data collection began in 1978, but since it became evident that variability in soil drainage would confound the long-term treatment effects, subsurface drain lines were installed in the center of and between each 0.4 ha plot in 1979.

To minimize soil disturbance, a trenchless drain plow was used to install the center drain tile, but lines between plots were installed using a trencher. This procedure resulted in tile-spacings of 29.3 m. All plots were tiled, regardless of their topographical position or apparent need for drainage.

Information on fertilizer, insecticide, and herbicide rates applied at the site is summarized in Table 1. Lime was applied to all treatments in 1981 and 1989 at rates of 7.8 and 6.7 Mg/ha, respectively. Corn hybrids include Pioneer (2) 3780 between 1977 and 1983, Ames Best SX37 in 1984, Pioneer 3747 in 1985 and 1986, Pioneer 3782 in 1987, and Golden Harvest H2343 in 1988 and 1989. Soybean varieties include Corsoy in 1977 and 1978, Harcor in 1979 and 1980, Vickery in 1981, Corsoy 79 in 1982 through 1986, Elgin in 1987, and Hardin in 1988 and 1989.

Profile NO_3-N concentrations were measured in 1988 by collecting soil cores 64 mm in diameter with a tractor-mounted Giddings sampler before planting and after harvest. Samples were collected to a depth of 2.4 m in spring and 1.8 m in autumn from: 0 to 0.15-, 0.15 to 0.3-, 0.3 to 0.6-, 0.6 to 0.9-, 0.9 to 1.2-, 1.2 to 1.5-, 1.5 to 1.8-, 1.8 to 2.1-, and 2.1 to 2.4-m, respectively. Samples were air-dried, crushed and sieved through a 2-mm screen, extracted with 2N KCl, and analyzed with a LACHAT flow-injection ion analyzer. Another set of soil samples was collected for the 0 to 5-, 5 to 10-, 10 to 15- and 15 to 20-cm depth increments during October 1988 to measure pH, Bray P1, 1M NH_4OAc exchangeable K, Ca, and Mg, and total C and N concentrations.

Crop yields were measured by harvesting the entire 0.4 ha plot with a combine. Total N accumulation was measured at physiological maturity by

Table 1. Cultural practices used in evaluation of sustainability attributes of alternate cropping and tillage methods.

Crop sequence	Year(s)	N-P-K kg ha^{-1}	Insecticide (kg *ai* ha^{-1})	----- Herbicide ----- (kg *ai* ha^{-1})
Continuous corn	1977-1982	202-26-50[†]	Terbufos[‡] (1.2)	Alachlor[‡] - Atrazine[‡] (2.2) - (2.8)
Continuous corn	1983-1989	202-17-66[†]	Terbufos (1.2)	Alachlor - Atrazine (2.2) - (2.8)
Rotation corn	1977-1982	168-58-110[†]	--	Alachlor - Cyanazine[‡] (2.2) - (2.8)
Rotation corn	1983-1989	168-38-147[†]	--	Alachlor - Cyanazine (2.2) - (2.8)
Rotation soybean	1977-1989	0-0-0	--	Alachlor - Metribuzin[‡] (2.2) - (0.45)

[†] Starter fertilizer providing an additional 4-6-12 kg ha^{-1} N-P-K was applied in a band to corn at planting.

[‡] Alachlor = 2-chloro-2'-6'-diethyl-N-(methoxymethyl)-acetanilide
Atrazine = 2-chloro-4-ethylamino-6-isopropylamino-1,3,5 triazine
Cyanazine = 2-{[4-chloro-6-(ethylamino)-s-triazin-2-yl]amino}-2-methylpropionitrile
Metribuzin = 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-trizain-5(4H)-one
Terbufos = S-{[(1.1-Dimethylethyl)thio]methyl}0,0-diethyl phosphorodithioate

collecting six representative plants, drying them at 65°C, grinding to pass a 0.5-mm screen, ball milling for 5 minutes, and analyzing the samples for total N with the Carlo-Erba dry combustion analyzer. Yield and total N accumulation were used to calculate N use efficiencies.

