AN OVERVIEW OF THE THOMPSON/BAKER FARMING SYSTEMS STUDY

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ABSTRACT

There is a general lack of quantitative information, collected from field-scale studies, that can be used to assess long-term effects of alternative farming systems. The objective of an on-going study in central Iowa is to quantitatively evaluate several chemical, physical, biological, and economic parameters on the Richard Thompson (alternative) and Eugene Baker (conventional) farms. This project was initiated in 1989 on adjacent 32-ha tracts of land, that have Clarion loam, Nicollet loam, Canisteo silty clay loam, and Webster silty clay loam as the predominant soil map units. Profile N and physical characteristics, after more than 20-yr of alternate farming practices, were measured by collecting 64 cores, averaging 4.5 m in depth, from the south 16-ha of each tract in April, 1989, and 32 cores, averaging 3.0 m in depth, from the north 16 ha of each tract in autumn 1990. Water infiltration was measured in September of 1989 and 1991. Earthworm populations and species were determined in autumn of 1989 and 1990. Soil aggregation was evaluated in 1990 and 1991. Spatial variability in grain yield has been measured each year since the study was initiated. Rainfall, temperature, nutrient concentrations, and management input costs are being collected so that long-term nutrient and economic budgets can be computed. Farming practice significantly affected total-N, NH_4-N, and NO_3-N concentrations measured at the various sampling depths, but differences were small and inconsistent. Steady-state measurements suggested that water infiltration rates were somewhat higher for the alternative farming system. The largest number of earthworms were found on the Thompson farm, with the predominant species being <u>A. tuberculata</u>. The alternative farming practices resulted in greater water stability of soil aggregates, higher organic carbon content, and lower bulk density than conventional practices. Including oat and hay crops in the rotation and adding 45 Mg ha^{-1} of animal manure plus municipal sludge during the first 3-yr of each 5-yr rotation presumably provided increased C input that created many of the differences on the Thompson farm. Yield measurements have shown that soil map units alone do not account for the variability. Spatial variability in soil-test properties is being determined so that residual soil fertility and topography can be used to refine crop yield projections for individual soil map units.

OBJECTIVES

This project was initiated in 1989, shortly after the National Research Council's <u>Alternative Agriculture</u> publication (NRC, 1989) aroused public interest in alternative agriculture. The overall objective was to provide quantitative data needed to compare environmental effects of alternate farming practices; a need identified by several scientists who reviewed the initial report (CAST, 1990). Specific components of this farming-systems investigation have included an assessment of:

- Nitrogen distribution profiles on selected soil map units;
- Soil water gradients as affected by soil map unit and farming system;
- Earthworm populations and species;
- Soil aggregation characteristics;
- Crop yield gradients, as a function of soil map unit;
- Microclimatic and energy balance effects;
- Water infiltration characteristics;
- Soil organic matter levels;
- Tillage-energy requirements;
- Soil profile structure, mineralogy, and porosity; and
- Farming system economics.

METHODS AND MATERIALS

This study is being conducted on two adjacent 32-ha tracts within the Clarion-Nicollet-Webster soil association in Boone County, Iowa. The east one-half of the study area (Fig. 1) is part of the Richard and Sharon Thompson farm that was used as Case Study No. 5 in Alternative Agriculture (NRC, 1989). The field is divided into two 16-ha areas for crop rotation purposes and represents an alternative farming system. The management practices include a 5-yr crop rotation (corn, soybean, corn, oats, and hay, the latter consisting of a mixture of alfalfa, red clover, alsike clover, timothy, and orchard grass) and weed control without herbicides. A manure and municipal sludge mixture is applied in spring at a rate of 44.8 Mg dry matter ha^{-1} yr^{-1} during the first 3 yr of each 5-yr rotation. Estimated nutrient content of this material is approximately 6.6-1.8-4.1 kg N-P-K Mg ha^{-1} (Rodale Institute, 1990) which provides 295-82-186 kg N-P-K ha^{-1}. Weeds are controlled without herbicides by rotary hoeing approximately 7 and 15 days after planting and cultivating twice to rebuild ridges for subsequent crops.

