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UNIVERSITY OF ALBERTA

Carbon Cycling In Two Long-Term Cropping Systems on A Gray Luvisol At Breton, Alberta

by

ALFREDO ANTONIO CARCAMO 

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

SOIL SCIENCE

Department of Renewable Resources

Edmonton, Alberta

Fall 1997

University Of Alberta

Library Release Form

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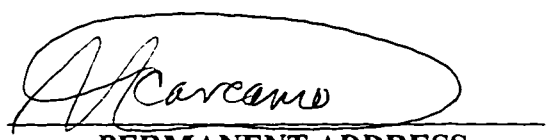

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled: **Carbon Cycling in Two Long-Term Cropping Systems on a Gray Luvisol at Breton, Alberta**. Submitted by Alfredo Antonio Carcamo in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOIL SCIENCE.

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Dated: October 6, 1997

DEDICATION

To my Mother *Margarita Trinidad Melendez*,
and my Sister *Patricia Elena Carcamo*:

Without your help and support I could not have come this far.

ABSTRACT

Experiments were conducted at the University of Alberta Breton Plots to determine the impact of crop (2-year wheat-fallow, and 5-year wheat, oat, barley, hay-1, and hay-2) and treatments (control, NPKS fertilizer and manure) on labile organic matter and seasonal soil respiration in two long-term crop rotations in central Alberta. Active carbon fraction of SOM was <3.2% as microbial biomass, about 8% as light fraction organic matter, and <8% as potentially mineralizable carbon. Total organic C, labile and mineralizable C were greater in the 5-yr rotation than the 2-yr wheat fallow. Peak respiration rates were about 1.0 g CO_2 m^{-2} hr^{-1} in the wheat and oats phase of the 5-yr rotation and occurred in late June. Soil respiration was lower in the 2-yr cropping system by about 20 to 50%. Active carbon pools are dynamic and have to be used cautiously as indicators of changes in SOM in different cropping systems.

Acknowledgements

First and foremost I would like to thank my supervisor, Dr. Noorallah Juma for having the patience and taking the time to teach me the scientific method amidst the challenging times at the University of Alberta.

I thank the members of my committee, Dr. John Hoddinott and Dr. Cesar Izaurralde who helped with various stages of the project regardless of the distance. I thank Dr. John Hoddinott who was always willing to spend the time in developing my writing and technical skills. His help in the set up of the IRGA was essential in getting my experiments up and running. I thank Dr. Izaurralde for sharing his expertise with Breton Plots, his experience with measurements of greenhouse gases and his assistance in refining measurement techniques in the field. I am grateful to Dr. Robert Grant for his helpful criticism of this work and his role as examiner.

I thank Monica Molina-Ayala for her wealth of knowledge in the laboratory as well as her warm friendship. Her assistance in guiding me through the laboratory was instrumental and has enhanced my technical skills. I would like to thank Clive Figuereido and Chung Nguyen for their assistance and patience with measurements and data analysis.

I thank Heloisa Modesto for her assistance in the field and laboratory work as well as valuable discussions; for her contribution to the Latin American team in the Biochemistry lab. I also thank Claudia Gomez, Emanuel Mapfumo, Rupa Pradhan and Xiao Yuan Geng for their assistance and valuable discussions as well as their warm friendship. I would like to thank my fellow graduate students who shared their friendship and provided valuable input over a glass of Traditional Ale.

I would like to thank my father and mother for their encouragement to continue and my brothers and sister for their support and particularly Jando for his comments which have been so valuable in setting new standards for my work.

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Chapter 1. Introduction

The atmospheric CO_2 concentration has steadily increased over the last century and a half from 280 ppm prior to the industrial revolution to 350 ppm today (Allen Jr., 1990). Concentrations are expected to reach between 440 and 660 ppm by the year 2050 (Bouwman, 1990). The increase of concentration of CO_2 in the atmosphere has led to the development of various scenarios for assessing the impact of global environmental change on the productivity of ecosystems. Wood (1990) and Reicosky and Lindstrom (1993) have estimated that higher atmospheric CO_2 will result in drier soils, increased temperatures and drought over present agricultural production areas of temperate regions. This scenario will have an marked impact on food production and has led to examination of global carbon fluxes between the atmosphere, biosphere, hydrosphere and lithosphere.