Data were analyzed using the SAS general linear model (GIM) procedure (23). Single degree of freedom contrasts were made to compare (i) moldboard plowing with three forms of conservation tillage, (ii) profile mixing effects of moldboard and chisel plowing, and (iii) cultivation intensity associated with ridging and the "cultivated" no-tillage treatment. The single degree of freedom contrasts were also used to evaluate effects of crop rotation and crop sequence (corn-soybean vs soybean-corn) on the resultant soil chemical properties.

RESULTS AND DISCUSSION

Profile Nitrate: The 1988 spring soil samples showed a highly significant response to tillage system and depth of sampling, while the autumn samples showed significant differences for depth of sampling and for the rotation by tillage interaction (Table 2). Average profile NO_3-N concentrations in the spring were 3.6, 1.7, 1.7 and 2.0 mg/kg [LSD(0.05) = 1.0] for moldboard, chisel, ridge-tillage, and no-tillage treatments, and 1.1, 1.2, 1.1, and 1.1 mg/kg [LSD(0.05) = 0.2], in autumn, respectively. Use of single degree of freedom contrasts showed that differences between the moldboard treatment and the conservation tillage treatments were significant at the 0.0001 level of probability for the spring sampling. Main effects of crop rotation did not significantly affect profile NO_3-N concentrations at either sampling time.

The crop rotation by tillage interaction was significant in the autumn sampling because residual NO_3-N concentrations were highest in corn plots and lowest in soybean plots that were chisel plowed. The crop rotation by sampling depth interaction was significant in the spring sampling because plots planted to corn in 1987 had higher NO_3-N concentrations in the surface (0.0-0.15 m) samples than plots planted to soybean in 1987 (Table 3). This probably occurred because the 12-year N fertilization rates for the rotated plots had been lower (Table 1), but it also supports observations that soybean are good scavengers (16) for inorganic N.

Table 2. Significance of variance sources for soil chemical properties and crop yields measured to evaluate 12-year effects of crop rotation and tillage systems in Iowa.

Variance	1977				1988									
source	pH	P	C	K	pH	P	K	Ca	Mg	C	N	C:N	S-NO_3	F-NO_3
Rotation (A)	NS[†]	NS	NS	NS	*	*	***	NS	*	NS	NS	*	NS[‡]	NS
Replicate (R)	***	***	***	***	*	NS	NS	NS	NS	***	***	NS	*	NS
A*R (Error A)	**	***	***	NS	***	***	NS	***	***	***	***	NS	*	NS
Tillage (T)	*	NS	NS	NS	***	***	NS	***	***	***	***	NS	***	NS
Depth (D)	NS	***	***	***	***	***	***	***	***	***	***	NS	***	***
A*T	**	NS	NS	NS	***	NS	NS	***	*	***	***	NS	NS	**
A*D	NS	NS	NS	NS	***	***	***	***	***	***	**	NS	**	NS
T*D	NS	NS	NS	*	NS	***	***	NS	NS	NS	NS	NS	NS	NS
A*T*D	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS	NS

	Corn yield	Soybean yield	Aerial N accumulation	
			1988	1989
Rotation (A)	***	--	NS	*
Replicate (R)	NS	NS	NS	NS
A*R (Error A)	*	--	NS	NS
Tillage (T)	***	***	NS	**
Year (Y)	***	***	--	--
A*T	***	--	NS	NS
A*Y	***	--	--	--
T*Y	***	***	--	--
A*T*Y	***	--	--	--

[†] *,**,*** Significant at the 0.10, 0.05, and 0.01 probability levels, respectively. NS, non-significant.

[‡] S-NO_3 indicates spring sampling, while F-NO_3 indicates the autumn sampling.

Table 3. Soil profile NO_3-N concentrations in 1988 after 12-years of alternate crop rotation treatments.

