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NITROGEN CYCLING AND SEASONAL DYNAMICS OF BARLEY, MICROBIAL BIOMASS AND FAUNAL POPULATIONS IN CONVENTIONAL AND ZERO TILLAGE SYSTEMS

BY

KAREN HAUGEN-KOZYRA (C)

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THE UNIVERSITY OF ALBERTA
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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled NITROGEN CYCLING AND SEASONAL DYNAMICS OF BARLEY, MICROBIAL BIOMASS AND FAUNAL POPULATIONS IN CONVENTIONAL AND ZERO TILLAGE SYSTEMS submitted by KAREN HAUGEN-KOZYRA in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE IN SOIL MICROBIOLOGY AND BIOCHEMISTRY.

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Date: Oct 13/89

Abstract

Alternative cropping systems to present day practices are needed on the Canadian prairies to conserve soil, water and nutrients. The purpose of this study was two-fold: (i) examine seasonal N dynamics and conservative properties of conventional tillage (CT) and zero tillage (ZT) systems and (ii) compare agroecosystem structure and interpret its impact on the response of the soil - plant systems. The 8-year tillage plots were located on a Black Chernozemic soil (Typic Cryoboroll) in central Alberta. Microplots were fertilized with urea solution (59 kg N ha^{-1}, 6.2% ^{15}N excess), seeded to barley (*Hordeum vulgare* (L.) Empress) in the spring of 1987 and destructively sampled 4 times at Feeke's stages 2, 10.4, 11.2 and 11.4. Distributions of and overall concentrations of ^{14}N and ^{15}N pools, soil carbon, soil microbial biomass and fauna were studied at 3 depth intervals. Overall, recovery in the soil plant system was 74% in ZT and 65.1% in CT. Greater penetration of mineral N occurred on date 1 under ZT (12.3% ^{15}N recovery in the second depth versus 1.9 % for CT). This lead to greater immobilization under the ZT system with 29.1 % recovery in non-microbial organic N forms as compared to 24.9 % under CT overall. N budgets showed that grain removal from CT was 76 kg ha^{-1} and 56 kg ha^{-1} in ZT. Temporal discontinuity between plant demand and nitrogen application, along with the altered conditions imposed by the two systems, led to differences in the distribution and dynamics of nitrogen in barley, mineral and organic N pools as well as plant fertilizer utilization within the plant-soil system.

Under ZT, the distribution of C with depth (6.22%, 5.48% and 4.32% for 0-5, 5-15 and 15-30 respectively) differed from that of CT (6.01%, 5.71% and 4.24%), showing a surface concentration effect. Populations of protozoa and mites were higher overall in the ZT system (29.4×10^{11} m^{-2} and 3.02×10^{6} m^{-2} respectively) relative to the CT system (5×10^{11} m^{-2} and 2.65×10^{4} m^{-2}) while nematodes were higher overall under CT (5.8×10^{6} m^{-2}) versus ZT (4.6×10^{6} m^{-2}). The faunal groups mentioned above showed a stratification with depth under ZT. BiomassC:respired C was lower under CT (6.1) than under ZT (8.1) indicating a

more metabolically active and less energetically efficient biomass. Thus differences in agroecosystem structure induced by the type of residue placement and degree of soil disturbance altered ecosystem response. Zero tillage in combination with residue management would be a viable addition to present day cropping systems in central Alberta.

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Chapter 1. Introduction

Managed ecosystems are driven by external regulators interested in optimum production. Practices associated with these production oriented systems such as tillage, residue removal and summer fallowing can lead to soil organic matter deterioration, loss of soil water and soil erosion (Coleman and Hendrix, 1988). A temporary decoupling of C and N cycles results from the removal of annual crop litter and exogenous N inputs from fertilization. An imbalance is created with the mineral N pool becoming highly exaggerated due to: (1) the lack of residues with high C:N ratios from the previous year's crop to immobilize mineral N; and (2) the addition of fertilizer early in the season at a time when crop demand is low or nonexistent (Juma and McGill, 1986). The relatively large mineral N pool becomes vulnerable to chemical and microbial processes like volatilization, fixation, nitrification, denitrification and leaching. Natural grasslands tend to cycle organic N more tightly than managed systems. Early season mineralization-immobilization turnover (MIT), which normally supplies plant nutrients via the flush of decomposition generated by spring rains and abundant residues, is replaced by an early season spike of high amounts to the mineral N pool in managed systems. Efficiency of N use then depends on synchronizing crop demand with the trends in the mineral N pool. Quite often this does not occur resulting in low plant recovery of fertilizer N (Newbould, 1989). In this recent article, Newbould (1989) states that to improve N use in agroecosystems, we need to better understand the "...interactive flows between soil, plants and animals and the atmosphere.". The alteration in cycling of matter and fluxes of energy at the agroecosystem level can impact at the global level in the form of contaminated groundwater or atmospheric degradation (Coleman and Hendrix, 1988). More conservative, self-sustaining techniques of crop production which are less dependent on costly inputs and unbalanced outputs are needed to carry agriculture into the 21st century.

Tillage has been used in agroecosystems to reduce weed populations, prepare a good seedbed, incorporate fertilizer and residues and stimulate mineralization. CT has afforded the prairies many years of f' .: production, however the erodibility of a 'clean field' and the decline of soil organic matter are drawbacks to this form of management. Zero tillage and other forms of reduced tillage management are used to minimize soil erosion, conserve soil water and reduce fuel costs (Doran, 1980). However, zero tillage may not be an alternative for some producers due to the increased use of chemicals as a substitute for tillage, the need for acute managerial skills, cool spring temperatures, residue-borne diseases, problems with small grain seeding and compaction problems with heavy clay soils (Philips and Young Jr., 1983).

Reduced tillage systems represent more ecologically balanced forms of management than standard agricultural practices. They feature several characteristics which resemble natural grassland systems such as organic matter and biological stratification (greater concentrations near the surface), greater pore continuity and pore size distribution, greater nutrient retention and longer nutrient turnover times (House et al, 1984; Groffman et al, 1986; Doran et al, 1987; Coleman and Hendrix, 1988). The detrital food web under ZT is typically more diverse featuring organisms with more complicated life cycles and specialized feeding habits (Andren and Lagerlof, 1983; Coleman et.al., 1984; Ryszkowski, 1985).

Altered ecosystem structure under ZT systems impacts on ecosystem response as a whole. Studies reporting lower yields and increased N requirements under ZT are not uncommon in the literature (Doran et al, 1987). We decided to take an integrative approach in the study of ZT and CT systems on the central Canadian prairie to determine if, after 8 years, a difference existed in agroecosystem structure and response. Studies which integrate the key components of agroecosystems with inputs and outputs stand a better chance of aiding in the development of management practices that are both sustainable and productive (House

et al, 1984). Therefore this study was composed of two major parts. The first part was an agronomic study to determine differences in N cycling between CT and ZT management. The plant was percieved to significantly influence other agroecosystem components therefore sampling dates coincided with significant stages in the development of a barley plant. In order to study whether a vertical redistribution of biological and chemical properties occurred under ZT, a depth variable was chosen based on previous studies on the Canadian prairies (Carter and Rennie, 1984). The dynamics of several important N pools were examined in order to determine differences in the partitioning patterns of urea-^{15}N between the two systems and their effects on N yield.

The second part of the study was designed to assess whether differences in ecosystem structure between ZT and CT existed. The distribution and concentrations of organic matter, microbial biomass and fauna were compared at the various depth intervals. The metabolic status of each soil was examined using key indices of ecosystem response in order to evaluate the impact of ecosystem structure. These indices would indicate the quality/activity of decomposers in the two systems. Net primary production was also used to compare the relative responses of the systems.

Finally, the synthesis of this study compares the seasonal response of the various agroecosystem components; plant, microbial and faunal, to assess how differences in ecosystem structure affected the integrated response of the two systems as wholes. Implications for ZT as an environmentally sound alternative to present day operations are discussed.

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Chapter 2. Seasonal Nitrogen Partitioning and Cycling in Conventional and Zero Tillage Systems

Introduction

Zero tillage (ZT) to conventional tillage (CT) is a continuum of management practices on the Canadian prairies. Reduced tillage intensity, over a sufficient time period, causes a surface concentration of organic matter, residues and organisms which regulate the cycling of nutrients within the system (Selles et.al., 1984; Doran et al, 1987). Increased immobilization of fertilizer, in conjunction with the less oxidative environment generated under reduced tillage management, alters the activities of microbial biomass causing less nitrogen and carbon mineralization (Doran, 1980; Linn and Doran, 1984; Coleman, 1985). The mineralization - immobilization turnover (MIT) of N is slower under ZT allowing greater reserves of organic forms to build and overall lower amounts of plant available N (Fredrickson et al, 1982; House et al, 1984; Rice and Smith, 1984; Doran et.al., 1987; Carter and Rennie, 1987). However, over the long term the large organic reserves formed under ZT allow the flux of mineral N through MIT to be comparable to that of the more rapidly mineralizing, smaller organic pools under CT (Rice et al, 1986).

This study attempts to assess if, after 8 years, there are differences in the N dynamics of the plant - soil systems under CT and ZT management. The plant was treated as an integrator of the system components with the sampling dates chosen to coincide with particular developmental stages of barley. Examination of the state of each system at various time intervals allowed insights into the short term uptake and accumulation of N in plants. Addition of ^{15}N labelled urea and soil sampling by depth were designed to examine differences in the seasonal MIT and partitioning of N between the various soil components. The objectives of this study were to: (i) examine the short term plant dynamics at key points

in their development to determine if differences existed in the short- term uptake and partitioning of N among plant components; (ii) examine the partitioning and stocks of N in the various soil pools to determine if differences in N cycling existed; and (iii) integrate the results from the above objectives in an overall assessment of an early season urea injection in terms of yields, fertilizer distribution and N budgets. This last objective has implications for ZT management.

Materials and Methods

Soil and Site Description

The experiment was conducted on adjacent zero and conventional tillage plots on an Eluviated Black Chernozemic soil (Typic Cryoborall) located at the Ellerslie Research Station at (NE 24-51-25 W4), Edmonton, Alberta (Bowser et.al., 1962). Average long term (30 year) annual precipitation at this site is 452 mm, of which 340 mm occurs as rain principally in the months of June, July and August (Environment Canada Met. Info.). This site has an average of 109 frost free days and 1090 growing degree days (Thomas, 1984). Soil properties and management history of the plots are described in Table 2.1.

Table 2.1. Selected Soil Properties of the Two Systems.

Depth (cm)	C[a] (%)	N (%)	pH (1:2) (soil:H_2O)	Bulk Density (Mg/m^3)	Texture
			Conventional Tillage		
0 - 5	6.01	0.52	5.6	0.88	
5 - 15	5.71	0.47	6.0	0.94	SiCL
15 - 30	4.24	0.36	6.5	1.06	
			Zero Tillage		
0 - 5	6.22	0.53	5.5	0.93	
5 - 15	5.48	0.49	6.0	0.99	SiCL
15 - 30	4.32	0.37	6.5	1.03	

a Significant tillage by depth effect at $p<0.05$

Management History

Prior to the current management system, the plots used in this study were continuously cropped to barley for a period of 13 years. Since 1979, the conventional tillage plots were tilled in the spring and fall to a depth of 10 to 12 cm with a rototiller. Residue management and fertilizer placement for the conventional tillage plots consisted of incorporating 56 kg N/ ha spring applied urea, 30 kg/ha P_2O_5 and at approximately 75 % of the residues. The only disturbance in the zero tillage plots occurred during seeding. Fertilizer and residues under ZT were broadcasted over the entire plot. Since their inception both plots have been continuously cropped to barley (*Hordeum vulgare* L.) and weed control for the last four years was attained via an application of Chlorsulfuron/Diclofop-methyl mixture (Glean/Hoegrass (284)).

Experimental Design and Sampling Procedure

The experiment consisted of a factorial split split plot design involving three blocks, two tillage treatments within each block, four sampling dates and three soil depths. On May 28, 1987 eight open ended steel cylinders (20 cm diameter and 30 cm depth) were installed in each block, four in each of the treatment plots. Six to eight vitavax (a fungicide) treated seeds were sown in each cylinder. Ten mL of ^{15}N-urea solution (39.59 mg N mL^{-1}, 59 kg N ha^{-1}, 6.20 % excess) were applied to each cylinder approximately two cm below the mineral surface. The solution was injected at five points in each cylinder and was followed by 200 mL of distilled water to distribute the fertilizer in the top 5 cm. The plots were destructively sampled four times over the growing season corresponding to the following plant growth stages: Feekes' stage 2 (Date 1, June 18, 1987); Feekes' stage 10.4 (Date 2, July 21, 1987); Feekes' stage 11.2 (Date 3, August 10, 1987) and Feekes' stage 11.4 (Date 4, September 9, 1987). These stages respectively represent the fifth leaf, ear emergence, grain filling and harvest events of the crop.

At each sampling date, six cylinders were randomly sampled, two from each block, one from each of the tillage treatment plots. Above-ground material in each cylinder was harvested, the cylinder removed, taken to the laboratory where the soil was divided into three depths, 0 - 5 cm, 5 - 15 cm and 15 - 30 cm and roots were manually separated from soil. Similar studies on the Canadian prairies have indicated that the depths chosen in this study were logical boundaries for studying redistribution patterns induced by reduced tillage management (Carter and Rennie, 1984). Soil subsamples were dried at 105 °C for moisture content determinations and the rest of the bulk soil stored moist at 5 °C for further analysis. Above-and-below ground plant samples were dried at 70 °C and weighed.

Analyses

Dried above and below ground plant material was ground to 10 mesh in a Wiley mill. Plant material and dried soil subsamples for ^{15}N and total N determinations were further ground in an Brinkmann ultra high speed mill. Ground shoot, root and soil samples were dispensed into a Carlo Erba Model 1500 ANA (Automatic Nitrogen Analyser), combusted, analysed for N content and the effluent introduced directly into the mass spectrometer for isotope ratios analysis. ^{15}N and total N analyses were performed on a VG Isogas ANA-SIRA, (Automatic Nitrogen Analyser- Stable Isotope Ratio Analyser) Dumas combustion - mass spectrometer train system.