Carbon dioxide accounts for 50 to 60 percent of the increase in radiative forcing caused by gases contributing to global warming. Global soil respiration from plants, soil microbes and soil fauna contribute about 60 Gigatons (Gt) C yr^{-1}. Prior to 1960, this flux was almost balanced by photosynthesis. Therefore, the atmospheric CO_2 was almost in a steady condition. Schimel (1995) has provided an overview of the global carbon cycle showing the annual fluxes and reservoirs (Fig. 1.1). Over the past 30 years, CO_2 emissions from fossil fuel burning and industrial sources have increased to about 5.5 Gt C yr^{-1} (Schimel, 1995). Contribution from deforestation is estimated at about 1.6 Gt C yr^{-1}. These perturbations have resulted in an increase of CO_2 in the atmosphere. Consequently, the stabilization of atmospheric CO_2 has become a global concern. In order to stabilize the CO_2 concentration in the atmosphere, two approaches can be used: (1) decrease CO_2 emissions; or (2) sequester the carbon fixed through photosynthesis in terrestrial and aquatic ecosystems in the form of organic carbon.

Plant biomass accounts for 25% and soil organic matter accounts for 75% of total C in terrestrial ecosystems (Kuikman and Gorissen, 1993). Carbon sequestration in soils can be increased if a larger portion of CO_2 sequestered through photosynthesis is translocated into the roots and root derived products. Decomposition of plant-derived

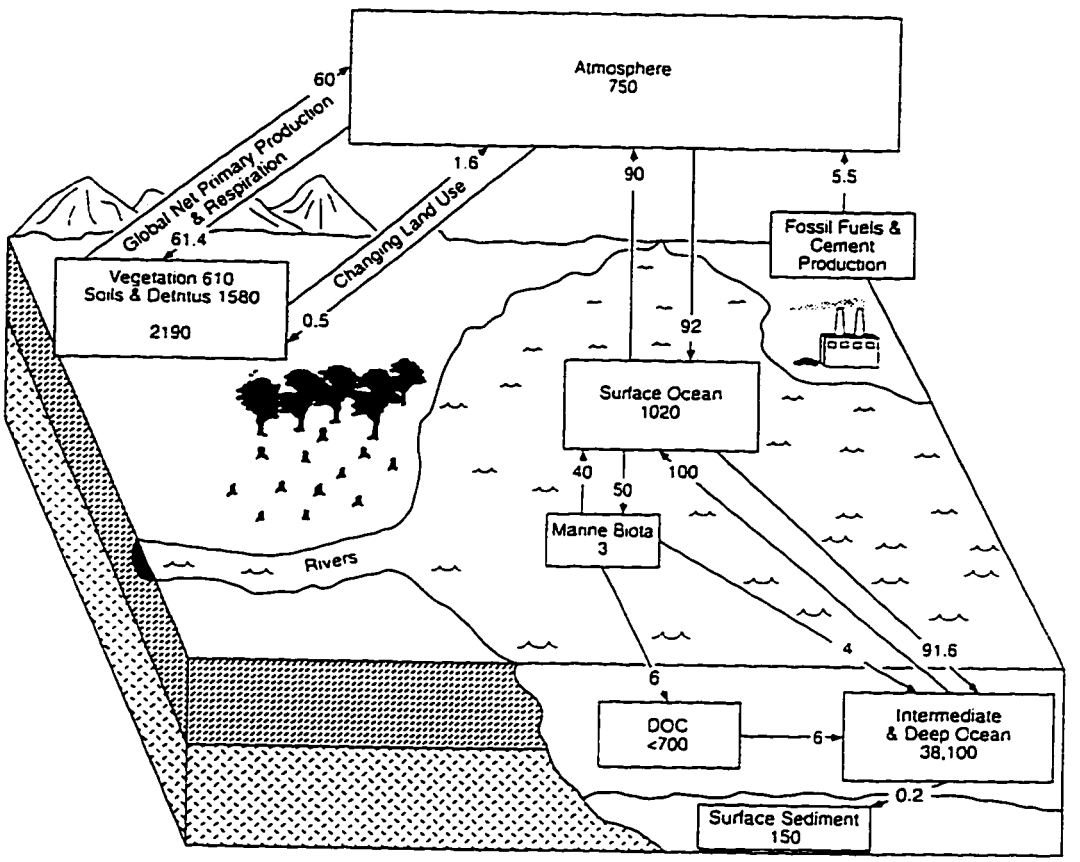

Figure 1.1. The global carbon cycle, showing the reservoirs (Gt C) and fluxes (Gt C y^{-1}) relevant to the anthropogenic perturbation as annual averages over the period 1980-1989 (Schimel, 1995). The component cycles are simplified and subject to considerable uncertainty. In addition, this figure represents average values.