Crop rotation rotation	Sampling depth	Spring NO_3-N	Autumn NO_3-N
	---- m ----	----- mg kg^{-1}	------
Continuous corn	0.0 - 0.15	9.7	2.1
Continuous corn	0.15 - 0.3	6.5	1.9
Continuous corn	0.3 - 0.6	2.0	1.1
Continuous corn	0.6 - 0.9	0.6	0.6
Continuous corn	0.9 - 1.2	0.7	0.6
Continuous corn	1.2 - 1.5	1.1	0.6
Continuous corn	1.5 - 1.8	1.8	0.6
Continuous corn	1.8 - 2.1	2.6	---
Continuous corn	2.1 - 2.4	1.3	---
Corn-soybean	0.0 - 0.15	2.2	2.1
Corn-soybean	0.15 - 0.3	5.4	2.3
Corn-soybean	0.3 - 0.6	1.8	1.0
Corn-soybean	0.6 - 0.9	0.9	0.6
Corn-soybean	0.9 - 1.2	0.2	0.5
Corn-soybean	1.2 - 1.5	0.3	0.6
Corn-soybean	1.5 - 1.8	1.3	0.6
Corn-soybean	1.8 - 2.1	0.9	---
Corn-soybean	2.1 - 2.4	1.2	---
Soybean-corn	0.0 - 0.15	7.2	2.4
Soybean-corn	0.15 - 0.3	3.8	2.3
Soybean-corn	0.3 - 0.6	2.0	1.1
Soybean-corn	0.6 - 0.9	1.9	0.7
Soybean-corn	0.9 - 1.2	0.5	0.6
Soybean-corn	1.2 - 1.5	0.6	0.6
Soybean-corn	1.5 - 1.8	1.0	0.6
Soybean-corn	1.8 - 2.1	0.9	---
Soybean-corn	2.1 - 2.4	0.3	---
LSD(.05)		2.8	NS
CV(%)		200	74

These results for inorganic N are similar to findings in Kansas (14) that show decreased soil organic N with increasing frequency of soybean in the rotation.

Profile NO3-N concentrations averaged for the four tillage methods are presented in Table 4. All measurements were quite low with the lowest concentrations being measured at or below the tile lines (~1.2 m).

Table 4. Profile NO_3-N concentrations in the spring and autumn of 1988 averaged across all tillage methods.

Depth -m-	Spring	Autumn
	---------- mg kg^{-1}	----------
0.0 - 0.15	6.5	2.2
0.15 - 0.3	5.2	2.2
0.3 - 0.6	1.9	1.1
0.6 - 0.9	1.1	0.6
0.9 - 1.2	0.5	0.6
1.2 - 1.5	0.7	0.6
1.5 - 1.8	1.4	0.6
1.8 - 2.1	1.5	-
2.1 - 2.4	0.9	-
LSD (0.05)	1.6	0.3
CV (%)	200	74

Surface Soil-Test Parameters: Surface soil-test data for samples collected in autumn 1977 when this study was initiated are presented in Table 5. There were small, statistically significant differences among the three replicates and for the four depth increments (Table 2), but in general, the experimental site was very uniform. There were no significant differences among areas where the rotation treatments were subsequently established, and single degree of freedom contrasts showed no significant differences between moldboard plow areas and those that were to become conservation tillage treatments. The initial soil-test values were representative of cultivated soils in northeast Iowa. Bray P1 and 1M NH_4OAc exchangeable K values averaged 35 and 200 mg/kg, respectively, in the tillage management zone (upper 200 mm). These are equivalent to "very high" soil-test ratings for both elements (24).

Measurements in 1988 after 11 years (Table 6) showed significant replicate effects for pH, total C, and total N, but P and K variation among replicates was not significant (Table 2). Crop rotation effects were significant at the 1% level for K and at the 10% level for pH, P, Mg, and the C:N ratio.