The west one-half is owned and was farmed by Eugene and Dorothy Baker from 1932 to 1980. It has been farmed as part of a 700 ha custom farm operation since 1981. This conventional field is divided into two 16-ha areas that have been in a 2-yr corn and soybean rotation since 1957. The current management practices include applying 135 kg N ha^{-1} using anhydrous ammonia, chisel plowing following corn harvest, incorporating 35-38-93 kg ha^{-1} N-P-K with a field cultivator, and controlling weeds with herbicides. Long-term soil and crop management practices for both farming systems are summarized in Table 1.

Soil profile samples were collected from the south 16 ha (Fig. 1) of each farm in April, 1989. A 5 cm soil core was taken every 48.8 m using a Giddings[1] hydraulic sampler. In each field, 64 cores were taken to depth sufficient to penetrate the unoxidized glacial till. This depth ranged from 3 to 5 m and averaged 4.4 m for both fields. In September and October

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[1]Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may also be suitable.

1990, another 32 cores in a 48.8- by 97-m grid were collected to an average depth of 3 m from the 16-ha conventional and alternative fields just north of those sampled in 1989 (Fig. 1).

Samples were dried at 40° C, crushed to pass a 2 mm screen, and extracted with 2 M KCl prior to measuring NH_4-N and NO_3-N concentrations colorimetrically (Keeney and Nelson, 1982) using flow injection analysis technology from the Lachat Corporation. Subsamples to a depth of 1 m from each core and of selected cores to their full depth from the south one-half were pulverized for 5 min in a SPEX ball mill. Total N and total C concentrations were measured using dry combustion methods in a Carlo-Erba NA1500 NCS elemental analyzer. The soil map unit represented by each core was determined by locating each sampling position on the published soil survey map (USDA, 1981). Detailed morphological characterizations were made for each sampling site (Steinwand, 1992), but for this analysis, soil inclusions were not separated from the predominant map unit. For each sampling depth, statistical analyses were performed using individual cores from each soil map unit as samples in a univariate procedure (PROC UNIVARIATE, SAS Institute, 1985).

Earthworms were collected in 20- by 45-cm soil cores with a modified Giddings hydraulic sampler in October, 1989 and September, 1990. In 1990, we extracted 20 samples, approximately 300 m (Fig. 1) from the south boundary for both farming systems. This provided a measure of earthworm activity in Clarion (138B), Nicollet (55), and Canisteo (507) soil map units. In 1989, 30 cores were extracted from the same area on the Thompson (alternative) farm, but sampling in the conventional field produced no earthworms nor sign of earthworm activity. Therefore, since our coring was beginning to interfere with the custom farming operation, we extracted only five samples from the conventional field. We collected and identified the species of all mature earthworms in each sample. Immature worms and cocoons were placed in dark growth chambers at 15° C in a mixture of soil and partially decomposed horse (Equus caballus) manure and allowed to mature before being counted and identified. PROC MEANS (SAS Institute, 1985) was used to determine the mean number of worms m^{-2} for each farming system.

Infiltration at two sampling sites, approximately 300 m from the southern boundary for both fields, was measured in 1989. Soils at these locations were Webster (107) and Clarion (138B). After removing the corn crop at anthesis (11 to 14 July), we used an oscillating rainfall simulator (Kay and Baker, 1989) to provide water at an intensity of 64 ± 14 mm hr^{-1} to duplicate small plots at each sampling site. Runoff was estimated by sampling at fixed time intervals beginning 5 minutes after surface runoff began and continuing at 5 minute intervals until a uniform runoff rate was achieved. Steady-state infiltration was calculated using application intensity minus the uniform runoff rate. In 1991, small single ring and tension infiltrometers (Ankeny et al., 1988), a double ring infiltrometer and another rainfall simulator were used on Webster and Clarion soils in the southwest and northeast 16 ha tracts. Location had to be changed on the Thompson farm because of his 5-yr crop rotation. The simulator used in 1991 was built after the design of Onstad et al., (1981) and provided a uniform rainfall intensity of 60 mm hr^{-1} for a 60-min duration. Runoff was measured with a computer-read tipping bucket in a pit and corroborated with a water-stage recorder on the water collection tank. Infiltration was computed by determining the steady-state slope of the runoff curve for minutes 51 through 60 and subtracting this value from the applied rainfall intensity. Runoff and steady-state infiltration rate were analyzed using PROC UNIVARIATE (SAS Institute, 1985) procedures.