organic carbon by microorganisms, and soil fauna leads to formation of new biomass, CO_2 and organic products which are stabilized in the soil (Kuikman and Gorissen, 1993). The crop root system can also be used to sequester and redistribute atmospheric C deeper in the soil profile where it is less susceptible to oxidation to CO_2, although in the temperate ecosystems, roots are often distributed in upper soil horizons (Buyanovsky and Wagner, 1983). In order for soils to become sinks of atmospheric carbon soil organic matter must be increased and organic carbon should be taken out of the rapidly mineralizable fractions and into the stable humified pools. Lal et al. (1995) have

proposed the following strategies for carbon sequestration in soils: (1) increase total soil organic carbon content; (2) increase soil organic carbon content of the sub-soil horizons; (3) increase micro-aggregation; and (4) increase soil biodiversity. In order to increase soil organic C soil management which emphasizes crop rotations, soil fertility management have been show to be successful at storing carbon over the long term. Management of agroecosystems can lead to changes in plant productivity and soil organic matter content. A brief overview of these practices is presented below.

Impact of Management on Carbon Cycling in Agroecosystems

Agricultural practices such as summer fallow, crop residue burning and cultivation have increased the rate of oxidation of soil organic matter (SOM) contributing to carbon dioxide in the atmosphere. After cultivation soils with high organic matter content have experienced a rapid decline in SOM, sometimes as high as 50% of the original SOM, within the first 10 to 30 years. The SOM content generally stabilizes after about 50 to 60 years (Rasmussen et al., 1980; Campbell et al. 1995). However, if cultivated soils are properly managed by changing tillage methods, adding organic matter in the form of plant residues and animal manures, and addition of inorganic fertilizers, it is possible to increase the amount of SOM (Kern and Johnson, 1993; Reicosky and Lindstrom, 1993; Varvel, 1994; Campbell et al., 1992, Juma et al., 1997).

Conservation tillage practices cause less disturbance of soil than conventional tillage and result in lower soil temperature, higher moisture content which slow the rate of oxidation of SOM. Larney et al., (1997) in southern Alberta, found that intensively-worked conventional tillage systems reduced total organic carbon by 2.2 Mg ha^{-1} compared to zero tillage, and concluded that increased frequency of cropping by reducing summer fallow, and reduction of tillage intensity were the first steps towards sequestering plant C into SOM. Kern and Johnson (1993) found that an increase of 57% conservation