Lower soil pH in continuous corn plots was anticipated because more fertilizer N had been applied and N applications were made annually (Table 1). A single

Table 5. Autumn 1977 soil-test parameters for Clyde, Kenyon, and Floyd soils near Nashua, Iowa.

Sample depth	pH	Bray P_1	Total C	NH_4OAc Exchangeable K
-- mm --		mg kg^{-1}	g kg^{-1}	--- mg kg^{-1} ---
0- 50	6.2	44	14.0	327
50-100	6.1	38	16.6	185
100-150	6.1	35	15.7	161
150-200	6.2	22	14.8	127
LSD(.05)	NS	4	1.1	14
CV(%)	5	22	14	15

degree of freedom contrast between continuous corn and the rotation plots showed the difference to be significant at $P \leq 0.04$. A single degree of freedom contrast showed that NH4OAc exchangeable K levels in continuous corn plots were significantly higher ($P \leq 0.007$) than for the rotation plots (180 vs 145 mg/kg). Overall, soil-test ratings for both rotations remained at "very high" and "high" levels, respectively. When compared to 1977 soil-test values the K concentrations in the tillage management zone (200 mm) declined from 200 mg/kg in autumn 1977 to 156 mg/kg in autumn 1988. Although K fertilizer rates were increased in 1983 (Table 1), K fertilizer applications did not maintain the initial levels of exchangeable potassium.

Crop rotation did not affect total C and N concentrations, but C:N ratios were significantly different (Table 2). Actual differences were small, averaging 13.4 following soybean and 13.1 following either continuous or rotated corn. Therefore, single degree of freedom contrasts showed no significant differences for C, N, or the C:N ratio at $P \leq 0.15$.

Tillage methods resulted in significant differences for pH, Bray P1, NH4OAc exchangeable Ca and Mg, and total C and N (Table 7). Single degree of freedom contrasts confirmed that soil pH was significantly higher ($P \leq 0.0001$) for moldboard plow than lower for the conservation tillage treatments, and that moldboard plow and chisel-plow treatments were also significantly different ($P \leq$

Table 6. Soil-test characteristics in autumn 1988 after 11 years of alternate tillage methods.

Sample depth	pH	Bray P_1	Total C	Total N	C:N ratio	NH_4OAc Exchangeable K	NH_4OAc Exchangeable Ca	NH_4OAc Exchangeable Mg
-- mm --		mg kg^{-1}	g kg^{-1}	g kg^{-1}		mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
				Moldboard plow				
0- 50	6.6	57	20.4	1.55	13.2	210	2278	372
50-100	6.5	46	19.9	1.50	13.3	123	2281	354
100-150	6.4	38	20.3	1.56	13.1	134	2271	360
150-200	6.3	36	19.7	1.51	13.1	144	2299	366
				Chisel plow				
0- 50	6.8	101	21.3	1.58	13.7	274	2315	392
50-100	6.5	84	20.4	1.53	13.4	157	2211	365
100-150	6.1	30	19.6	1.48	13.4	107	2156	330
150-200	5.7	13	18.6	1.43	13.1	80	2131	322
				Ridge-tillage				
0- 50	6.7	120	20.8	1.57	13.2	288	2116	372
50-100	6.1	47	19.0	1.44	13.2	138	2040	329
100-150	5.9	25	17.6	1.37	12.8	88	1977	305
150-200	5.9	13	17.6	1.38	12.8	95	2041	317
				No-tillage				
0- 50	7.0	141	21.4	1.62	13.3	329	2254	381
50-100	6.1	55	18.3	1.36	13.6	133	1815	300
100-150	5.7	18	17.7	1.39	12.8	123	1863	271
150-200	5.8	15	17.3	1.32	13.4	80	1992	295
LSD(.05)	0.2	12	1.1	0.11	NS	40	152	25
CV(%)	6	36	47	50	8	40	11	11

Table 7. Average soil-test values measured in 1988 for the top 200 mm after using moldboard, chisel, ridge-tillage, or no-tillage methods for eleven years.