Soil aggregates were sampled from a Clarion soil map unit (138C2, 5-9% slopes, moderately eroded) for each farming system following grain harvest in October 1990. Each 15 cm by 15 cm by 7.5 cm deep sample was excavated using a hand trowel and passed through a screen with 6.35 mm openings. One-half of each sample was air dried at ambient (25° C) temperature, while the other half was maintained in a "field-moist" condition by refrigerating it at 4° C in a sealed plastic container. Water stability of air-dry and field-moist soil aggregates was determined using the method of Kemper and Rosenau (1986).

In Spring, 1991, 12 samples were collected from Clarion loam in the alternative fields and 12 samples were collected from the conventional fields. The samples were collected from 15 cm by 15 cm by 7.5 cm deep areas centered on the row. The sample areas were closely matched based upon the following criteria: presence of 13-18 cm of mollic epipedon, no free carbonates, as determined by examining for effervescence after adding dilute HCL to the soil, subsoil colors indicating good drainage, and a gently sloping ridgetop position. This provided a total of 24 samples for which water stability of the soil aggregates was determined. Data were analyzed using paired t-tests.

Detailed microclimate studies were conducted in 1989 to compare the microclimatic and water use differences between the ridge tillage system used on the Thompson field and the conventional tillage practices used on the Baker field. Measurements were made of net radiation at 1.0 m above the canopy, soil heat flux at 10 cm, soil temperatures at 1.0, 2.0, 5.0, 10.0, 25.0, and 50.0 cm, air temperature, water vapor pressure, and wind speed at 0.25 and 1.25 m above the canopy. These measurements commenced when the corn was 30-cm tall and continued until maturity. Instruments were positioned in the middle of each field to insure that there was adequate fetch from all directions. Each instrument was sampled at one-minute intervals with either a 30-minute average or a total calculated by the data acquisition system.

Tillage energy measurements were made in 1989 in the two south fields (Fig. 1) and in the north fields in 1990. The objectives were to determine if there were significant differences in draft among soil map units in each field and to obtain a general estimate of tillage energies required for the same soils under two different management schemes. These measurements were made with a John Deere Model 3020 tractor in 1989, while in 1990 a White Model 4-160 tractor was used. Both tractors were instrumented with transducers to measure draft, fuel supplied to the injectors, and fuel returned to the tank. A Campbell Scientific 21X datalogger was used to record 5-second averages for each of the transducers. The averages provide a measure of tractor performance for a given area of the field depending on travel speed and implement width. Tillage tools used to provided resistance included a disk in 1989 and a chisel plow in 1990. Replicated data were collected using the same travel direction for several transects across the field. The data were plotted onto a computerized soil survey map and grouped according to soil map unit and slope direction for statistical analyses.

Corn and soybean yields were measured continuously along each of the eight transects using a modified Gleaner K combine (Colvin, 1990). Grain weight and moisture content were measured for approximately 240 plots that were approximately 12-m long. Oat and hay yields for the Thompson farm were measured on 1-m long sections of windrow. To date, positions have been determined by dead reckoning after harvest, however we are beginning to work with a Global Positioning System (GPS) which can provide 1/100th of a second location without dependence on clear lines of vision (Colvin et al., 1991). The GPS consists of a Trimble 10X Navigation Receiver, a Zenith 184 lap top portable computer, and a GeoLink Software package (GeoResearch Co.). Coordinates for each plot were used to identify the soil map unit associated with each sample.