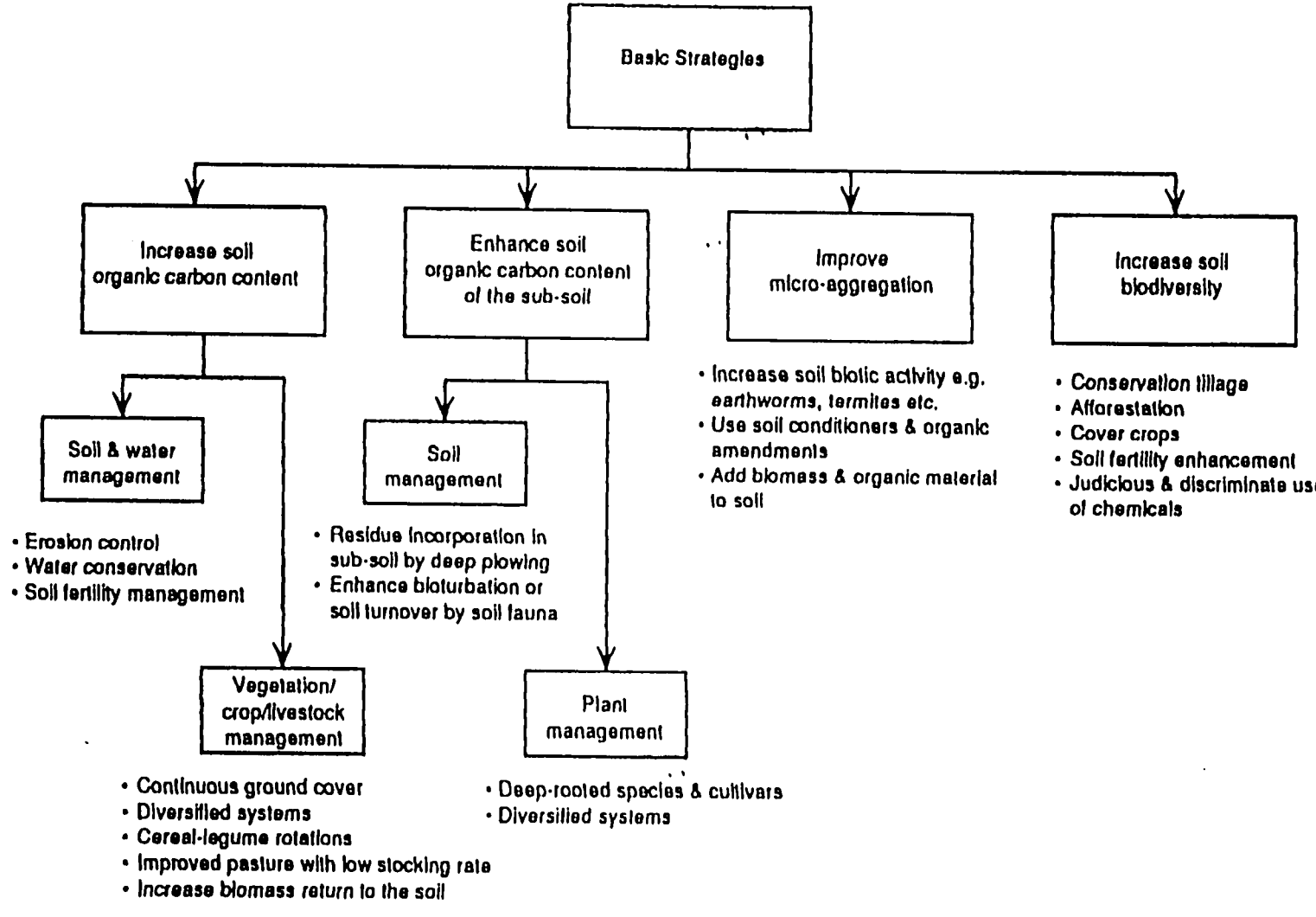

Figure 1.2. Basic strategies for increasing C sequestration in soil (Lal et al. 1995).

tillage use in the United States would result in a net gain of 80 to 129 Tg of organic C in the top 30 cm of soils within the next 30 years. In addition to this, emissions of CO_2 from fossil fuel combustion would also decrease as reduced tillage requires less fuel for field operations (Kern and Johnson, 1993).

Rasmussen et al. (1980) found that SOM content is linearly related to amount of plant and residue applied. They found that the addition of manure was the most effective way of maintaining soil organic C and N (Rasmussen et al. 1980). Results from Breton Classical plots agree with other long-term studies that manure additions are the most effective way of maintaining SOM (Cannon et al. 1984; Robertson. 1979; Izaurralde et al., 1996; Juma et al. 1997).

Crop rotations have been found to increase the organic matter content of soil when compared with monocultures (Campbell et al. 1991; Janzen 1987; Izaurralde et al. 1996). Varvel (1994) studied 2-yr (corn-soybean and grain sorghum-soybean) and 4-yr (corn-oat + clover- grain sorghum- soybean) cropping systems and found that soil C and N levels were greater in the 4-yr than the 2-yr rotation. Addition of fertilizer produced the highest rates of carbon sequestration in the 4-yr rotation. Crop rotations which include fallow produced more rapid loss of soil C and N (Rasmussen et al. 1980; Campbell et al. 1991; Janzen 1987; Izaurralde et al. 1996).

The discussion presented above represents some general trends of impact of management on SOM content in diverse agroecosystems. In the following section. I will focus on the Breton Plots.