Bulk density was calculated by dividing the oven dry weight of the soil from each depth by the volume occupied by that depth in the cylinder. Subsamples of each depth were used to determine gravimetric moisture content. Percent Water Filled Porosity was calculated assuming a particle density (Dp) of 2.65 Mg m^{-3} and using the equation:

$$\% WFP = (Om \times Db/(1-(Db/Dp))) \times 100$$

where Om = gravimetric moisture content and Db is the bulk density.

A Leco Carbon Determinator model CR-12 was used to analyze for C contents of ground soil and texture was analysed manually.

Soil mineral N was extracted by shaking 25 g (oven dry basis) of fresh soil with approximately 135 mL (weighed to exact mass) of 2M KCl solution for 1 hour and filtering the mixture through a Whatman no. 2 filter paper. Soil NH_4-N and NO_3-N were then respectively determined using a Technicon AutoAnalyser II and the Berthelot and the Griess-Ilosvay copperized-Cd column methods (Keeney and Nelson, 1982). The ^{15}N diffusion technique (Turner and Bergersen, 1980) was used to prepare the ^{15}N in the KCl extracts for isotope ratio analysis. Briefly, KCl extracts were placed in specimen containers, a glass filter disc saturated with 10 µL of $KHSO_4$ suspended above the solution to trap the evolving NH_3, the appropriate reagent added and the containers capped and left for a period of 6 days. NH_4-N^+ was collected by adding sufficient MgO (approximately 0.2 g) to convert all the NH_4-N to NH_3. For NO_3-N^- the container was left uncapped initially to let the NH_4-N^+ ammonia dissipate. Devarda's alloy (approximately 0.4g) was then added, the container capped and left until all the NO_3-N^- was collected as ammonia on the disks. After the required time, the discs were removed, allowed to dry in an equilibrated atmosphere of H_2SO_4 and placed directly in the ANA-SIRA train for N and ^{15}N analysis.

Duplicate samples of twenty five grams sieved soil (2 mm), adjusted to 55% water holding capacity, were used for microbial biomass N determinations. Microbial biomass N was estimated after Shen et al (1984), using the formula $B_n = F_n/k_n$, where k_n is equal to 0.68 and F_n is the difference between mineral N (NH_4-N^+ and NO_3-N^-) accumulated in fumigated soil and unfumigated soil for a period of 10 days. Mineral N accumulated in the 10 day incubation of the fumigated sample was used as an estimate of net N mineralization.

Organic ^{15}N was calculated by subtracting the predetermined mineral ^{15}N from soil ^{15}N. Non-microbial organic ^{15}N (NMO^{15}N) was then taken as the difference between the organic ^{15}N and the microbial ^{15}N.

All results are expressed in concentration units of g m^{-3} and are means of 3 replicates. To convert data to $\mu g\ g^{-1}$ divide by the bulk density of the appropriate soil layer (Table 2.1). To convert data to g m^{-2}, multiply the values by the appropriate thickness (in meters) of the soil layer.

Statistical Analyses

The data were analysed on a microcomputer version of S.A.S.® usi.ıg the General Linear Model procedure. ANOVA was used to test for any significant tillage, depth or date effects. Least Squares Difference analysis was performed on the ^{15}N recoveries in the soil-plant system.

Results

Soil Properties

Soil C and N levels did not differ between tillage systems however C levels were higher in the top depth under ZT and declined more steeply with depth than CT (Table 2.1). C levels in the the CT system by comparison, gradually declined from the 0-5 cm depth to the 5-15 cm depth. pH values increased with depth and were similar for both treatments.

There were no differences in bulk densities between the two systems however there appeared to be a tendency for higher bulk densities in the top two layers under ZT (Table 2.1). Bulk densities increased with depth.

Field and Soil Environment

Seasonal precipitation was typical for this site with 85% of the 340 mm of annual rainfall occurring between May and September (Figure 2.1). The average daily air temperature over the growing season ranged from a low of 7.1 C in May to a high of 20.9 C in July.

Overall, gravimetric water content and percent water filled porosity did not differ with tillage treatment (Figure 2.2). The trend in moisture conditions reflect substantial rainfall and plant events with date 2, sampled at ear emergence, being the driest and date 3, sampled after the season's largest rainfall, being the wettest of the 4 dates. Gravimetric water content was higher overall in the surface layer and declined with depth. On those dates which were preceded by a substantial amount of rainfall, the top depths were consistently wetter than the lower depths. Percent water filled porosity under ZT was more variable than CT, declining to a greater extent at the ear emergence stage of the crop and having higher pore water content on the third date. Water filled porosity did not show a depth trend probably due to the inclusion of bulk density in the calculation of this property.

Seasonal Plant and Soil Dynamics

Shoot and root N concentrations were highest in both systems at the fifth leaf stage of the plant (Table 2.2). Shoot N concentrations were higher in ZT on the first date but declined over the next three sampling dates to lower N levels than those of the CT system. On the first date, root N concentrations declined more with depth than on the following 3 sampling dates.

Nitrogen in shoots and roots (g m^{-2}) were not affected by tillage (Table 2.2). Shoot N followed shoot mass trends, peaking on the third date and then stabilizing or declining slightly towards harvest. Root N peaked by the second sampling date, emphasizing the

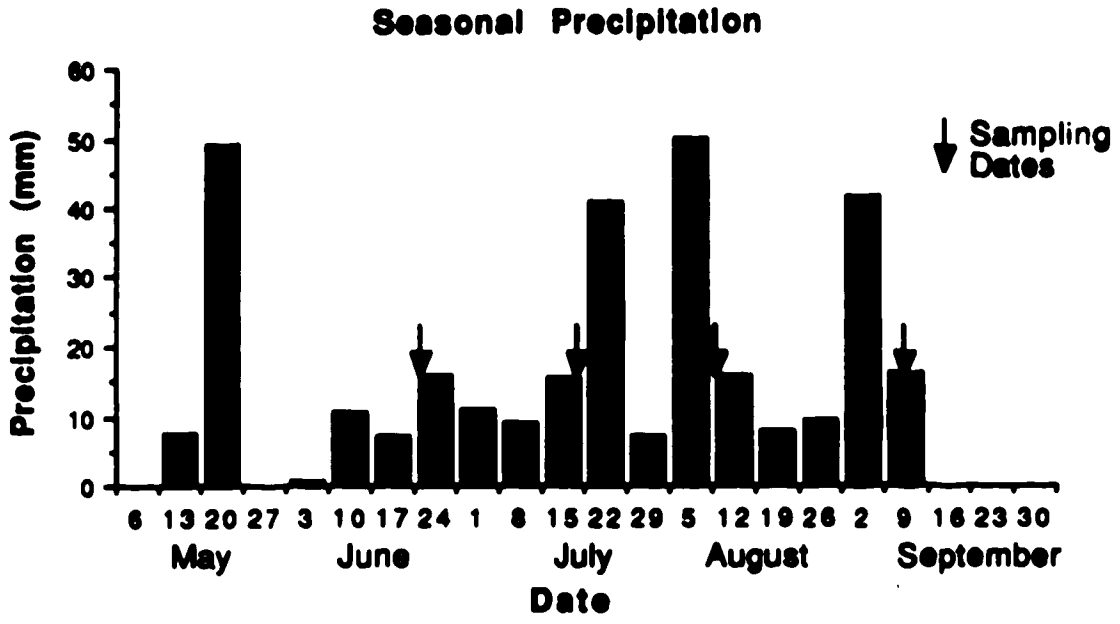

Figure 2.1. Seasonal precipitation (mm) in the 1987 crop year

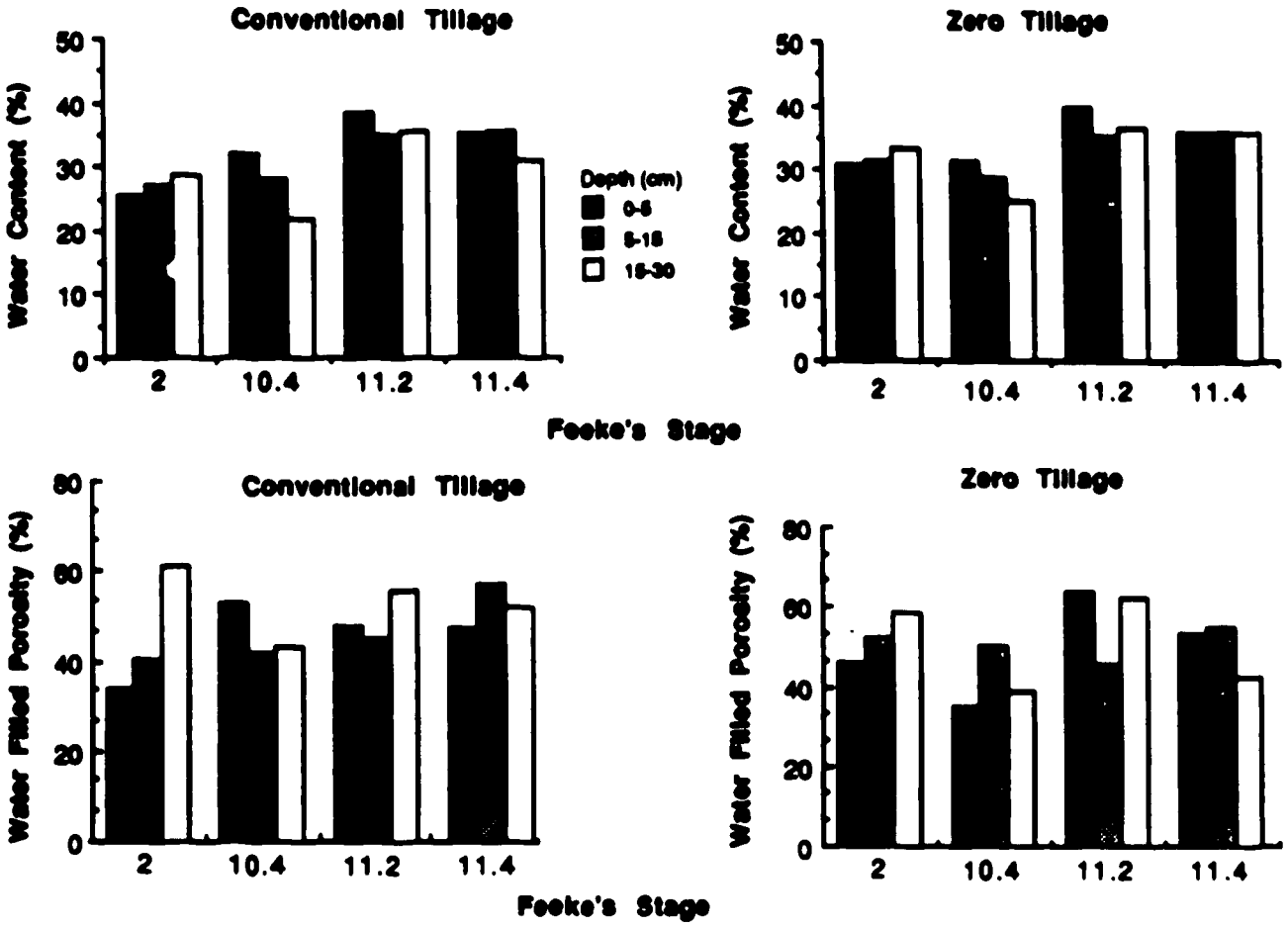

Figure 2.2 Soil water dynamics in zero and conventional tillage systems

Table 2.2. Seasonal Dry Matter Accumulations, Nitrogen Budget and C:N Ratios in Conventional and Zero Tillage Plots (means of 3 replicates)

Variable	Depth[b] (cm)	Feeke's Growth Stage[a] 2	10.4	11.2	11.4
		Conventional Tillage			
Shoot N Conc.(%)		5.0	1.7	1.3	1.2
Shoot N (g m^{-2})		1.1	7.7	10.6	7.6
Shoot C:N		7.4	24.6	33.9	33.8
Root N Conc.(%)	0 - 5	2.4	1.2[b]	1.0	1.1
	5 - 15	1.6	1.2	1.5	1.5
	15 - 30	1.4	1.0	1.1	1.2
Root N (g m^{-2})	0 - 5	0.3	0.7[b]	0.6	0.5
	5 - 15	0.2	0.2	0.2	0.1
	15 - 30	0.1	0.1	0.1	0.0
Root C:N[d]	0 - 5	14.8	30.8[b]	39.2	35.6
	5 - 15	21.2	32.3[b]	25.2	24.4
Soil N (g m^{-2})	0 - 5	236	245	219	218
	5 - 15	413	448	419	496
	15 - 30	498	492	526	520
		Zero Tillage			
Shoot N Conc.(%)		5.4	1.5	1.1	1.1
Shoot N (g m^{-2})		1.3	7.6	8.1	7.8
Shoot C:N		6.8	27.7	41.0	38.1
Root N Conc.(%)	0 - 5	2.5	1.2	0.9	1.1
	5 - 15	1.6[b]	1.5	1.1[b]	1.5
	15 - 30	1.3	1.2	0.9	1.0
Root N (g m^{-2})	0 - 5	0.3	0.8	0.5	0.4
	5 - 15	0.1[b]	0.3	0.1[b]	0.1
	15 - 30	0.1	0.1	0.1	0.1
Root C:N[d]	0 - 5	14.3	30.0	46.1	34.9
	5 - 15	22.9[b]	25.5	28.5[b]	23.7
Soil N (g m^{-2})	0 - 5	262	212	260	247
	5 - 15	506	566	414	442
	15 - 30	530	502	512	474

Mean Square of ANOVA[c]

Source of Variation	df	Shoot N (%)	Shoot N (g m^{-2})	Shoot C:N	Root N (%)	Root N (g m^{-2})	Root C:N (g m^{-2})	Soil N
Block	2							
Tillage	1	0.002	1.800	72.66	5.40×10^{-3}	5.0×10^{-5}	6.733	74.62
Error 1	2	0.057	1.214	19.50	3.50×10^{-3}	3.0×10^{-4}	4.528	40.78
Date	3	23.65***	77.53***	1172***	1.72***	3.8×10^{-3}***	447.2***	43.01
Till x Date	3	0.124*	2.646	19.55	0.100	2.0×10^{-4}	33.56	29.17
Error 2	12	0.020	1.331	15.25	0.054	3.2×10^{-4}	17.97	20.07
Depth	2				0.649***	0.065***	262.0***	807.2***
Till x Depth	2				0.012	3.0×10^{-5}	8.862	38.80
Date x Depth	6				0.665***	2.18×10^{-3}	282.4***	49.67
Till x Date x Depth	6				0.016	2.0×10^{-4}	11.50	69.84
Error 3	32				0.044	3.0×10^{-4}	20.34	59.67

[a] Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987.