RESULTS AND DISCUSSION

Profile N Concentrations

Total-N concentrations in April, 1989 in Canisteo (507), Nicollet (55) and two Clarion (138B and 138C2) map units within the two fields (Fig. 1) showed significant differences for the 0.0- to 0.1- and 0.1- to 0.2-m depth increments and a similar but nonsignificant trend was measured for the 0.2- to 0.3-m depth (Karlen and Colvin, 1992). Each of these depth increments showed higher total-N concentrations for the alternative field than for the conventional field (Table 2). This was observed even though the conventional field had been fertilized with anhydrous ammonia in November, 1988 and the manure/sludge mixture for the alternative field had not been applied prior to sampling. Presumably, this reflected a higher soil organic matter content in surface horizons of the alternative field. Significant differences in total C measurements between the farming systems for the 0.0- to 0.1-, 0.1- to 0.2-, 0.2- to 0.3-, and 0.3- to 0.45-m increments (8.5, 4.6, 6.2, and 3.9 g kg^{-1}, respectively) support that hypothesis. Below the 0.3-m depth, differences in total-N concentrations for each soil map unit did not show a consistent trend. Concentrations of both NH_4-N and NO_3-N fluctuated, but showed no distinct accumulation zones (Table 2). We concluded that all N values were low and very similar for both farming systems, and that neither the use of a manure/sludge mixture nor anhydrous ammonia to supply N was causing a substantial accumulation of subsurface NO_3-N in these soils.

Earthworm Evaluations

The largest number of earthworms (Table 3) was found where alternative farming practices have been used for more than 20 years (Berry and Karlen, in review). The predominant species in 1989 was *Aporrectodea tuberculata* (92.2%), with *A. trapezoides* accounting for 4.6%, and *Lumbricus terrestris* accounting for 2.7%. In 1990, a low population of *A. rosea* was identified in the alternative field in addition to those species found in 1989.

Earthworm numbers in the alternative field were lower in 1990 than in 1989, but *A. Tuberculata* was once again the predominant species (88.3%). The population reduction in the alternative field may have been caused by fall and spring tillage which included multiple passes with an off-set disk to prepare the field before seeding the oat, legume, and grass mixture. It may also reflect the lack of manure application to that site during 1990.

The largest number of worms was found in the Canisteo soil in 1989 (Table 3). This series is found in the toeslope position and presumably had the most favorable soil water content at the time of sampling. Earthworms were also found on the hilltops (Clarion soil) in the alternative field. In 1989, the conventional field had no visual sign of earthworm activity (ie. casting materials, burrows, etc.) so although fewer soil cores were taken, we are confident that the number of worms was much lower there than in the alternative field.

Samples collected in the alternative field in 1990 once again resulted in more worms being found in the Canisteo soil than in either the Nicollet or Clarion. Also, the only location where earthworm activity was evident in the conventional field was in the Canisteo soil.

Infiltration Evaluations

A limited number of infiltration studies at this site has shown less runoff (Table 4) from two soils on the Thompson farm than from the same two soils on the Baker farm (Logsdon et al., in review). Measurements in 1991 also showed that soils in the Thompson field had faster infiltration, greater macroporosity, and lower bulk density in the surface layer than on the conventional field.

Aggregation Evaluations

Jordahl (1991) showed that practices used at the Thompson farm resulted in greater aggregate stability, higher organic carbon content, and lower bulk density than conventional practices at the Baker farm. He concluded this occurred because of the 45 Mg ha^{-1} addition of animal manure/municipal sludge during the first 3 yr of every 5 yr rotation and because oats and hay were included in the rotation. He also suggested that farming practices that could supply more carbon through manure, cover crops, or rotations that included forages would create more favorable soil physical, chemical, and biological conditions and presumably reduce long-term soil erosion losses.

Crop Yield Variation

Evaluations of average crop yield as a function of soil map unit showed high variation within each map unit, suggesting that this factor alone is not sufficient to explain variations in crop yield across each field. A more detailed soil map has been prepared for these evaluations, but a model that incorporates factors including residual soil fertility and topography with soil map unit will probably be needed to achieve useful predictions for site-specific soil and crop management (Colvin et al., 1991). Field averages for 1989, 1990, and 1991 are presented in Table 5.