Tillage method	1:1 pH	Bray P_1	------Total----- C	N	C:N ratio	------ NH_4OAc Exchangeable ------ K	Ca	Mg
		mg kg^{-1}	---- g kg^{-1} ----			------------ mg kg^{-1} --------		
Moldboard plow	6.4	44	20.0	1.53	13.2	153	2282	363
Chisel plow	6.3	57	20.0	1.50	13.4	154	2203	352
Ridge tillage	6.2	51	18.7	1.44	13.0	152	2044	331
No-tillage	6.1	57	18.6	1.42	13.2	166	1981	312
LSD(0.05)	0.1	6	0.6	0.05	NS	NS	76	12
CV(%)	5	35	9	11	8	40	11	11

0.01). Ridge-tillage and no-tillage treatments were not significantly different. This presumably reflects the stratification of lime that occurred for the chisel plow, ridge-tillage, and no-tillage treatments (Table 6).

Bray P1 soil-test concentrations with moldboard plowing were more uniform throughout the 200 mm tillage management zone than for the other treatments because of stratification associated with conservation tillage practices (Table 6). A series of single degree of freedom contrasts showed that the average concentration for the moldboard plow treatment was significantly lower ($P \leq 0.0001$) than for the conservation tillage treatments (Table 7). They also showed that the chisel plow and moldboard treatments were significantly different ($P \leq 0.0001$), and that ridge-tillage and no-tillage concentrations were slightly different ($P \leq 0.048$). Bray P1 soil-test ratings (24) for all tillage treatments after 11 years were "very high" indicating that the only P fertilizer that is needed would be a small amount of "starter" for corn (24).

Single degree of freedom contrasts showed that 1M NH_4OAc exchangeable Ca and Mg concentrations were significantly higher ($P \leq 0.0001$) for the moldboard plow treatment than for the conservation tillage treatments (Table 7). Stratification of lime and the lower pH values below 100 mm for chisel plow, ridge-tillage, and no-tillage treatments (Table 6) presumably also caused these differences.

Total C and N concentrations for the ridge-tillage and notillage treatments were significantly lower than for moldboard or chisel-plowing treatments (Table 6). The single degree of freedom contrasts also showed that C and N concentrations for the moldboard treatment were significantly higher ($P \leq 0.0001$ and $P \leq 0.0014$, respectively) than for the conservation tillage treatments. This presumably reflected lower continuous corn yields (Table 8) with ridge-tillage and no-tillage methods. Lower grain yields would have resulted in less crop residue being incorporated into the soil each year, thus contributing to a gradual decline in total C and N. Decreased mixing and more rapid decomposition of crop residue left on the soil surface than of residue that is incorporated deep (150-200 mm) in the soil are also factors contributing to the differences in total C and N among the tillage treatments.

The significant depth effect for all soil-test parameters except the C:N ratio (Table 2) was caused by differences in the amount of mixing in the top 200 mm associated with each tillage method (Table 6). For example, even with chisel

Table 8. Crop rotation and tillage effects on corn grain yield from 1978 to 1989.