[b] n=2 rather than n=3

[c] The difference between means is significant at; [i], p<0.10, *, p≤0.05; **, p≤0.01; ***, p≤0.001

[d] Since root C was measured for 2 depths, the degrees of freedom for root C:N are depth (1), till x depth (1), date x depth (3), till x date x depth (3) and error 3 (16)

importance of root activity at this stage in the barley plant's development. Like root mass, the majority of the root N was found in the top layer in both systems. The second date had 2 times the amount of root material in the second depth relative to the other sampled growth stages.

The shoot C:N ratio in both systems increased as the plants developed (Table 2.2). Over the last two dates N was conserved relative to C as the senescence of lower leaves caused a narrowing of the C:N ratio in the shoots. Root C:N ratios followed similar trends. However, average root C:N ratios in the second depth interval remained constant and were narrower than in the first depth.

Soil N was not different over the growing season and declined with depth (Table 2.2).

Mineral and Microbial N Dynamics

On average, more ammonium existed under CT, emphasizing more plant available N under this system (Table 2.3). The levels in the first date reflected the recent hydrolysis of urea and were higher under CT. After the first date, ammonium declined until harvest where a slight increase occurred under the ZT system.

Nitrate dynamics did not differ with tillage treatment (Table 2.3). Amounts were high at the fifth leaf stage of the plant as a result of hydrolysed urea, nitrification and low plant uptake. Levels dropped by the ear emergence stage and remained low for the rest of the season. Nitrate was highest on the first date in the top depth and levels in the next two depths on this date indicate the movement of nitrogen in the mineral form. Amounts in the various depths over the rest of the growing season remained low.

Nitrate was the main form of mineral N that moved down the solum on date one. The mineral N dynamics paralleled the nitrate trends (Table 2.3). On average, nitrate levels were

Table 2.3 Seasonal Mineral and Microbial N Dynamics in Conventional and Zero Tillage Plots (means of 3 replicates)

Variable ($g\ m^{-3}$)	Depth (cm)	Feeke's Growth Stage[a] 2	10.4	11.2	11.4
		Conventional Tillage			
NH_4^+-N	0 - 5	41	4	2	3
	5 - 15	2	2	1	2
	15 - 30	2	2	1	1
NO_3^--N	0 - 5	87	4	3	5
	5 - 15	13	2	2	4
	15 - 30	9	2	2	3
Mineral N	0 - 5	128	8	4	8
	5 - 15	15	4	4	6
	15 - 30	11	5	4	4
Microbial N	0 - 5	36	34	56	46
	5 - 15	39	28	42	42
	15 - 30	21	18	23	12
		Zero Tillage			
NH_4^+-N	0 - 5	23	3	3	4
	5 - 15	4	2	2	2
	15 - 30	3	2	1[b]	2
NO_3^--N	0 - 5	102	3	4	4
	5 - 15	21	3	3	3
	15 - 30	11	2	2	2
Mineral N	0 - 5	124	5	7	8
	5 - 15	24	5	4	5
	15 - 30	14	5	3	3
Microbial N	0 - 5	36	29	66	50
	5 - 15	42	26	32	31
	15 - 30	20	12	20	17

Source of Variation	df	Mean Square of ANOVA[c] NH_4-N	NO_3-N	Mineral N	Microbial N
Block	2				
Tillage	1	2.29×10^{-3} i	4.9×10^{-3}	5.7×10^{-4}	3.3×10^{-3}
Error 1	2	1.7×10^{-4}	2.6×10^{-3}	1.6×10^{-3}	0.030
Date	3	0.047***	0.627***	1.019***	0.073***
Till x Date	3	3.4×10^{-3}	9.1×10^{-3}	2.0×10^{-3}	2.2×10^{-3}
Error 2	12	4.6×10^{-4}	5.4×10^{-3}	7.6×10^{-3}	2.2×10^{-3}
Depth	2	0.054***	0.361***	0.693***	0.428***
Till x Depth	2	4.3×10^{-3}***	1.4×10^{-3}	1.7×10^{-3}	6.7×10^{-3}
Date x Depth	6	0.040***	0.319***	0.586***	0.030***
Till x Date x Depth	6	5.3×10^{-3}***	1.5×10^{-3}	2.0×10^{-3}	6.9×10^{-3}
Error 3	32	4.4×10^{-4}	2.4×10^{-3}	3.8×10^{-3}	7.5×10^{-3}

[a] Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987.

[b] n=2 rather than n=3

[c] The difference between means is significant at: i, $p<0.10$, *, $p\leq0.05$; **, $p\leq0.01$, ***, $p\leq0.001$

2.6 times greater than the ammonium, therefore taken collectively in the variable mineral N, the ammonium trends were masked by the nitrate trends. Mineral N levels were highest on the first date, especially in the first depth and declined throughout the rest of the season.

Microbial biomass N was not affected by tillage (Table 2.3). Biomass N fluctuated over the growing season in response to soil moisture conditions, which declined on the second sampling date and increased on the third (Fig. 2.2). The first depth on the third date showed a flush of biomass N in response to the favorable moisture conditions. Microbial N declined with depth.

^{15}N Recovery in the Soil-Plant System

On average recovery of ^{15}N in shoot material did not differ between tillage systems (Table 2.4). By the fifth leaf stage, ^{15}N fertilizer was being utilized by the plant and was maximal at the ear emergence stage. Shoot ^{15}N recovery under CT significantly declined upon maturation and was lower than ZT at harvest.

Recovery of ^{15}N in roots showed no tillage effect and peaked at the ear emergence stage (Table 2.4). Most of the ^{15}N was recovered in roots within the top depth. Recovery of ^{15}N in roots on the second date in the second depth were highest relative to other dates.

On average, there were no differences in recovery of total soil ^{15}N between the two systems (Table 2.4). Recovery of ^{15}N was the highest on the first date, declining to a residual level by the second date and remained so for the rest of the growing season. The majority of the soil ^{15}N was recovered in the top layer, however on the first date under ZT, a larger amount of ^{15}N occurred in the second depth.

Total recovery of ^{15}N was not different in the two systems (Table 2.4). The first date had nearly complete recovery, with the high numbers indicating the cumulative error

Table 2.4. Percent ^{15}N Recovery in the Soil-Plant System under Conventional and Zero Tillage (means of 3 reps)

Variable	Depth (cm)	Feeke's Growth Stage[e] 2	10.4	11.2	11.4
		Percent Recovery Under Conventional Tillage			
Shoot N		7.4a	54.3b	52.0b	33.3c
Root N	0 - 5[f]	1.6a	3	2.4a	1.6a
	5 - 15	0.4c	0.	0.4c	0.2c
	15 - 30	0.1c	0.2	0.1c	0.1c
Total Soil N	0 - 5	102.5a	25.8c	26.5c	22.7c
	5 - 15	4.5d	3.1d	4.3d	6.0d
	15 - 30	-	1.1d	1.0d	1.1d
Total Recovery		116.3a	89.0b	86.7bc	65.1c
		Percent Recovery Under Zero Tillage			
Shoot N		13.2a	57.8b	49.6b	39.6b
Root N	0 - 5	2.2a	4.4b	3.0ab	1.5a
	5 - 15[g]	0.5c	1.6a	0.2c	0.3c
	15 - 30	0.1c	0.4c	0.2c	0.2c
Total Soil N	0 - 5	85.2b	22.9c	26.7c	23.5c
	5 - 15	22.3c	8.1d	5.5d	6.9d
	15 - 30	-	5.2d	1.9d	2.0d
Total Recovery		124.5a	100.4ab	87.2bc	74.0c

Mean Square of ANOVA[h]

Source of Variation	df	Shoot ^{15}N	Root ^{15}N	Soil ^{15}N	Total Recovery
Block	2				
Tillage	1	64.52	0.746	33.01	354.0
Error 1	2	66.20	0.363	25.77	144.7
Date	3	2518***	5.345***	3902***	2375***
Till x Date	3	23.44	0.097	2.470	39.21
Error 2	12	71.35	0.317	61.66	193.5
Depth	2		37.36***	7831***	
Till x Depth	2		0.257	148.4*	
Date x Depth	6		1.757***	1523***	
Till x Date x Depth	6		0.108	148.5*	
Error 3	32		0.280	50.34	

a,b,c d Same lowercase letter indicates no significant difference between tillage treatments at a given date or depth ($p<0.05$)

e Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987

f n=2 rather than n=3, for 2nd date

g n=2 rather than n=3, for 1st and 3rd date

h The difference between means is significant at: *, $p\leq0.05$; **, $p\leq0.01$; ***, $p\leq0.001$

associated with summing separately determined pools. There was a significant drop under CT from date one to date two, presumably due to more partitioning of ammonium into various N pools. The total recovery under ZT declined more gradually from date one to date three (Table 2.4). The decline in recovery in ^{15}N in both systems from date three to date four was mainly due to shoot loss.

^{15}N Distribution in the Soil Compartments

The ^{15}N recovery in the total mineral N pool (NH_4-N and NO_3-N) shows that the majority of the label was in mineral form on the first date (Table 2.5 and Fig. 2.3a and 2.3b). On average, mineral ^{15}N did not differ between tillage systems, but more mineral ^{15}N moved into the second depth on the first date under ZT. This pool remained low and stable for the last three dates in both systems.

On average, microbial biomass ^{15}N, like microbial biomass N, was quantitatively unaffected by tillage (Table 2.5 and Fig. 2.3a and 2.3b). The amount of label in the biomass was high in the beginning of the season, three weeks after fertilization, as the microbes actively competed for the mineral N pool. By ear emergence, recovery of ^{15}N in the biomass had dropped to about 3% . The ^{15}N recovery in the biomass from the CT system was greater in the first depth. The favorable moisture regime on the third date led to an increase in recovery of ^{15}N in microbial biomass as it reimmobilized portions of organic ^{15}N.

The NMO^{15}N pool was 1.2 times greater under ZT (Table 2.5 and Fig. 2.3a and 2.3b). By the fifth leaf stage of the crop, three weeks after fertilization, this pool of residual ^{15}N had already been established with the ratio of NMO^{15}N:biomass ^{15}N approaching 3 for the ZT system and 1.5 for the CT. This pool which contained 20 to 25% of the original label, remained stable for the rest of the growing season. Part of the mineral ^{15}N which had moved down to lower depths under ZT was also converted to organic forms in the second and third depths.

Table 2.5. Percent ^{15}N Recovery in the Soil Compartments Under Conventional and Zero Tillage (means of 3 reps)

N Compartment	Depth (cm)	Feeke's Growth Stage[e] 2	10.4	11.2	11.4
		Percent Recovery Under Conventional Tillage			
Total	0 - 5	72.2a	0.9d	0.4d	0.3d
Mineral N	5 - 15[f]	1.9d	0.1d	0.3d	0.32d
	15 - 30[f]	0.9d	0.1d	0.1d	0.1d
Microbial N	0 - 5	12.8a	1.9	3.0c	2.4d
	5 - 15	0.4d	0.3d	0.9d	0.6d
	15 - 30	0.1d	0.2d	0.2d	0.2d
Non-Microbial	0 - 5	17.4a	23.0a	23.1a	20.1a
Organic N	5 - 15[f]	2.9bc	2.7bc	3.1bc	5.1bc
	15 - 30	-	0.8c	0.7c	0.8c
		Percent Recovery Under Zero Tillage			
Total	0 - 5	63.3b	0.4d	0.4d	0.4d
Mineral N	5 - 15[g]	12.3c	0.2d	0.3d	0.1d
	15 - 30[h]	0.2d	0.1d	0.0d	0.1d
Microbial N	0 - 5	6.9b	2.0d	3.6c	2.5cd
	5 - 15	1.7d	0.5d	0.8d	0.6d
	15 - 30	0.2d	0.3d	0.3d	0.3d
Non-Microbial	0 - 5	18.0a	20.5a	22.7a	20.6a
Organic N	5 - 15[g]	8.4b	7.4bc	4.3bc	6.2bc
	15 - 30[h]	-	4.9bc	1.6bc	1.6bc

Source of Variation	df	Mean Square of ANOVA[i] Mineral ^{15}N	Microbial ^{15}N	Non-Microbial Organic ^{15}N
Block	2			
Tillage	1	2.9×10^{-3}	1.546	43.50*
Error 1	2	6.092	0.137	2.578
Date	3	1964***	29.66***	0.928
Till x Date	3	0.050	3.020*	6.751
Error 2	12	18.37	0.631	7.706
Depth	2	1192***	121.8***	2019***
Till x Depth	2	23.75	4.376***	8.720
Date x Depth	6	1688***	26.03***	10.90
Till x Date x Depth	6	31.18	5.887***	7.021
Error 3	32	42.10	0.657	18.14

a, b, c, d Same lowercase letter indicates no significant difference between tillage treatments at a given date or depth ($p<0.05$)

e Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987

f n=2 rather than n=3, for 1st and 2nd date

g n=2 rather than n=3, for 3rd date

h n=2 rather than n=3, for 2nd, 3rd and 4th date

i The difference between means is significant at; *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$