Microclimate Evaluations

The microclimate data set covered 98 days in both fields with less than two days of missing data. Early season temperatures were cooler throughout the soil profile with ridge tillage compared to the conventional tillage. However, these differences disappeared as the corn crop shaded the soil surface. At maturity there were no differences in the soil microclimate between the two fields. There was little radiant energy available at the soil surface and soil heat flux values were small throughout the day. Other measurements made to compare fall tillage effects on soil microclimate showed that differences in soil temperature reappeared after harvest and fall tillage operations.

Bowen ratio calculations over each field were made with the 30-minute averages throughout the season. Daily total net radiation values were not different between the two fields with daily totals in the midseason near 13-14 MJ m^{-2} d^{-1}. Later in the season, values declined to between 8 and 10 MJ m^{-2} d^{-1}. Latent and sensible heat flux values between the two fields exhibited only minor differences with the daily totals within 1 MJ m^{-2} d^{-1}.

Total water use for the season as calculated from the Bowen ratio was 650 mm for the conventional-till and 646 mm for the ridge-till. Differences in water use were insignificant between the two fields. This may be due to the below normal rainfall for 1989. The soil hydraulic properties have been assembled along with the meteorological data for the season. Computer simulation of the partitioning of soil water evaporation between the two fields is being studied. Preliminary measurements indicated that the soil water evaporation rate was less in the ridge-till, thus partitioning more water to plant evaporation. However, this effect would only occur in the early season because of the limited energy available for latent heat exchange throughout most of the season.

Other Comparisons

Tillage energy evaluations showed similar variation in draft among soil map units. No conclusions are possible with the information collected thus far.

Effects of alternative soil management practices on corn grain quality is another factor which is being evaluated. We anticipate that it may be very difficult to show a clear relationship, but we have begun a program to evaluate quality factors including amino acid composition. In addition to data from the Thompson and Baker fields, the same hybrid (Pioneer 3417) has also been planted on three fields in the Walnut Creek MSEA (Management System Evaluation Area) watershed just south of Ames, IA. Evaluations of spatial variability in soil-test parameters and of K accumulation by corn on the Thompson farm are also in progress.

We currently plan to continue these investigations until it is possible to compute long-term economic and nutrient budgets for the two farming systems. Preliminary evaluations show good agreement with our average field yields and those provided to us by our cooperators. With that information, we anticipate that we will be able to achieve our overall objective of providing a quantitative comparison of two central Iowa farming systems.

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Table 1. Management practices used for the two farming systems on the Clarion-Nicollet-Webster soil association in central Iowa.

Factor	Period	-------- Farmer Supplied Information --------
		Conventional System
Rotation	1932-1957	Corn, oats, and hay
	1957-1991	Corn and soybean
Fertility	1932-1979	Hog (Ungulata) manure and 0-17-33 kg N-P-K ha^{-1} yr^{-1} was applied to corn
	1960-1980	As above plus an additional 112 kg N ha^{-1} yr^{-1}
	1981-1991	168-38-93 kg N-P-K ha^{-1} yr^{-1} applied to corn
Tillage	1932-1981	Moldboard plow, disking, and harrowing
	1981-1991	Chisel plow and field cultivator
Pesticides	Before 1981	"Low" rates of atrazine† plus occasional 2,4-D† applications during the early 1960's
	1981-1991	Banvel†, butylate†, 2,4-D, cyanazine†, alachlor†, (EPTC + R25788)†, and atrazine for corn Basagran†, trifluralin†, and alachlor on soybean
	1988	Dimethoate† on soybean for spider mite control
		Alternative System
Rotation	1967-1991	5-year, corn, soybean, corn, oat, and hay
Fertility	1967-1984	No commercial fertilizer, manure (Bovine, and Ungulta) applications totaled 45 Mg ha^{-1} yr^{-1} for row crops, none to oat or hay crops.
	1984-1987	Municipal sludge mixed with manure
	1988-1991	Manure/sludge applied plus 112 kg ha^{-1} yr^{-1} K as kiln dust in the manure/sludge mixture
Tillage	1967-1980	Moldboard plow, disking, and harrowing
	1980-1991	Ridge-tillage, disking prior to oats
Pesticides	1967-1991	None, rotary hoe & cultivate to control weeds
Cover crops	1984-1991	Hairy vetch (*Vicia villosa* Roth.), oats, and winter rye (*Secale cereale* L.)