The Breton plots were developed in the 1930s and compare two cropping systems. a wheat-fallow and a continuous cropping 5-yr rotation (Robertson, 1979); three contrasting amendments have been selected for this thesis project to highlight the response of soil biochemical properties onto long-term management practices. Fertilizer. manure and control have been compared and results indicate that significant increases in SOM have resulted due to management (Juma et al., 1997). The 2-yr rotation shows no significant changes in total soil N where as in the 5-yr rotation soil organic N content was 37. 42 and 42 percent higher in the soil of control. NPKS and manure treatments.

respectively. of the 5-yr rotation than in those of the corresponding 2-yr rotation (Juma et al. 1997). McGill et al. (1986) studied soluble carbon and microbial biomass C and N in the two rotations and found that microbial biomass N was 117 % higher in the continuous cropping system compared to the wheat-fallow rotation. Manure amended plots had higher microbial population than control plots however no significant difference was found between manure and fertilizer treatments nor between fertilizer and control. Soluble organic carbon was significantly higher in the manure treatment than in the control or fertilizer treatment. Both soluble organic carbon and microbial biomass show similar trends to soil organic matter suggesting that these labile pools may be used as indicators of soil quality (McGill et al. 1986).

Fyles et al. (1988) compared microbial and faunal populations in oats and alfalfa plots of the five year rotation and found that the microbial population in the (0- 15 cm) depth in the oats was higher than the alfalfa plots. In addition they found that oat root mass was significantly lower than alfalfa root mass and the size and the extent of the rhizosphere. They concluded that the differences reflect the short-term influence of different crop types and management practices in the rotation.

Thesis Objectives

The overall objective of this thesis is to compare the short term dynamics of carbon cycling from two long-term crop rotations at Breton and to quantify the CO_2 gas emissions from these rotations into the atmospheric. In order to assess the contribution of soil organic carbon to the atmospheric carbon pool, it is necessary to assess the changes due to management. The changes are often small and difficult to quantify due to the heterogeneity of soil organic matter. In contrast, active carbon pools may be more sensitive to short-term changes. Therefore, microbial biomass, light organic matter and potentially mineralizable carbon were measured in this study. These measurements were done in the laboratory and represent the readily available carbon which microbes can utilize in the field. Potentially mineralizable carbon is an indicator of the amount of carbon respired in the absence of plants.

Soil respiration measurements are most representative if collected in the field and in chapter 3, I have measured soil respiration during the growing season in the 5-yr and 2-yr rotation. In addition soil microbial biomass, mineral N and soil moisture represent factors which control soil respiration and will help understanding the dynamics of soil respiration.

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Chapter 2. Total organic carbon, light organic matter fraction, microbial biomass and carbon mineralization potential in two long-term cropping systems at Breton, Alberta.

Soil organic matter (SOM) influences soil productivity by providing available plant nutrients and maintaining desirable physical properties for plant growth in both cultivated and undisturbed systems (Bradley and Fyles, 1995; Smith et al., 1994). Although SOM has been the focus of research for several decades, it has gained considerable importance recently with the increase in greenhouse gases in the atmosphere. The terrestrial ecosystem is an important component of the global carbon cycle particularly as it can be a potential source or sink of atmospheric carbon (Biederbeck et al., 1994). Its size is estimated at 2100 Gigatons, with 75% of this pool being in SOM (Kuikman and Gorissen, 1993). Consequently, studies of SOM do not focus simply on quantifying total organic carbon stored but rather the rates of carbon turnover and the particular pools which make up soil organic carbon. There is increased interest in determining the effect of management on carbon storage in various ecosystems.

Continuous cultivation of soils often leads to the substantial loss of SOM over the long term. Mann (1986) reviewed 50 studies from temperate zones which reported carbon content in cultivated and uncultivated soils and found losses as high as 70 % and gains as much as 200 % depending on soil type, sampling depth, and management history. In a review of long-term crop rotations in the prairies, Campbell et al. (1991) concluded that soil productivity can be sustained over the long-term by adoption of proper management techniques for specific climatic conditions. In contrast, Rasmussen et al. (1980) found that many sub-humid areas show a rapid decline in total organic carbon and nitrogen in the first 10 to 30 years after cultivation began, and continued loss of carbon at a slower rate approaching a new equilibrium after 30 to 50 years. In temperate ecosystems, on the conversion from native vegetation to permanent cropping, soils lose organic matter rapidly in the first few years (Mann, 1986). In the Canadian prairies estimates indicate that between

15 to 40 percent of original SOM has been lost due to cultivation (Bremer et al., 1994). McGill et al. (1988) reported carbon losses between 15 and 31% from Ap horizons of prairie Chernozemic soils. However, the losses of SOM can vary depending on environmental factors as well as management.