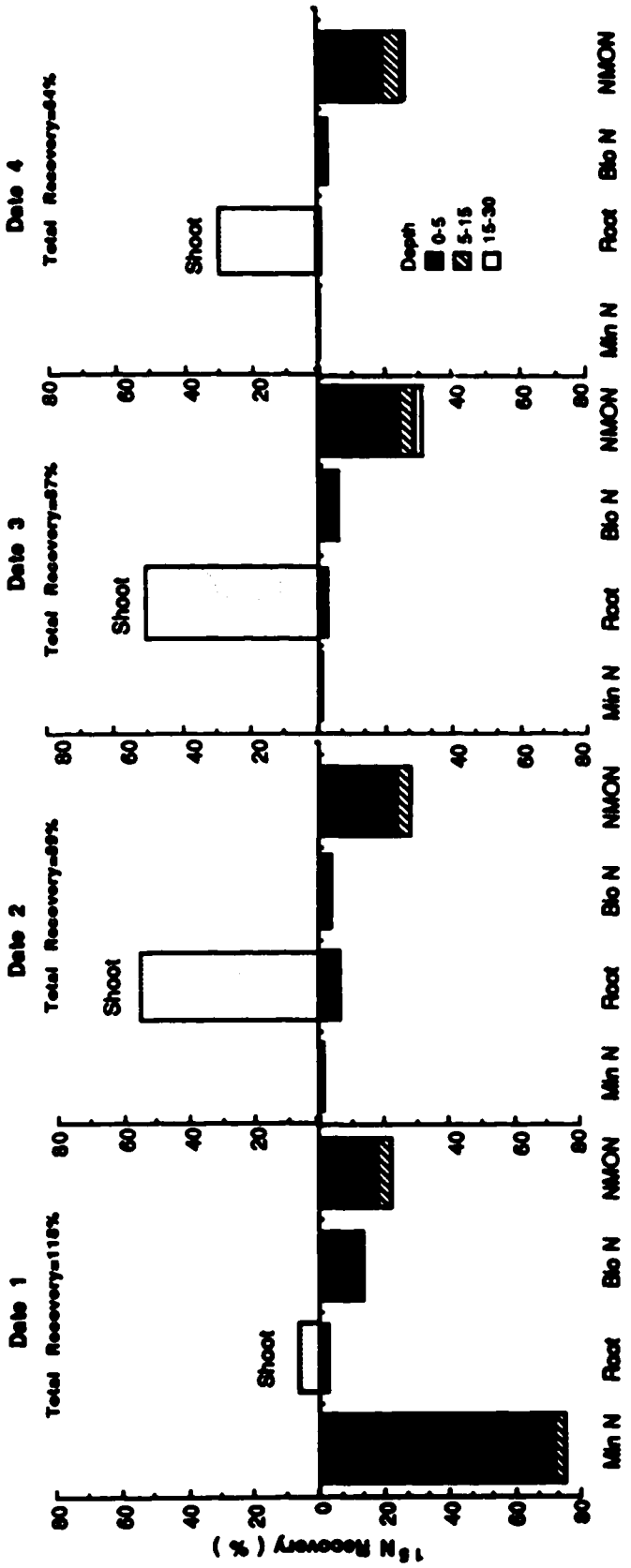

Figure 2.3a.^{15}N Dynamics in the N pools under Conventional tillage

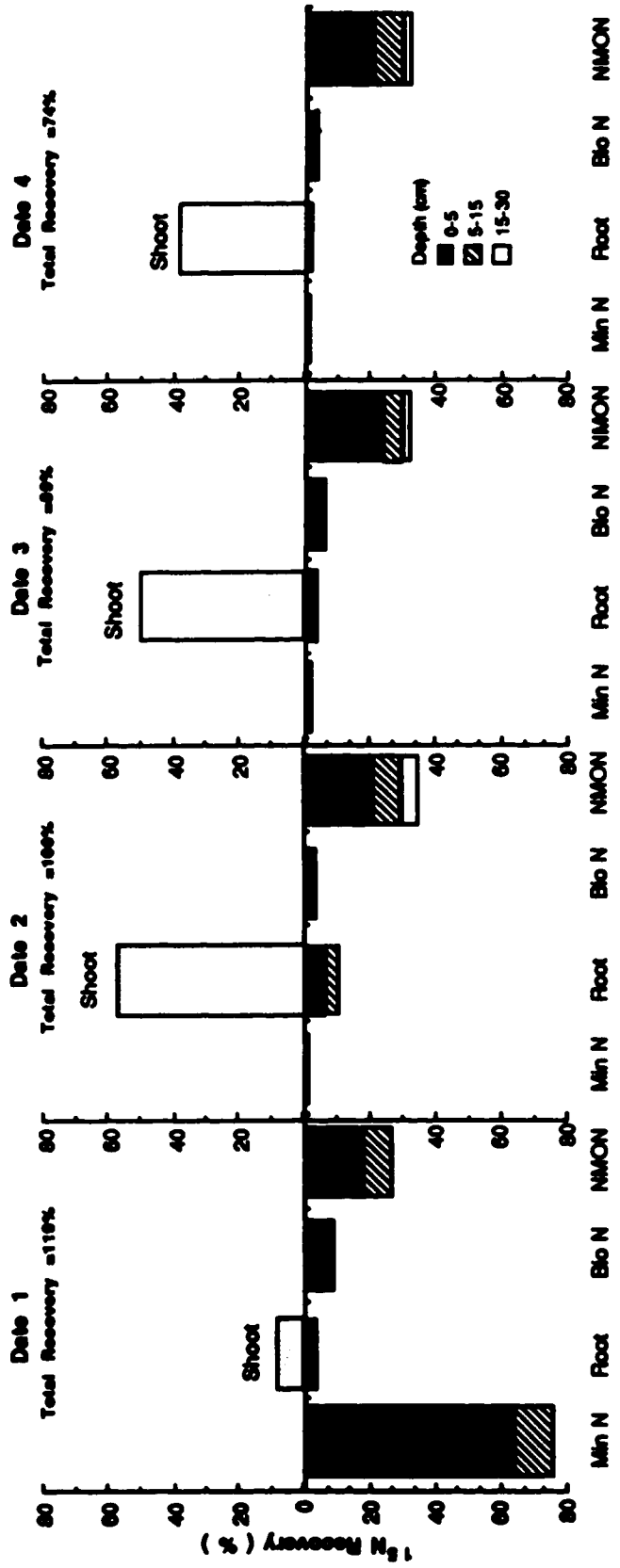

Figure 2.3b. ^{15}N Dynamics in the N pools under Zero tillage

Discussion

Plant Nitrogen Dynamics

Temporal discontinuity between plant demand and nitrogen application, along with the altered conditions imposed by the two systems, led to differences in the distribution and dynamics of nitrogen in barley, mineral and organic N pools as well as plant fertilizer utilization within the plant-soil system. The development of a cereal plant is highly influenced by environmental factors and the particular variety chosen (Blake, 1965). In order for the plant to progress physiologically, it is essential that the right combination of photoperiod, thermoperiod and available nutrients be present. The fifth leaf stage of the crop in this study approximately coincided with the beginning of the double ridge or reproductive phase of the plant. It is essential that environmental factors be adequate at this stage because the bud or spikelet primordia are being laid down (Blake, 1965). Thus at the fifth leaf stage, the plant began to draw upon the nitrogen and other nutrient reserves in the soil. Shoot N was low at this date but the ^{15}N data showed that approximately 8% of the fertilizer had been utilized by this point (Fig. 2.3a and 2.3b). The fifth leaf stage occurred almost one month after fertilization, a time when plant demand was low and hydrolysis of urea was probably complete.

The increase in shoot nitrogen and mass between the fifth leaf and ear emergence phase indicated the demand by the plant on its environment, in particular, light, water and nutrients. The decline in soil water content despite recent rainfall and maximal root masses in all depths on this date further showed that a large root mass was needed to explore the soil and obtain sufficient nutrients and water to meet the plants' requirements for internode elongation and ear development. The high recovery of ^{15}N in shoots and roots at ear emergence demonstrated the dramatic uptake of available nitrogen by the plant from the soil mineral N pool at this phase in the development (Fig. 2.3a and 2.3b).

Shoot N levels continued to increase on the third date while root N levels declined as the grain was being filled. Plant uptake was essentially complete by this stage and levels of N in the plant material either declined or remained stable until harvest. Favorable moisture conditions due to a substantial rainfall event (55mm two days earlier) near the third sampling date created a flourish of microbial and faunal activity.

As cereal plants ripen, both nitrogen and carbohydrates from fresh photosynthate and metabolic carbon residing in the various senescing organs of the plant, are shunted to the grain (Blake, 1965). Structural carbon is lost in the senescing tissues and therefore a decline in above ground mass usually occurs towards harvest. Shoot C:N levels in the two systems show the conservation of nitrogen relative to carbon in the maturing plants. The values gradually widened as the plants developed but narrowed towards the end of the season as grain nitrogen was formed and lower leaves senesced. Although measured shoot N levels did not differ between tillage systems, there was a general trend for narrower shoot C:N ratios in the CT system. This trend for more N enriched plant tissues was also seen in the shoot concentration values under CT (especially in the latter stages of the season). The ^{15}N data also support this trend through the significant decline in the recovery of ^{15}N from date 3 to date 4 under CT. The decline in ^{15}N recovery was assumed to be due to a greater volatilization of ^{15}N-NH_3 and other amines from plant tissues upon senescence of the lower leaves. Those plants which experience the greatest losses towards harvest, tend to be those which have the greatest N accumulation in their tops at anthesis (Wetselaar and Farquhar, 1980; Myers et. al, 1989). This phenomenon, in conjunction with higher ammonium levels, the trends in shoot concentration and shoot C:N ratios, as well as an observed developmental lag by the crop under CT of around 5 to 7 days (in comparison to the ZT plants) seemed to indicate that there was more plant available N under the CT system. In a parallel study grain N uptake and content were significantly higher under CT with grain N contents of 8.1 g m^2 and 6.6 g m^2 for CT and ZT respectively (M. Nyborg, pers. comm.). The presence of a surface thatch,

moister environment, higher levels of denitrifiers, slower rates of mineralization and greater propensity for increased immobilization can contribute to lower levels of plant available N under ZT (House et al, 1984; Doran et al, 1987). The plant itself can act as a continuous monitor of the net results of MIT, accumulating mineral N as MIT proceeds. This study has shown that the MIT in the CT system resulted in net mineralization throughout the season, cycling mineral N in such a manner that the plant was able to accumulate levels above those of ZT.

Soil N Dynamics

Approximately 75% of the fertilizer still remained as mineral N at Feeke's stage 2 and the ZT system exhibited a significant movement of mineral ^{15}N into the second depth. This may have been due to differences in the soil physical environment created under ZT management. Less disturbance of the soil creates an open and continuous network of macropores yielding faster infiltration rates (Mielke et al, 1984; Grevers et al, 1986; Francis et al, 1987). Despite continuing reports of greater porosity under CT systems, there appears to be a greater preponderance of elongated pores between the sizes of 30 to 500 μm under ZT (Sequi et al, 1985). This altered physical structure may be due to a combination of less disturbance and earthworm activity (Lal and Akinremi, 1983) as a greater amount of the soil fabric had been worked by earthworms under ZT (R. Drijber, pers. comm.). This phenomenon may be responsible for the greater movement of fertilizer into the second depth.

The higher levels of ammonium under CT make it particularly susceptible to processes such as nitrification and subsequent denitrification and leaching. Nitrification occurred and NO_3^- was translocated downwards under ZT. The legacy of this movement remained in the non-microbial organic nitrogen (NMON) form. The NMON represents a fraction which is separate and distinct from the microbial biomass and is regarded as the end result of the activity of the microbial biomass, containing labile N as well as stabilized N. The

NMON pool had already been established by this point at approximately 20-25% and was greater under ZT (Fig. 2.3a and 2.3b). The high recovery of ^{15}N in the microbial biomass on the first date showed that N was immobilized by the microbes. Therefore those crucial 4 weeks from fertilization/seeding to initial plant uptake left the large mineral N pool susceptible, allowing the competing factors in the system to partition and allocate part of the mineral N into more "stable, conservative" organic forms. The total recovery of ^{15}N for the plant-soil system indicated that despite the lag between plant demand and fertilizer hydrolysis, almost complete recovery occurred at this date. More than complete recovery on the first date is a common methodological problem (Legg and Meisinger, 1982) and probably reflects problems of isotope exchange during N transformations, both biological and chemical (Stevenson, 1982), a patchy distribution of label on the first sampling date, as well as the variability inherent in adding separately determined pools. Rainfall over this 4 week period was light (20 mm total) which probably prevented any significant leaching or denitrification of mineral N from occurring. ZT systems, with their higher populations of denitrifiers, are particularly susceptible to denitrification and had the climatic variables been different, greater losses may have been apparent (Doran, 1980).

Mineral N and ^{15}N analysis showed the concomitant drop from date 1 to date 2 as the system partitioned this pool into the various components. A three-fold drop in recovery of soil ^{15}N occurred from date 1 to date 2 and was largely due to plant uptake but total recovery indicated a significant loss under CT to the soil-plant system overall. This loss may in part be due to the larger ammonium pool under CT, plus more fertilizer remaining in the top depth where losses of mineral N could occur through volatilization and denitrification. The microbial N pool declined on this date presumably due to the strong interaction of the plant and its demands on water and nutrients with the soil's water and mineral reserves. The amount of label in the microbial biomass coupled with the lack of a significant increase in the NMON pool, also reflects the biomass' lowered activity as the plant's demands and

subsequent activities overrode those of the soil organisms. By this second date then, the eventual partitioning of the fertilizer had been determined, with a large percentage recovered in organic forms and a large percentage in plant material. The ratio of NMON ^{15}N:microbial biomass ^{15}N increased over the season as the organic forms were formed. The ZT system exhibited higher conversion to organic ^{15}N forms presumably due to the larger amount of mineral fertilizer that moved into the second depth and was immobilized by the biomass to organic forms. Carter and Rennie (1987) found similar results with their ZT system immobilizing two times as much fertilizer than the CT system they examined. The significant drop in total recovery of ^{15}N from date 1 to date 2 under CT was probably a result of the larger, more susceptible ammonium pool, near the surface in the upper depth in this system.