†(Atrazine) 2,chloro-4-ethylamino-6-isopropylamino-1,3,5 triazine; 2,4-D - 2,4-(dichlorophenoxy) acetic acid; (Banvel) Dimethylamine salt of 2-meth-oxy-3,6-dichloro benzoic acid; (Butylate) S-Ethyl diisobutylthiocarbamate; (Cyanazine) 2-{[4-chloro-6-(ethylamino)-S-triazin-2-yl]amino}-2-methylpropionitrile; (EPTC + R25788) S-Ethyl-N,N, dipropylthiocarbamate plus N, N-diallyl-1,1-dichloroacetamide; (Alachlor) 2-Chloro-2'-6'-diethyl-N-(methoxymethyl)-acetanilide; (Basagran) 3-(1-Methylethyl)-1H-2,1,3-benzothiadiazin-4(3H)-one 2,2-dioxide; (Trifluralin) α,α,α-Trifluoro-2,6-dinitro-N,N-dipropyl-ρ-toluidine; (Dimethoate) O,O Dimethyl S-(N methylcarbamoylmethyl) phosphorodithioate;

Table 2. Mean total-N, NH_4-N, and NO_3-N concentrations in soils sampled in spring 1989 following soybean for conventional and alternative farming systems (after Karlen and Colvin, 1992).

Soil depth	-- Total-N --		-- NH_4-N --		--- NO_3-N ---	
	conv.	alt.	conv.	alt.	conv.	alt.
---- m -----	-----------------	-----------------	mg kg^{-1}	-----------------	-----------------	-----------------
0.0 to 0.1	1661	2285	7.8	3.2	39.9	17.8
0.1 to 0.2	1691	1979	12.5	1.4	42.6	13.6
0.2 to 0.3	1333	1690	3.8	1.7	15.0	10.3
0.3 to 0.45	988	1055	2.3	1.4	6.5	9.9
0.45 to 0.6	676	678	1.5	1.5	4.5	7.3
0.6 to 1.0	354	405	1.4	1.5	3.4	6.3
1.0 to 2.0	154	162	1.6	1.7	2.9	4.0
2.0 to 3.0	118	106	3.9	3.5	2.9	2.6
3.0 to 5.0	189	156	5.4	4.4	2.7	2.3
5.0 to 7.0	207	172	5.5	4.0	2.1	2.4

Table 3. Earthworm populations in 1989 and 1990 for conventional and alternative farming systems (after Berry and Karlen, in review).

Soil series	1989 Conventional mean SD	1989 Alternative mean SD	1990 Conventional mean SD	1990 Alternative mean SD
	worms m^{-2}			
Clarion	0.0	580 ± 353	0.0	81 ± 118
Nicollet	0.0	270 ± 229	0.0	0
Canisteo	0.0	837 ± 437	9.3 ± 3.1	127 ± 149