Crop rotation	Year	Plow	Chisel	Ridge	No-till
		Mg ha^{-1}			
Continuous corn	1978	9.2	7.9	7.4	7.4
Continuous corn	1979	10.0	9.6	9.2	9.0
Continuous corn	1980	9.6	9.4	9.3	9.5
Continuous corn	1981	10.2	9.9	9.9	9.6
Continuous corn	1982	7.6	7.6	7.4	7.2
Continuous corn	1983	5.9	5.0	5.1	5.0
Continuous corn	1984	6.1	5.6	5.2	5.0
Continuous corn	1985	7.8	7.4	7.5	7.6
Continuous corn	1986	10.3	10.6	9.9	9.8
Continuous corn	1987	8.4	8.2	8.0	7.9
Continuous corn	1988	5.4	5.4	4.6	4.6
Continuous corn	1989	6.1	7.2	6.7	6.3
Corn-Soybean	1978	9.3	9.4	9.0	9.7
Corn-Soybean	1979	-	-	-	-
Corn-Soybean	1980	9.5	9.9	9.7	9.6
Corn-Soybean	1981	-	-	-	-
Corn-Soybean	1982	7.7	7.6	7.9	7.7
Corn-Soybean	1983	-	-	-	-
Corn-Soybean	1984	7.7	8.1	7.2	6.5
Corn-Soybean	1985	-	-	-	-
Corn-Soybean	1986	10.8	10.8	10.6	10.8
Corn-Soybean	1987	-	-	-	-
Corn-Soybean	1988	6.2	7.0	5.8	6.2
Corn-Soybean	1989	-	-	-	-
Soybean-Corn	1978	-	-	-	-
Soybean-Corn	1979	10.3	10.2	9.9	10.2
Soybean-Corn	1980	-	-	-	-
Soybean-Corn	1981	10.7	10.5	10.1	10.0
Soybean-Corn	1982	-	-	-	-
Soybean-Corn	1983	7.0	7.0	6.5	6.7
Soybean-Corn	1984	-	-	-	-
Soybean-Corn	1985	9.2	8.7	8.8	8.6
Soybean-Corn	1986	-	-	-	-
Soybean-Corn	1987	9.3	8.9	8.8	9.1
Soybean-Corn	1988	-	-	-	-
Soybean-Corn	1989	7.4	7.6	8.4	8.4
LSD(0.05)			0.6		
CV(%)			4		

plowing, the apparent mixing zone did not extend much below 100 mm. For ridge-tillage and no-tillage treatments, the pH, P, and K concentrations in the 100- to 200-mm zone were lower than for moldboard and chisel-plow treatments. Previous research (10) suggests that stratification occurs quickly with conservation tillage on these soils, but fortunately, the impact on yield is generally small. Tillage and cropping methods may have to be rotated to minimize compaction and stratification, but since the latter can occur within one year (10) other methods need to be examined to prevent them from becoming a problem. One new technology that may reduce stratification and improve positional availability of plant nutrients is the point-injector applicator (3). This tool places fertilizer in a more favorable position for plant uptake and may increase nutrient use efficiency and decrease the residual amounts available for leaching or other losses.

Corn and soybean emergence, anthesis, and maturity dates were recorded each year (data not presented), and generally showed that both the ridge-tillage and no-tillage treatments required one or two more days than the moldboard or chisel-plow treatments to reach each growth stage. Cooler soil temperature at planting, reduced aeration, and positional unavailability of P and K are factors that may have caused these differences in plant growth and development.

Sustainability Assessment: Crop yield is the most common parameter used to evaluate sustainability attributes of any production practice at the farm level. Currently, rotating corn and soybean crops is considered to have more sustainable attributes than continuous cropping. Average corn grain yields (Table 8) confirm this hypothesis for this northeastern Iowa location.

Soil Conservation Service (SCS) soil productivity ratings for Clyde, Kenyon, and Floyd soils estimate grain yields of 9.1 and 3.0 Mg/ha for corn and soybean. The 12-year average yield for rotated corn was 8.7 Mg/ha compared to 7.7 Mg/ha [LSD(0.05) = 0.3] for continuous corn. The 12-year average yield for soybean (Table 9), grown in rotation with corn, was 2.6 Mg/ha.

Sustainability attributes can also be evaluated by estimating nutrient use efficiencies. Total aerial N accumulation for continuous and rotated corn averaged across all tillage treatments was 128 and 123 kg/ha in 1988 and 1989, respectively. There were no significant effects due to crop rotation or tillage in 1988, presumably because yields were limited by severe drought. Crop rotation and tillage effects were both significant in rotational plots in 1989. Total N

Table 9. Crop rotation and tillage system effects on soybean yield from 1978 to 1989.