The third date exhibited a flourish of activity, especially in the top layer of both systems, in response to the favorable moisture conditions generated by the recent heavy rainfall (see Fig. 2.1). The microbes reimmobilized some of the recently stabilized ^{15}N in the active fraction and as a result higher recoveries in the microbes occurred in the top layer on the 3rd date. The rest of the system remained unchanged as far as redistribution of N. The loss of ^{15}N in the ZT system between date 1 and date 3 may have been a result of the flourish of microbial activity on the third date, a net MIT and subsequent denitrification since these systems are characterized by high populations of denitrifiers (Doran, 1980).

Carter and Rennie (1987) found that the release of residual fertilizer ^{15}N in their CT system was three times that of the ZT system even though the ZT system had a higher amount of potentially mineralizable N. The ZT system released mineral ^{15}N at a much slower rate, therefore less plant available N occurred in their ZT system. These researchers also found that the ZT system had 96% more residual N bound in the NMON pool. The NMON pool in this study, despite the apparent mineralization of organic forms, remained fairly stable even until harvest. This pool, which is established shortly after urea hydrolysis and when

plant competition for mineral N is low, accounted for almost 50% of the remaining added N in the system. Stevenson (1982) indicates that this pool can remain in the soil for several decades. Jansson (1963) through the use of first order kinetics predicted that the half life for the residual ^{15}N in soil would be approximately 15 years. Legg and Allison (1967) found that the residual ^{15}N uptake can range from 10-41% of the residual fertilizer N.

This pool then, accounts for a major portion of the fertilizer which is subject to a slow mineralization process over subsequent cropping years and a slow stabilization process which makes it relatively unavailable to plants over time. Most studies account for the increased immobilization of fertilizer and subsequent conversion to NMON forms under ZT as due to the increased biomass and/or thatch layer at the surface of these soils (Doran,1980; Rice and Smith, 1984; Fredrickson et al, 1982; Carter and Rennie, 1987). In this study however, biomass levels were similar between tillage treatments at all depths. The cause for greater immobilization in this case appeared to be the increased movement of mineral fertilizer N in to the lower depths where it was immobilized and converted to NMON forms. Doran (1980) has attributed differences in biomass to the moister environment and thatch layer existing under ZT. In central Alberta, moisture is not always the limiting factor therefore a difference in microbial biomass was not seen. In addition, residue management was an important feature of both systems, not just ZT like most of the studies concerning tillage. If fertilizer placement had been broadcast rather than a solution injection, differences in crop yield may have become apparent (Doran, 1982; Carter and Rennie, 1984; House et al, 1984).

System Level Dynamics

The standing stocks of the various N compartments measured in this study indicated that by the end of the season, both systems were extracting more nitrogen than was allocated by the fertilizer addition (Table 2.6). The amount of ^{15}N relative to ^{14}N in shoots on the first date under CT and ZT reflect the differences in plant available N in the systems and demonstrate the large proportion of plant N derived from native organic matter, especially under CT. Insight into the dynamics of ^{14}N and ^{15}N is shown by the mineral and soil N isotope comparisons (Table 2.6). For most of the eason, the majority of the N present in the mineral N pool is derived from the native organic matter. This emphasizes the substantial N supplying power of the large soil N reserves in the Black Chernozem. Shoot N, the continuous montior of the net processes of MIT, showed that the amount of native N in the crop at the end of the season is more than double the N derived from fertilizer. The resultant partitioning and plant recovery at harvest of added fertilizer, even at such a low rate, shows how the systems responded through their inherent subsystem feedbacks, to a large mineral N addition at a time when plant demand was low.

Although separate grain and straw analyses were not performed on shoot material in this study, data from the larger plot study indicated that the grain:straw ratio for N content would yield shoot N values of 7.6 g m^{-2} under CT and 5.6 g m^{-2} under ZT (Based on third date values;maximum N content). The fertilization rate was 5.87 g m^{-2} therefore the CT system showed almost a 2 g m^{-2} export from then system whereas the ZT system was more conservative.

Considering the fertilizer application and residue placement methods in this study, it is not surprising that explicit, significant differences in shoot N were not apparent. Most tillage studies compare moldboard plowing with minimum tillage (shallow discing) or ZT (seed drilling with no other disturbance). In addition, broadcasting is the usual method of

Table 2.6. Differences Between the Partitioning and Dynamics of Shoot Nitrogen in the Two Systems (all units are in g m^{-2} to a depth of 15 cm)

Variable	Feeke's Growth Stage[a]			
	2	10.4	11.2	11.4
	Conventional Tillage			
Shoot N	1.1	7.7	10.6	7.6
Shoot ^{15}N	0.4	3.2	3.1	2.0
Shoot ^{14}N	0.7	4.5	7.5	5.6
Root N	0.44	1.02	0.75	0.55
Root ^{15}N	0.11	0.21	0.16	0.11
Root ^{14}N	0.33	0.81	0.59	0.44
Mineral N	7.80	0.70	0.60	1.00
Mineral ^{15}N	4.33	0.05	0.03	0.03
Mineral ^{14}N	3.47	0.65	0.57	0.97
Microbial N	5.74	4.48	7.04	6.49
Microbial ^{15}N	0.77	0.14	0.23	0.18
Microbial ^{14}N	4.97	4.32	6.81	6.31
Soil N	649.36	692.19	637.82	713.81
Soil ^{15}N	6.28	1.69	1.80	1.68
Soil ^{14}N	643.08	690.50	635.93	712.13
	Zero Tillage			
Shoot N	1.3	7.6	8.1	7.8
Shoot ^{15}N	0.8	3.4	3.0	2.3
Shoot ^{14}N	0.5	4.2	5.2	5.5
Root N	0.46	1.23	0.59	0.46
Root ^{15}N	0.16	0.32	0.19	0.11
Root ^{14}N	0.30	0.91	0.40	0.35
Mineral N	8.60	0.80	0.80	0.80
Mineral ^{15}N	4.45	0.03	0.04	0.03
Mineral ^{14}N	4.15	0.77	0.76	0.77
Microbial N	6.03	4.08	6.50	5.60
Microbial ^{15}N	0.53	0.15	0.26	0.19
Microbial ^{14}N	5.51	3.94	6.25	5.42
Soil N	771.25	777.37	673.89	639.38
Soil ^{15}N	5.39	1.82	1.90	1.79
Soil ^{14}N	765.86	775.55	671.92	696.59

fertilizer application, especially in ZT treatments. Therefore studies which have greater contrast in methods of fertilizer application and residue placement are apt to have exaggerated differences in N cycling. This study took a conservative approach, choosing an 8-year old system of CT which involved residue retention, shallow discing and liquid urea injection and compared it to a ZT system of the type used in most studies. It can be seen then that from this study, fertilizer placement is critcal in order to obtain comparable yields. The larger plot study (M. Nyborg., pers. comm.) indicated significantly higher yields under CT with incorporated urea, whereas in this study, with urea injection, yields were quite similar. The deviations in results of the various studies indicate the need for a manager to closely examine the type/timing of fertilizer application and residue placement in the particular cropping/ tillage system. ZT systems have the potential of conserving N.

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Chapter 3 Agroecosystem Structure and Response under Conventional and Zero Tillage

Introduction

E. P. Odum (1969), in analyzing ecosystem development and function, describes the ultimate strategy of an ecosystem is one of increased control of and homeostasis with the physical environment. Only then can an ecosystem achieve maximum protection from environmental perturbations. Temperate, natural grasslands undergo uninterrupted seasonal successions which allow for intimate associations and reciprocal adaptations between the interacting members of the below ground detrital food web. As a result, complex and diverse soil community subsystems have evolved in these systems (House, et al, 1984). As ecosystems evolve towards maturity, the P:R ratio (production:respiration) gradually decreases due to a less energetically wasteful system developing (Odum, 1969; Insam and Haselwandter, 1989). The later study validated Odum's original hypothesis on ecosystem development by finding a decline in the metabolic quotient over time in successional ecosystems. Conversely, agroecosystems with their typical, frequent perturbations in the form of mechanical disturbances, fertilization and other disruptive management practices are production oriented with high P:R (production:respiration) ratios. Odum (1984) designates the term "A-selected" (allocation selected) for those organisms found in managed ecosystems as they are adapted to stochastic environments. These organisms are typically smaller, have shorter generation times, are less diverse, require rapid dispersal mechanisms, omnivorous feeding habits and have an overall more oxidative metabolic status when compared to organisms in cultivated systems (Doran, 1980; Andren and Lagerlof, 1983; Ryszkowski, 1985; Hendrix et al, 1986).

Reduced tillage systems resemble the natural grassland situation where the solum features a stratification of physical, biological and chemical properties. Organic matter, nutrients and soil organisms are concentrated at the surface rather than distributed through the plow layer. The control of residue placement and degree of soil disturbance under ZT essentially regulates the biological community; its location and its activity, via substrate accessibility and spatial organism habitat (Doran et al, 1987). As a result, reduced tillage systems typically have greater nutrient retention, lesser organic matter mineralization and greater immobilization of fertilizer N (House et al, 1984; Groffman et al, 1986; Doran et al, 1987; Coleman and Hendrix, 1988).

This study was designed to: (i) determine if after 8 years, there were differences in the distribution and overall concentrations of organic matter, soil microbial biomass and soil faunal populaitons in ZT and CT systems in central Alberta, and (ii) compare the metabolic status of the two soils and assess the quality and activity of the food webs. We took an ecological approach in examining the functional interactions between microbes, fauna and plants in the soil systems. Ecosystem structure and response were studied at several levels, in order to understand differences between the systems.

Materials and Methods

Soil and Site Description

This is presented in Chapter 2.

Experimental Design and Sampling Procedure

This is presented in Chapter 2.

Analyses

Above-and below-ground plant material was dried at 70 °C, weighed and ground to 10 mesh with a Wiley mill. Plant material was further ground in an ultra high speed mill for C determinations. A Leco Carbon Determinator model CR-12 was used to analyze for C contents of shoot and root material from the 0 - 5 cm and 5 - 15 cm depth increment.

Protozoa, nematode and microarthropod determinations were performed on field moist, unsieved soil within a day or two of sampling. Duplicate 25g samples of sieved soil (2 mm), adjusted to 55% water holding capacity, was used for microbial C and N determinations. The formula $B_c = F_c/k_c$ was used to estimate the microbial biomass C, where F_c is the difference between the amount of CO_2-C evolved from the fumigated soil in 10 d less that evolved from the unfumigated soil in the same period (Jenkinson and Powlson, 1976). This flush of CO_2-C was divided by a k_c of 0.411 to estimate microbial biomass C (Anderson and Domsch, 1978). Microbial respiration was estimated from the 10 d incubation of the unfumigated sample. Microbial N was estimated after Shen et al (1984), using the formula $B_n = F_n/k_n$ where F_n is the difference between mineral N (NH_4-N· and NO_3-N·) in fumigated soil less that in unfumigated soil for 10 d. A k_n factor of 0.68 was used to determine microbial biomass N.

The protozoa were determined by adding 20 g of moist soil to 100 ml of 3% soil extract. This initial stock solution was then serialy diluted to 10^{-8} strength with 5 tubes made at each dilution (Stout et al, 1982). The tubes were incubated at room temperature for 1 week, after which aliquots of each culture were analysed in a microtitre dish with a Lietz inverted microscope. Tubes were scored negative or positive and then rescreened two weeks later for slow growers. The results of the analysis were compiled using an MPN software program designed by Clarke and Owens (1983).

Nematodes were extracted from soil using a modified petri plate method (C.C. Mishra, pers. comm.). Fresh soil was placed upon a moistened double layer of tissue suspended by a metal screen over a quiescent layer of tap water in the bottom of a 15 cm petri dish. Petri plate lids were used to maintain a high humidity. At the end of three days, the water layer containing the extracted nematodes was collected, subsampled and analysed under a stereo microscope. The nematodes were counted and separated on the basis of development into adults and juveniles.

Microarthropods were extracted from 50g soil samples, collected in ethylene glycol and enumerated with the aid of a stereo microscope (Berg and Pawluk, 1984). The animals were broadly categorized into acari and collembola groupings and then separated into their respective suborders. The suborder data will not be presented here.

All results are expressed in concentration units of g m^{-3} or individuals m^{-3}. To convert data to $\mu g\ g^{-1}$ or individuals g^{-1}, divide by the bulk density of the appropriate depth (Table 2.1). To convert data to g m^{-2} or individuals m^{-2}, multiply the values by the appropriate thickness (in meters) of the soil layer.

Statistical Analyses

The data were analysed on a microcomputer version of S.A.S.® using procedure General Linear Model for analysis of variance. ANOVA was used to test for the presence of any significant tillage, depth or date effects. Due to the presence of heterogeneous variances within some of the fauna data, log 10 (x+1) transformations were performed on protozoan, collembolan and acari populations.

Results

Plant Dry Matter and Carbon Trends

There were no tillage effects in any of the examined plant trends (Table 3.1). However, the barley in the ZT plots was physiologically advanced by 5 to 7 days leading to an onset of the reproductive phase at an earlier date compared to CT. Shoot masses followed the typical sigmoidal trend with a rapid increase up to the ear emergence phase, a maximum mass during grain filling and declined as the plants matured. Shoot C showed similar trends (Table 3.1). Root mass and root carbon levels both peaked on the second date, and gradually declined until harvest (Table 3.1). Both root mass and carbon levels were greatest in the top layer and at the ear emergence phase extended to a greater degree into the second depth (Table 3.1).

Soil Microbial Biomass and Faunal Populations

Microbial biomass carbon and nitrogen appeared not to be affected by tillage (Figure 3.1 and Table 3.2). Microbial biomass carbon declined with depth and decreased on the third date. This drop in biomass C may have been due to methodological problems. The soil samples on date three were wet and sieving compressed the 2 mm peds hindering penetration of chloroform and/or inhibiting carbon dioxide evolution from the fumigated samples (Ross, 1988). Biomass N measurements were not affected by the wet sieving problems since the flush of mineral N (NH_4^+-N and NO_3^--N) does not depend upon the aerobic status of the soil and most nitrifiers were killed during fumigation. Therefore biomass N may be a better indicator of the trends in biomass over the growing season. The microbial biomass N fluctuated over the growing season, reflecting the moisture status of the soil. Biomass N declined gradually with depth in both systems. It nearly doubled in size on the third date in the top depth, in response to the favorable moisture status.