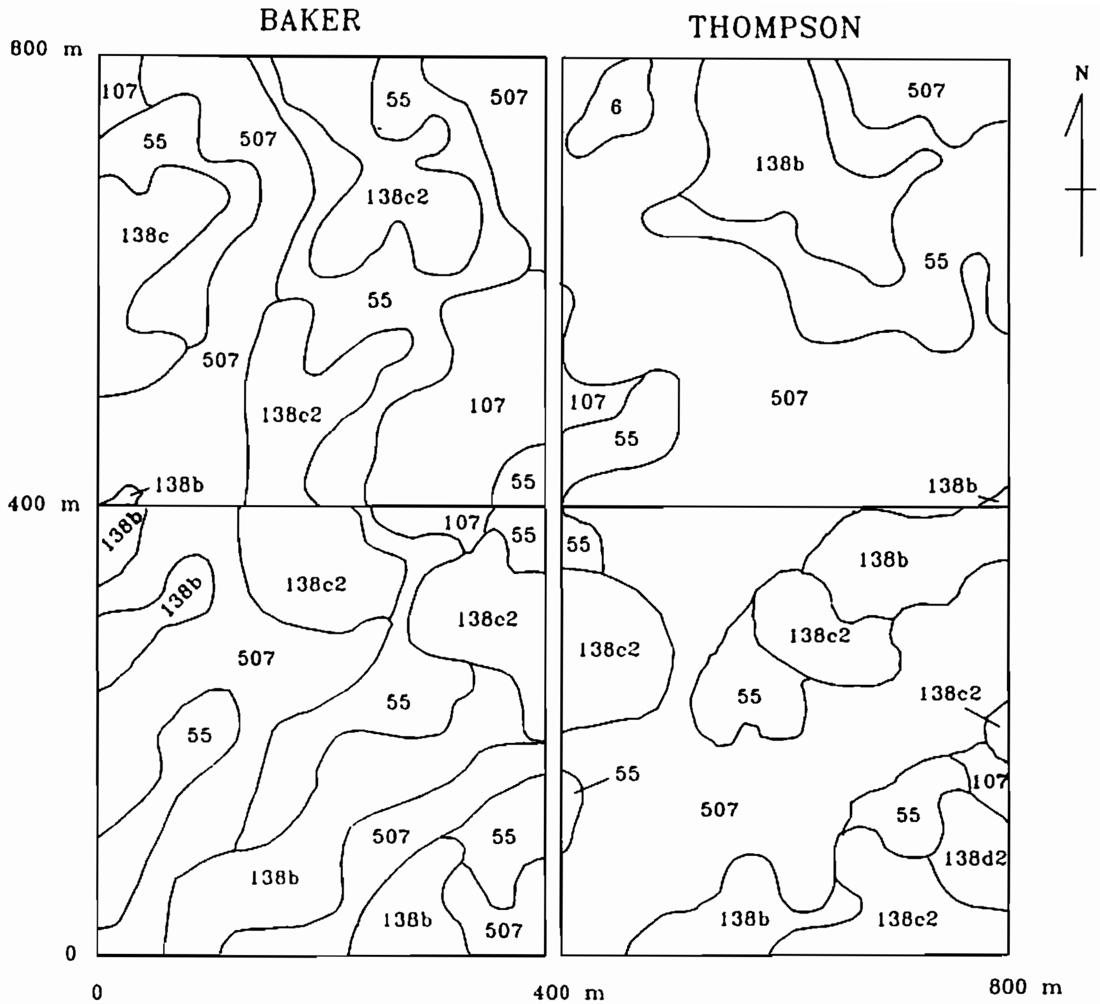
Table 4. Median runoff for conventional and alternative farming systems (after Logsdon et al., in review).

Measurement $\mu m\ s^{-1}$	Conventional		Alternative	
	Clarion	Webster	Clarion	Webster
1989 Runoff	8.32	1.13	3.19	1.49
1991 Runoff	0.17	0.66	0.14	0.04

Table 5. Crop yield response during 1989, 1990, and 1991 for conventional and alternative farming systems in central Iowa.

Farming system	Year	Crop yield Corn	Soybean	Oat	Hay†
		kg ha^{-1}			Mg ha^{-1}
Conventional	1989	9093	----	----	----
Conventional	1990	7577	4022	----	----
Conventional	1991	9360	2959	----	----
Alternative	1989	8977	----	----	----
Alternative	1990	----	----	3228	10.8
Alternative	1991	6792	----	----	12.4

†Dry matter per hectare.



SOIL IDENTIFICATION

Soil name	Map unit	Classification
Clarion loam,		Fine-loamy, mixed, mesic Typic Hapludolls
2 to 5% slopes	138b	
5 to 9% slopes	138c2	(moderately eroded)
9 to 14% slopes	138d2	(moderately eroded)
Nicollet loam,	55	Fine-loamy, mixed, mesic Aquic Hapludolls
Canisteo silty clay loam	507	Fine-loamy, mixed (calcareous), mesic Typic Haplaquolls
Webster silty clay loam	107	Fine-loamy, mixed, mesic Typic Haplaquolls

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