Crop rotation	Year	Plow	Chisel	Ridge	No-till
		Mg ha^{-1}			
Corn-Soybean	1978	-	-	-	-
Corn-Soybean	1979	2.4	2.3	2.4	2.5
Corn-Soybean	1980	-	-	-	-
Corn-Soybean	1981	1.6	1.7	1.6	1.8
Corn-Soybean	1982	-	-	-	-
Corn-Soybean	1983	3.0	3.1	2.6	3.0
Corn-Soybean	1984	-	-	-	-
Corn-Soybean	1985	2.3	2.4	2.2	2.3
Corn-Soybean	1986	-	-	-	-
Corn-Soybean	1987	2.9	2.8	2.8	2.8
Corn-Soybean	1988	-	-	-	-
Corn-Soybean	1989	2.6	2.9	2.9	2.8
Soybean-Corn	1978	3.2	2.9	2.9	2.9
Soybean-Corn	1979	-	-	-	-
Soybean-Corn	1980	2.9	2.8	2.4	2.6
Soybean-Corn	1981	-	-	-	-
Soybean-Corn	1982	2.8	2.8	2.7	2.6
Soybean-Corn	1983	-	-	-	-
Soybean-Corn	1984	2.6	2.5	2.5	2.5
Soybean-Corn	1985	-	-	-	-
Soybean-Corn	1986	3.4	3.3	3.2	3.3
Soybean-Corn	1987	-	-	-	-
Soybean-Corn	1988	2.1	2.0	2.0	2.0
Soybean-Corn	1989	-	-	-	-
LSD(0.05)			0.2		
CV(%)			4		

accumulation averaged 131 and 115 kg/ha [LSD(0.1) = 14] for continuous corn and rotated corn, and 139, 118, 108, and 128 kg/ha [LSD(0.05) = 19] for moldboard plow, chisel plow, ridge-tillage, and no-tillage, respectively. Lower fertilizer application rates (Table 1) probably contributed to lower N accumulation for the rotated corn than for continuous corn. The reduced N rates were justified on an assumed N credit established using results from long-term crop rotation by N-rate studies in Iowa (personal communication, J. R. Webb, 1990). Results of this 12-year study agree with those from Kansas (14) showing that soybean yielding approximately 2 Mg/ha potentially decreases soil N by as much as 25 kg/ha/yr. This also agrees with previous studies (16) showing that soybean grown in the Midwest are good scavengers for inorganic nitrogen. Although long-term studies suggest that N credits for corn following soybean should be increased (personal communication, R. J. Killorn, 1990), results from this study do not support that conclusion.

Apparent fertilizer use efficiencies show a positive response to crop rotation. Continuous corn yields averaged 5.0 and 6.6 Mg/ha compared to 6.3 and 8.0 Mg/ha for rotated corn in 1988 and 1989, respectively (Table 8). Fertilizer use efficiencies were 40 and 50 kg grain per kg N for continuous corn and 48 and 69 kg grain per kg N for rotated corn in 1988 and 1989, respectively.

Soil-test changes over time can be used to measure attributes of sustainability. These results suggest that P fertilizer rates can be reduced from the present levels of application since soil-test levels were initially "very high" and have continued to increase. Fertilizer additions of K were not adequate to maintain soil-test levels on these soils.

CONCLUSIONS

Crop yield and nitrogen use efficiencies both suggest that a corn-soybean rotation has more *sustainable attributes* than a continuous corn rotation for the Clyde-Kenyon-Floyd soil association in northeastern Iowa. Chisel plow, ridge-tillage, and no-tillage methods resulted in more stratification in soil chemical properties than moldboard plowing, but this did not appear to reduce crop yield. Analyses after 12-years of tillage and cropping treatments suggest that fertilizer rates can be adjusted from present recommended rates because soil-test P levels are increasing, K concentrations are decreasing, and credit for available N accruing from soybean may be high.

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