Table 3.1. Shoot and Root Mass and Carbon Levels in Conventional and Zero Tillage Plots (means of 3 reps)

Variable (g m^{-2})	Depth (cm)	Feeke's Growth Stage[a] 2	10.4	11.2	11.4
		Conventional Tillage			
Shoot mass		22	462	830	628
Shoot C		8.2	189.5	348.9	253.0
Root mass	0 - 5	12.5	60.0	62.0	39.0
	5 - 15	9.0	18.0	10.0	5.0
	15 - 30	4.5	7.5	4.5	3.0
Root C[d]	0 - 5	4.5	21.5	23.5	16.5
	5 - 15	3.0	9.0[b]	4.0	2.0
		Zero Tillage			
Shoot mass		24	507	762	711
Shoot C		8.9	211.1	328.3	296.1
Root mass	0 - 5	14.0	62.5	59.0	38.5
	5 - 15	7.0	21.0	7.0	5.0
	15 - 30	6.0	7.5	6.0	6.0
Root C[d]	0 - 5	5.0	23.0	23.5	13.5
	5 - 15	3.0[b]	8.0	2.0[b]	2.0

Source of Variation	df	Mean Square of ANOVA[c] Shoot mass	Shoot C	Root mass	Root C
Block	2				
Tillage	1	1445	750	0.085	0.340
Error 1	2	1913	316	1.262	0.538
Date	3	$6.9 \times 10^{5***}$	$1.2 \times 10^{5***}$	48.410***	9.102***
Till x Date	3	6281	1125	0.329	0.129
Error 2	12	3690	689	1.963	0.749
Depth	2			526.3***	75.98***
Till x Depth	2			0.181	0.140
Date x Depth	6			38.14***	6.503***
Till x Date x Depth	6			0.280	0.441
Error 3	32			2.629	0.337

a Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987.

b n=2 rather than n=3

c The difference between means is significant at: *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$

d Since root C was measured for 2 depths, the degrees of freedom are depth (1), till x depth (1), date x depth (3), till x date x depth (3) and error 3 (16)

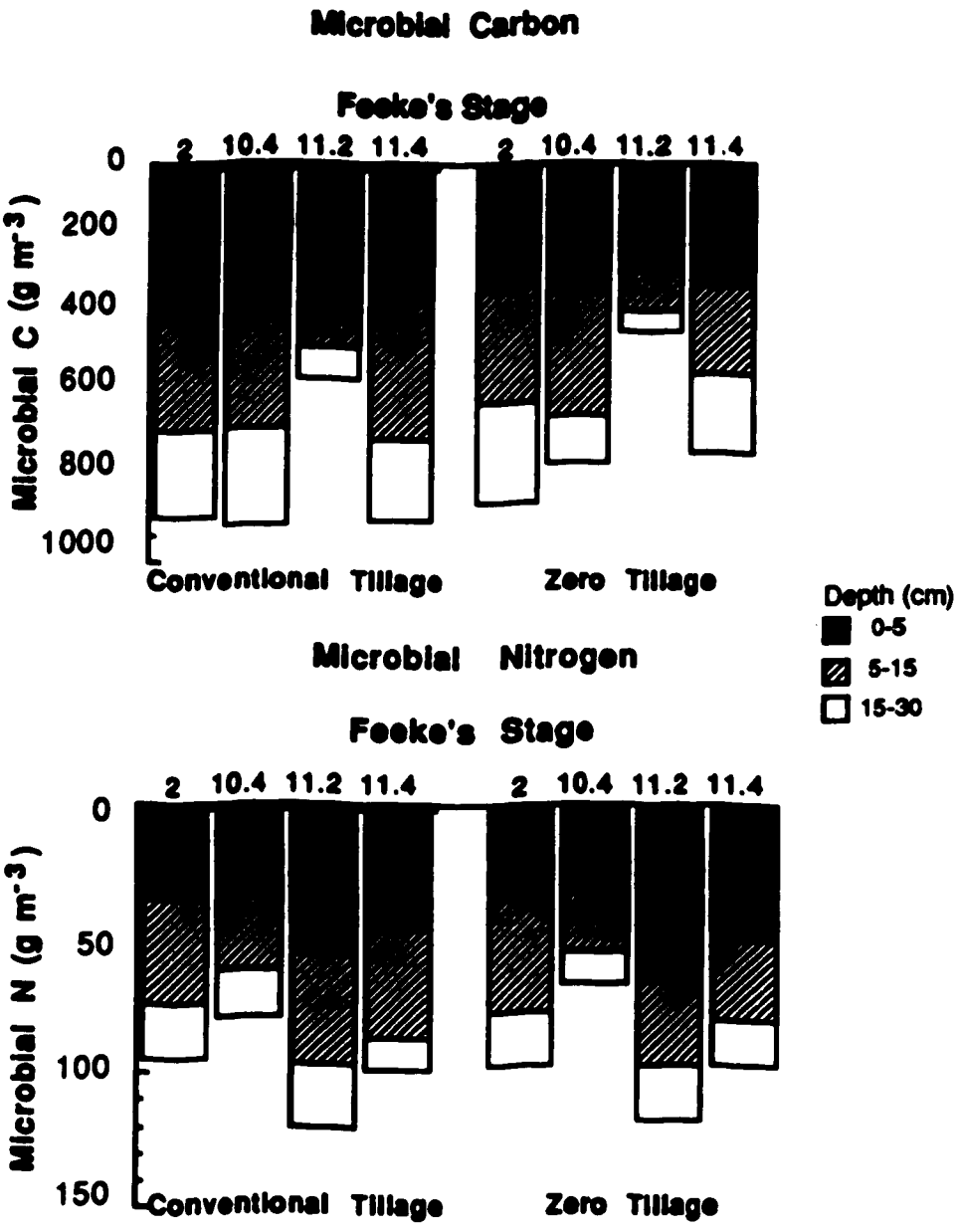

Figure 3.1. Seasonal Microbial C and N in Zero and Conventional Tillage Systems

Table 3.2. Mean Squares and Level of Significance[a] for Microbial C and N and Soil Fauna

Source of Variation	df	Biomass N	Biomass C	Protozoa[b]	Adult Nematodes	Juvenile Nematodes	Acari[b]	Collembola[d]
Block	2							
Tillage	1	3.25×10^{-3}	1.999	0.925*	5.6×10^{5}**	5.3×10^{9}	1.103*	1.148
Error 1	2	0.032	1.266	0.055	2.6×10^{8}	4.5×10^{9}	0.103	0.481
Date	3	0.073***	6.713***	1.712***	6.0×10^{10}[i]	1.0×10^{10}[i]	0.603	0.804
Till x Date	3	2.20×10^{-3}	0.074	0.078	6.5×10^{9}	2.7×10^{9}	0.197	0.543
Error 2	12	0.279	0.282	0.279	2.2×10	3.1×10^{9}	0.166	0.942
Depth[c]	2	0.428***	13.68***	7.105***	1.4×10^{12}***	1.4×10^{10}**	15.96***	10.40***
Till x Depth[c]	2	6.69×10^{-3}	0.450	1.737*	9.7×10^{10}**	2.6×10^{9}	0.935[i]	0.226
Date x Depth[c]	6	0.030***	0.480	0.149	1.2×10^{10}	1.6×10^{9}	0.247	1.470[i]
Till x Date x Depth[c]	6	6.95×10^{-3}	0.472	0.500	5.6×10^{9}	8.5×10^{8}	0.194	0.454
Error 3[c]	32	7.49×10^{-3}	0.854	0.426	1.7×10^{10}	2.1×10^{9}	0.383	0.722

[a] The difference between means is significant at; [i], $p<0.10$ *, $p\leq0.05$; **, $p\leq0.01$; ***, $p\leq0.001$

[b] Determined on transformed counts (log10 (no./m^2))

[c] Since protozoa were measured for 2 depths, the degrees of freedom are depth (1), till x depth (1), date x depth (3), till x date x depth (3) and error 3 (16)

[d] Determined on transformed counts (log10 (x+1)) before conversion to m^2 as zero counts were obtained

The protozoa populations in ZT were 6.35 times greater than in the CT system (Figure 3.2 and Table 3.2). Both systems reacted similarly in fluctuations over the growing season and exhibited an inverse relationship to soil water content. The populations in the top layer were 30 times higher than the second depth. The ZT system had a greater amount of protozoa in its top depth than the CT system.

Overall, adult nematode populations were higher in CT than ZT (Figure 3.2 and Table 3.2). The nematode populations in CT and ZT differed with respect to their distribution within the soil.m. Nematodes were higher in the surface layer under ZT and declined much more steeply than CT. The second depth under CT was enriched with nematodes, and the overall distribution declined more gradually with depth. The population trends over the season roughly followed the soil moisture conditions. Juvenile nematodes were abundant at the beginning of the season, with a trend for higher numbers under ZT and gradually declined towards season's end.

On average acari were 1.2 times greater under ZT with the majority of the difference occurring in the top layer (Figure 3.3 and Table 3.2). This group remained fairly stable over the growing season, exhibiting less dependence on soil moisture. The collembolan populations were similar under both systems and did not fluctuate to any great extent over the growing season (Figure 3.3 and Table 3.2). The majority of the individuals existed in the top layer, declining with depth.

Soil Community Activity

Overall, $C0_2$-C evolution under laboratory incubations was not different from soil samples obtained from ZT and CT systems (Table 3.3). However, levels from individual depths indicated that there was a difference in activities of certain layers in the two systems The top layer under ZT had consistently higher activities throughout the growing season than

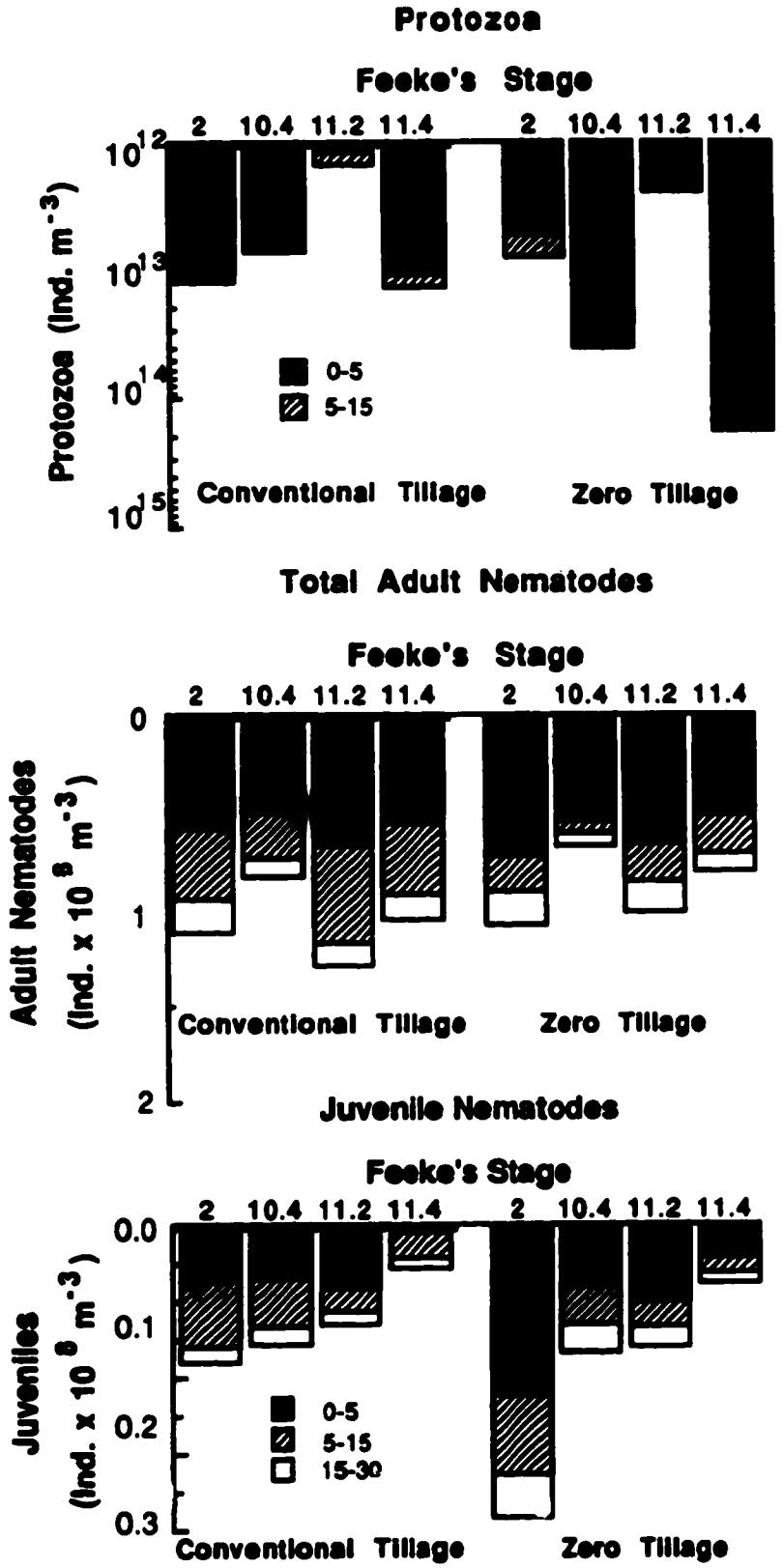

Figure 3.2. Seasonal Protozoan and Nematode Dynamics in Conventional and Zero Tillage Systems

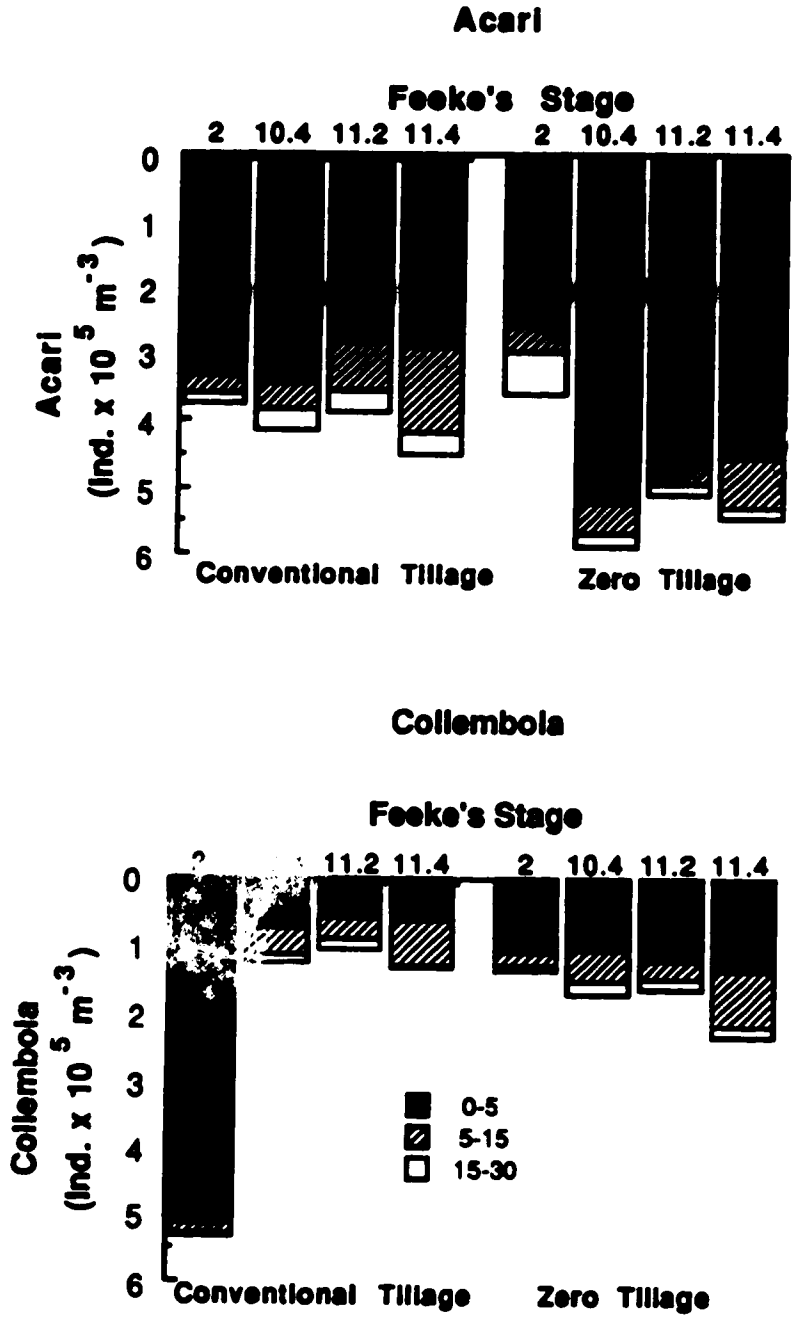

Figure 3.3. Seasonal Collembolan and Acari dynamics in Conventional and Zero tillage systems.

Table 3.3. Soil Community Activity over 10 day Incubations of Soil Samples From Conventional and Zero Tillage Systems (means of three reps)

Variable	Depth (cm)	Feeke's Growth Stage[a] 2	10.4	11.2	11.4
		Conventional Tillage			
CO_2-C Evolved ($g\ m^{-3}$)	0 - 5	87	89	148	137
	5 - 15	36	74	138	123
	15 - 30	17	24	77	55
Net N Mineralized ($g\ m^{-3}$)	0 - 5	133	13	5	15
	5 - 15	19	6	4	12
	15 - 30	14	5	2	5
Biomass C: CO_2-C	0 - 5	4	4	2	2
	5 - 15	11	4	2	3
	15 - 30	5[b]	29	3	4
		Zero Tillage			
CO_2-C Evolved ($g\ m^{-3}$)	0 - 5	115	92	184	186
	5 - 15	34	38	96	93
	15 - 30	3[b]	30	86	66
Net N Mineralized ($g\ m^{-3}$)	0 - 5	134	9	7	18
	5 - 15	29	7	5	10
	15 - 30	18	5	3	5
Biomass C: CO_2-C	0 - 5	2	3	1	2
	5 - 15	12	29	3	3
	15 - 30	24[b]	14	1	3

Source of Variation	df	Mean Square of ANOVA[c] CO_2-C Evolution	Net N Mineralized	Biomass C:CO_2-C
Block	2			
Tillage	1	1.07x-3	3.09×10^{-3}	605.7***
Error 1	2	0.157	2.73×10^{-3}	2.284
Date	3	2.330***	1.144***	852.8*
Till x Date	3	0.031	3.37×10^{-3}	355.6
Error 2	12	0.123	7.81×10^{-3}	195.9
Depth	2	4.469***	0.848***	815.6**
Till x Depth	2	0.481***	7.40×10^{-4}	259.2
Date x Depth	6	0.068	0.590***	241.0
Till x Date x Depth	6	0.046	1.37×10^{-3}	475.6*
Error 3	32	0.084	4.05×10^{-3}	144.1

[a] Feeke's stages correspond to June 18th, July 21st, August 10th and September 9th, 1987.

[b] n=2 rather than n=3

[c] The difference between means is significant at: *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$

CT. By contrast, the second depth under CT evolved more CO_2-C than the same depth interval under ZT. The soil community activity followed the same trends in soil moisture content, declining on the second date and peaking on the third.

The amount of net N mineralized was not affected by tillage (Table 3.3). Net N mineralization was very high at the fifth leaf stage of the crop, because of the large amount of available N and C and minimal plant competition. Levels dropped over the next two sampling dates with a slight increase on the fourth date.

The amount of biomass required to produce a unit of carbon dioxide was used to assess the relative activities of the two systems. On average, the CT system was 1.4 times lower than ZT indicating that less biomass was required to produce a similar amount of carbon dioxide (Table 3.3). The third date in both systems appeared to be the most active either as a result of the favorable moisture conditions or due to the exaggeration of activity from difficulties encountered in microbial biomass C measurements.

Discussion

System Level: Tillage Induced Differences

Differences between the two systems studied were related to residue placement and degree of soil disturbance. Despite similarities in seasonal organism dynamics, there were differences in the distribution of substrates and soil physical properties (Table 2.1) which led to changes in organism niche quality and subsequent community location. From a soil decomposer's perspective, the immediate physical environment in a ZT soil is moister, with a greater pore continuity, increased diversity of pore sizes and a stratification of substrates through the Ap horizon (Doran et al, 1987). Substrates are not distributed through the plow layer as in CT, but form a gradient from the surface downwards which limits the accessibility of reduced C under ZT (Doran et al, 1987). Lower accessibility and placement of residues

close to the surface resulted in greater C levels under ZT.

Larger soil fauna replace the role of tillage in distributing substrates in reduced tillage systems (House and Parmelee, 1985; Hendrix et al, 1986). ZT management favors earthworm populations which may increase nutrient flux and the biophysical alteration of soil fabrics (Barnes and Ellis, 1979; Coleman, 1985; House and Parmelee, 1985; Douglas, 1987; Anderson, 1988; Parmelee and Crossley, Jr., 1988). Hendrix et al (1987) attributed the main differences in faunal respiration to differences in earthworm biomass which was almost 5 times greater under ZT. Although earthworms were not counted in this study, micromorphological analyses performed on soil fabrics from the CT and ZT plots in this study indicated that more of the soil material under ZT had been worked by earthworms (R.Drijber, pers comm.).

Although the microbial biomass C data is shown, it is not likely that this is a reliable indicator of the true seasonal fluctuations in microbial biomass. Soils were very wet on date 3 and the sieving of wet soil often compresses the soil interfering with chloroform fumigation (Ross, 1988). Therefore the fumigated samples in this study evolved similar levels of CO_2-C as the unfumigated samples. This led to an underestimation of biomass C, especially on the 3rd date Based on microbial N levels, which are less susceptible to these problems (Ross, 1988) and CO_2-C evolution from unfumigated samples the 3rd date was indeed the most active date. Thus microbial biomass N appeared to be a better indicator of fluctuations than microbial biomass C. Most tillage studies find higher microbial biomass N levels or populations in the surface interval under ZT (Doran 1980; Carter and Rennie, 1987; Dormaar et al, 1987). These differences have been attributed to the moister environment and thatch layer existing under ZT (Doran, 1980). In central Alberta, moisture may not always be the limiting factor. In addition, no differences occurred in water content between the two systems therefore no differences in microbial biomass. It is also possible however that the top 5 cm

was too large a surface interval to detect changes in microbial biomass. Larger surface populations would have been obscured when diluted by the impoverished subsurface soil.

Protozoan populations were more than 6 times greater (20 times greater in the surface interval) under ZT. It is hard to conceive similar bacterial populations supporting such protozoan populations under both systems. I did not encounter any published accounts of higher population of protozoans under ZT. However, there are many studies which link earthworm activity to increased protozoan numbers (Bamforth, 1988). This increase in protozoa near the latter half of the season may then be due to an interaction of these two faunal groups. The protozoan populations in this study were 100-fold higher in comparison to other studies (Petersen and Luxton, 1982). On some dates and on average, protozoan C equalled or excelled that of microbial C (Table 3.4). Rutherford and Juma (1989) obtained similar average counts for protozoans in their studies of this soil under CT. In addition, studies involving short term dynamics of soil biota have shown that after a significant rainfall event, protozoan populations can be several-fold higher than bacterial numbers (Elliott et al, 1988). The relatively long intervals between sampling dates did not enable us to evaluate the short term dynamics of groups in this study.

Microarthropods are the most commonly cited group affected by tillage (Ryszkowski, 1985; Hendrix et al, 1986; Stinner et al, 1988). Their longer generation times and increased complexity of life cycles and feeding habits do not allow them to perform well in stochastic environments (Andren and Lagerlof, 1983; Ryszkowski, 1985). This study was no exception; ZT management selected for higher populations of mites. In addition, it can be inferred from the higher numbers that there is probably a higher diverstiy of mites under ZT as well (Andren and Lagerlof, 1983). Collembola populations were unaffected which is not unusual in arable soils (Andren and Lagerlof, 1983; Ryszkowski, 1985).Recent studies have rekindled interest in the role of microarthropod communities in nutrient cycling because

Table 3.4. Summary of Seasonal Standing Carbon Stocks and Mineralization Abilities of the Plant- Soil System to a depth of 15 cm (means of three replicates)

Variable ($g\ m^{-2}$)	Conventional Tillage	Zero Tillage	Significance of Tillage Effect[a]
Soil C	7978	8062	ns
Shoot C	200	211	ns
Root C	21	20	ns
Microbial C	48.2	42.8	ns
Protozoa C[b]	37.5	220.5	*
Adult Nematode C[c]	0.14	0.12	**
Juvenile Nematode C[c]	0.02	0.01	ns
Collembola C[d]	0.01	0.01	ns
Acari C[e]	0.06	0.07	*
CO_2-C Evolved over 10 days ($g\ m^{-2}$)	14.8	13.8	ns

a The difference between means is significant at: †, $p \leq 0.10$; *, $p \leq 0.05$; **, $p \leq 0.01$; ***, $p \leq 0.001$

b Assuming average dry weight of a protozoan to be 9×10^{-4} µg (Petersen and Luxton, 1982) with a dry weight carbon content of 50%.

c Assuming average dry weight of a nematode to be 0.05 µg (Petersen and Luxton, 1982) and 50% carbon.

d Assuming average dry weight of a collembolan to be 2.7 µg (Petersen and Luxton, 1982) and 60% carbon.

e Assuming average dry weight of a mite to be 4.3 µg (Petersen and Luxton, 1982) and 60% carbon.

they function as top predators of the detrital food web. Their roles as comminuters of detritus and generalist feeders of soil organisms may be considerable decomposition processes under ZT (Elliott et.al., 1988; Moore et al, 1988).

The higher nematode populations, both total and adults, sustained under CT management were not totally unexpected. Parmelee and Alston (1986) found that the monthly mean densities of nematodes, sampled over a period of one year, were also higher under CT. These authors attributed the differences to the types of decomposition processes dominating under each system. Thus, the larger microbiovore community under CT in summer was indicative of a more bacterially based food web while the dominance of fungivores relative to bacteriovores under ZT indicated a larger fungal community. The abundance of each group reflected the decomposition rates seen under the two systems. Trophic group separation was performed in this study also but neither group dominated in the two systems (data not shown). Higher protozoan populations (presumably sustained by higher bacterial populations) were present under ZT but not a higher microbiovore population. One possible reason for this could be the negative relationship between earthworms and nematodes populations (Yeates, 1981). Perhaps the soil structure generated by the unique melding of organic fabrics with soil minerals that occurs in the earthworm gut excludes the larger nematode community. Kerry (1988) speculated that earthworms may play a role in either dispensing nematophagous fungi throughout the soil or consuming the nematodes themselves. Regardless of the possible physical and/or biological reasons, there was a difference in nematode numbers between the two systems.

Given the alterations in biophysical properties and the restructuring of communities in both time and space under ZT, decomposition generally proceeds at a slower rate (Doran, 1980; Lussenhop, 1981; Andren and Lagerlof, 1983; House et al, 1984; Ryszkowski, 1985; Hendrix et al, 1986; Coleman and Hendrix, 1988). It has been speculated that tillage tends

to select for organisms which are specially adapted to stochastic environments (Andren and Lagerlof, 1983). The metabolic status of CT soils is on average more oxidative, harboring soil animals with short generation times, smaller body size, higher respiration rates, rapid dispersal and omnivorous feeding habits (Doran, 1980; Andren and Lagerlof, 1983; Ryszkowski, 1985; Hendrix et al, 1986). It has also been speculated and recent evidence shows that CT systems have more of a bacterially based food web and larger populations of enchytraieds contributing to overall higher respiration rates (Hendrix et al, 1986; Elliott et al, 1988). Holland and Coleman (1987) report that hyphal biomass under ZT is 144% of that found in CT systems and that fungal hyphal bridges may be an important mechanism of N transport (immobilization) into the straw layer for decomposition (Coleman et al, 1988). Overall, biomass:CO_2-C ratios, the index of metabolic activity in this study, was lower under CT (Table 3.4). This means that less microbial biomass was required in the CT system to respire the same amount of CO_2-C from the ZT system. Therefore the soil community was more active in the CT system. In addition, the CT system had greater net mineralization of N (Chapter 2). Insam and Haselwandter (1989), using the metabolic quotient (R:B (respiration:biomass)), found that over the long term the decomposer community became less wasteful in their energy utilization shown by a decline in R:B with time. In this study, the inverse of that quotient, B:R was used to measure metabolic activtiy or efficiency. The lower B:R ratio under CT indicates that this sytem is less mature in terms of community development and more wasteful in its functioning. Therefore ecosystem structure does appear to have an impact on the response of these two systems (Table 3.4).

Whether it is the alteration in spatial habitat for biological activity or changes in the metabolic status/structure of communities through improved acessibility to substrates , or both of these, CT systems mineralize substrates more rapidly (Table 3.4). House et al (1984) proposed that ZT systems allow for the development of functional subsytems of communities not unlike those of natural grasslands. It is decomposer contact with substrates which brings

about decomposition and the ensuing string of food web interactions which sustain nutrient cycling in agroecosystems. ZT systems offer a way of maintaining nutrient and soil retention, ensuring a beneficial decomposer/faunal community and controlling organic matter decomposition resulting in an overall more conservative approach to crop production.

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Chapter 4. Synthesis

Seasonal Plant, Microbial and Faunal Response

A hierarchial regulation in the seasonal response of the soil communities was evident because the various controls of the systems exerted their influence from different levels, each one becoming dominant as conditions changed. Man's influence was in terms of residue placement, soil disturbance, type of crop, timing, type and amount of fertilization and choice of pesticide control. These controls were considered inherent as they were part of the problem being investigated. In the systems studied, man's influence is intense up to the time of seeding. Then agroecosystem internal feedbacks respond to the changing conditions for the rest of the season. The foremost control on biotic interactions were climatic factors, in particular, rainfall events. However, plant activities, and their influence on soil water content, were a strong secondary control, especially on the second date when rainfall had been fairly constant for the preceding few weeks. Lastly, when conditions were relatively stable, the subtle control of predator-prey relationships influenced population dynamics.

The plant in this study was seen as the integrator of the seasonal dynamics of the two systems and soil microbial biomass and faunal communities were examined according to significant physiological stages of the plant. Plants play an integral role in the functioning of terrestrial agroecosystems. In below ground detrital food webs, plants can be used to partially elucidate some of the complex microbial - faunal interactions through their activities of nutrient uptake, reduced C exudation and root architecture responses when certain biotic groups are present (Anderson, 1988; Van Veen et al, 1989). Thus it may be possible to link microsite processes crucial to nutrient cycling with agroecosystem response (Anderson, 1988). Plant influence, in terms of water and nutrient uptake, on the soil communities over the season varied from mild (spring and harvest) to extreme (second date). The last level of

regulation in populations was predator-prey relationships. These did not influence the system until the latter part of the season when plant influences diminished and soil water contents were relatively stable. I think that these different levels of control and their effects on the microbial community (whose dynamics are reverberated through the grazer community) are largely responsible for any temporal displacements of fauna through the season (Ingham et al, 1986; Hunt et al, 1989). Decompositional changes in straw quality probably played a minor role in seasonal organism dynamics (Elliott et al, 1984).

The role of protozoan and microbivorous nematodes in the mineralization of N has been well documented in microcosm studies (Anderson et al, 1978; Coleman et al, 1978; Baath et al, 1981; Woods et al, 1982; Clarholm et al, 1985; Ingham et al, 1985) Recent investigations under field conditions have validated this finding as a true soil ecosystem phenomenon (Elliott et al, 1984; Ingham,et al, 1986; Elliott et al , 1988). Peak mineralization rates in most of these studies are correlated with a decrease in decomposer populations and an increase in protozoan biomass. Elliott et al (1988) document that about 40% of the N mineralization in soils is due to faunal grazing, with nematodes and amoeboe contributing 83% of the faunal N release. Thus biotic interactions can have considerable influence on nutrient availability to plants. Although the presence of plants can obscure estimates of mineral N release and accumulation, laboratory incubations of N mineralization in the unfumigated controls, in conjunction with mineral N levels (Table 2.3) obtained on the fourth date corroborate the above findings. A proposed seasonal sequence of events in microbial and faunal interactions is presented here but this should be interpreted with care as it is difficult to identify cause and effect relationships in such a complex system sampled intermittently over the season. Recent studies have pointed out that perhaps the best way to understand biotic interactions and the regulation of organism communities is to study short term pulse dynamics (Hunt et al, 1989). This may be the case especially for those organisms which have short generation times and some form of anhydrobiosis.

Favorable soil moisture conditions in the spring (May-June), coupled with the previous years residues, freshly hydrolysed urea and minimal plant influence led to a proliferation of microbial biomass and immobilization of N (Figure 2.3a, 2.3b and Table 2.3) The effect of this increase in microbial populations was exhibited through increased protozoa and nematode populations on the first date. Microbial populations typically peak early in the season in response to spring rains which usually brings about an increase in grazer populations (Elliott et al,1984; Ingham et al,1986). Increases in the concentrations of mineral N in the soil due to grazing were difficult to obtain on the first date due to fertilization and plant uptake. However, the high mineral N concentrations are indicative of the spike of N to the system. Plants had begun to withdraw N from the soil at this time (Table 2.4 and Figure 2.3a and 2.3b).

The strong impact of plant activities on the populations of soil decomposers and fauna was shown through the decreased levels of biomass N on date 2. By this stage of ear emergence, shoot mass and carbon in both systems had increased by 20-fold. Internode elongation and head formation occurring at this developmental stage was rapid with a decline of WFP on the second date and an increase in shoot recovery of ^{15}N (Figure 2.3a and 2.3b). The concomitant increase in root mass on this date demonstrates the need for maximum exploration of soil to supply the demands of the plant. In a recent study, Van Veen et al (1989) noted that plant induced changes in the mineral nutrient status of the soil may have direct effects on the composition and activities of the decomposer community. Soil mineral N concentrations (Table 2.3) fell drastically to very low levels by the second date. As a result of the diminished water and nutrient status of the soil and reduced microbial biomass, protozoan and nematode populations decreased as well.

Heal and Dighton (1985) characterize the water film interactions of bacteria, protozoans and nematodes as belonging to the microbiota group in soil. The dynamics of this

group, depend on the availability of water and parallel soil water fluctuations. The microbiota dynamics in this study paralleled the fluctuations in soil water content. Therefore the huge rainfall event before the third sampling date produced a pulse of microbial N. Nematode populations responded accordingly, however the protozoan populations showed a substantial decline. This was highly unexpected as the moist conditions and abundant prey should have produced a flush of activity. Protozoans, with their short generation times and ability to encyst and excyst rapidly, normally follow changes in soil water content quickly. It is possible that the composition of the microflora at this time was largely composed of fungi or that a large portion of the nematode community was composed of holophagous cephalobids capable of ingesting the small gymnamoeba and flagellates that would have responded to the favorable conditions. Coleman (1985) described an inverse relationship between protozoan and holophagous nematode populations. Thus with the increased predation, nematode populations increased and protozoan populations declined. The proliferation of microbial biomass N may in fact be due to both a rainfall effect and released predation pressure by protozoans through increased nematode predation. Net primary production and N uptake peaked on the third date as metabolic C and N compounds were shunted to the grain for protein formation (Table 3.1 and Table 2.2).

By the fourth date protozoan populations had surged to 40-fold from the third date. Biomass levels declined as did nematode populations. It is possible that the somewhat drier conditions caused a decline in nematode numbers which relaxed the predation pressure of soil protozoans. Increased earthworm activity may have had an adverse effect on nematode populations as it was noted that earthworms became more numerous as the season progressed (Yeates, 1981). The latter hypothesis may explain the surge in protozoan biomass, especially under ZT. Regardless of the possible explanations, microbial biomass declined on the fourth date in response to increased protozoan grazing. The laboratory mineralization study indicated that with the reduced microbial levels and increased grazing, there was an increase

in mineral N release. These results correspond well with those of other studies (Elliott et al, 1984; Ingham et al, 1986) which found that in the fall, when plant demand for N was essentially over, the impact of the predator-prey relationships on nutrient cycling became evident. Here, with relatively constant moisture conditions and minimal plant influence, the main control of the population dynamics was predator-prey relationships.

The plant dynamics and overall yields of the two systems did not differ, presumably due to the type of fertilizer placement. The ZT system conserved fertilizer soil N. This system immobilized more fertilizer due to the increased infiltration of mineral N into the second depth, where it was subsequently immobilized. The CT system appeared to have more plant available N and greater net MIT evidenced by increased NH_4-N overall, a lower trend in shoot C:N and a crop developmental lag of approximately one week.

The ZT system had greater C concentrations and densities of protozoans, nematodes and mites in the surface layer. Overall, protozoan counts and mites were higher under ZT management. Due to the more complex life cycles and longer generations of the diverse mite population, especially the larger predatory gamasids, minimal disturbance to the soil favors this group. CT, on the other hand, favored nematode populations. The metabolic index, biomass C:respired C, was lower under CT indicating a more energetically wasteful and less metabolically efficient suite of microflora.

Although the short term response in the dynamics of the plant-microbial-faunal system over the season was similar in the two tillage regimes, the differences found in ecosystem structure may effect ecosystem response in the long term.

Implications

The resemblance of ZT systems to natural grasslands both in structure and function, benefits the producer who adopts them, especially over the long term. This study has shown that with the proper fertilizer conditions, ZT can conserve more N than CT systems and produce the equivelant yields. ZT appears to promote a beneficial suite of organisms through uninterrupted successions of organism interactions which, in combination with the profile stratification and surface residues, is overall more metabolically efficient. Thus the potential for C conservation exists which will help in aggregation stabilization and increase siol organic matter.

The results of this study show that zero tillage incorporated into the appropriate cropping system will allow a producer to maintain or even increase soil organic matter. This can only improve the tilth and lessen the erodibility of soil.

Future Research

A number of areas still need to be examined:

1) Are ZT systems on different soil types more complex in terms of the composition and diversity of soil communities? Does this difference in complexity lead to lower mineralization rates or is it the physical location of the communities and substrates as this study and others suggest?

2) How does the localization of substrates control decomposition and what differences are there in the succession of soil organisms on those substrates?

   Holland and Coleman (1987) have speculated that fungal hyphal bridges are responsible for translocating mineral N into the thatch layer from the soil in order to decompose the high C:N residues. In comparison, the

buried residues under CT are like localized hotspots of activity. How do the succesion of organisms and other decompositional characteristics differ? In situ analysis with rhizotrons may yield interesting data.

3) Can tillage be used intermittently as a timed release of nutrients? Initial immobilization of fertilizer N to a greater extent under ZT may not always have the desired effect. Rice et al (1986) noted that over the long term, ZT systems may cycle as much N as CT due to the larger pool sizes formed under ZT. However, this may take a long time. Can the intensity of tillage be controlled to obtain timed release of nutrients without the degradative effect of intensive tillage (Doran et al, 1987)?

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Appendices

Table A.1. Summary of Seasonal Standing Stocks of the Plant- Soil System to a depth of 15 cm.(means of three replicates)

Variable	Feeke's Growth Stage[a]			
	2	10.4	11.2	11.4
	Conventional Tillage			
Shoot mass (g m^{-2})	22	462	830	628
Shoot C (g m^{-2})	8.2	189.5	348.9	253.0
Root mass (g m^{-2})	22.4	79.8	72.2	43.5
Root C (g m^{-2})	7.5	30.5	27.5	18.5
Microbial C (g m^{-2})	51.6	48.8	40.0	52.4
Microbial N (g m^{-2})	6.2	4.8	7.1	5.6
Protozoa (Ind. x 10^{11}) m^{-2}	6.8	4.1	0.9	8.2
Adult Nematodes (Ind. x 10^{6}) m^{-2}	6.6	4.9	3.4	8.4
Juvenile Nematodes (Ind. x 10^{6}) m^{-2}	1.0	0.7	0.6	0.3
Acari (Ind. x 10^{4}) m^{-2}	2.0	2.1	2.2	2.8
Collembola (Ind. x 10^{3}) m^{-2}	3.5	5.9	4.4	12.4
CO_2-C Evolved over 10 days (g m^{-2})	7.9	11.1	21.2	19.1
Net N Mineralized over 10 days (g m^{-2})	8.8	1.4	0.6	1.9
	Zero Tillage			
Shoot mass (g m^{-2})	24	507	762	711
Shoot C (g m^{-2})	8.9	211.1	328.3	296.1
Root mass (g m^{-2})	21.6	84.0	66.4	43.7
Root C(g m^{-2})	8.0	31.0	25.5	15.5
Microbial C (g m^{-2})	85.2	85.9	36.6	66.7
Microbial N (g m^{-2})	6.3	4.3	6.7	5.6
Protozoa (Ind. x 10^{11}) m^{-2}	5.2	20.2	1.3	90.7
Adult Nematodes (Ind. x 10^{6}) m^{-2}	5.4	3.3	5.4	4.5
Juvenile Nematodes (Ind. x 10^{6}) m^{-2}	1.7	0.7	0.7	0.3
Acari (Ind. x 10^{4}) m^{-2}	1.7	3.1	2.6	3.0
Collembola (Ind. x 10^{3}) m^{-2}	5.9	8.0	6.0	8.0
CO_2-C Evolved over 10 days (g m^{-2})	9.1	8.6	18.8	18.6
Net N Mineralized over 10 days (g m^{-2})	9.8	1.1	0.9	1.8