The Breton Classical plots in Central Alberta, established in the 1930's, to compare two cropping systems on Luvisolic soils, a 2-yr, wheat-fallow (WF) and a continuous cropping, 5-yr (wheat-oats-barley-hay-hay) (WOBHH) rotation (Juma et al., 1997). After sixty years of cropping the 5-yr rotation has significantly higher soil C and N over the 2-yr rotation. Luvisols occupy about 20 million hectares of land in Alberta and are the dominant soil in much of the potentially arable, unsettled land of Alberta (Juma et al., 1997). Significant increases in C and N at Breton have been due to below ground inputs and organic amendment additions because all above ground biomass is removed (Juma et al. 1997). These results support the conclusion that SOM dynamics after several decades of cultivation are largely governed by management decisions such as selection of cropping system, tillage intensity and fertilization rates (Biederbeck et al., 1994). However, it is difficult to quantify trends because: (1) small and gradual changes in total SOM are difficult to detect in the short term; and (2) the high background levels of organic carbon and natural variability of soils mask the small changes of SOM over time (Sparling, 1992). In contrast, labile fractions of SOM may be more sensitive to management practices and may indicate the general trend of SOM in different crop rotations.

Soil organic matter contains fractions which vary in turnover rate (Cambardella and Elliot, 1992; Hassink, 1995). Rapidly cycling pools have been described as active SOM, biologically active SOM, or labile OM (Wander et al., 1994; Biederbeck et al, 1994; Janzen et al., 1992). This biologically active fraction represents a small portion of total organic carbon, often less than 25 % (Ellert and Gregorich, 1993). However, it plays a significant role in soil nutrient dynamics and the soil carbon cycle. Bioassays provide a direct measure of the carbon which is available for decomposition. Therefore, incubation and physical fractionation of SOM can enhance our understanding of the nature of SOM, by providing

quantitative assessment of the proportion of carbon, nitrogen and its distribution in soil separates.

Although soil biota is a small pool, it plays a vital role in SOM turnover and nutrient cycling in the soil ecosystem. Consequently, microbial C has been combined with other labile pools to determine the active fraction of SOM. In addition, it has been suggested that light fraction and microbial biomass are not physically protected, making them readily available for mineralization (Hassink, 1995). Density fractionation assumes that SOM can be divided into two or more pools differing in structure and function based on the specific density of each fraction (Christensen, 1992; Magid et al., 1996; Meijboom et al., 1995). The light fraction is less dense than the organo-mineral fraction and can be separated by flotation in organic or inorganic solutions of various densities. The light organic matter fraction is more labile than the organic carbon in clay and silt size fractions (Christensen, 1992; Strickland and Sollin, 1987). Thus, these fraction are considered sensitive to management and have been used as indicators of SOM trends (e.g. Bremer et al., 1994; Dalal and Mayer, 1986) and of soil quality (Ellert and Gregorich, 1993).

Incubation studies are long and time consuming, however they provide a direct measure of the mineralizable carbon pool. This active fraction has been used to successfully measure changes in soil quality (Biederbeck et al., 1984). Carbon mineralization in a continuous wheat system was twice that in a wheat fallow rotation and the amount of C mineralized was affected by rotation phase (Janzen, 1987). Mineralized carbon provides a direct indicator of the availability of organic matter to the soil decomposer community (Larney et al., 1997). Therefore, the light fraction and the microbial biomass will correlate more strongly with C and N mineralization than with any other organic matter fraction (Hassink, 1995). The objective of this paper is to measure potentially mineralizable carbon, microbial biomass, and light fraction organic matter in 2-yr and 5-yr long-term crop rotations located on a Gray Luvisolic soil at Breton, Alberta.

Materials and Methods

The study site is located at the Breton Plots owned and operated by the University of Alberta near the town of Breton, Alberta (53° 07' N , 114° 28' N). 110 km southwest of Edmonton. Normal annual precipitation at Breton plots is 547 mm, the site receives an average of 405 mm as rain and 132 mm of snow. The months of greatest rainfall are June, July and August and the greatest snowfall occurs during December and January. Breton has an average of 80 frost-free days; the warmest month of the year is July with maximum average temperature of 21.2° C and the average minimum is 8.8°C. The coldest month of the year occurs in January with average minimum temperature of -19.5 and a maximum of -8.6°C. The potential evapo-transpiration is 732 mm (Izaurralde et al., 1995a).

Dominant soils at the Breton plots are Gray Luvisols (Gray Wooded) complexed with Dark Gray soils. The soils are acidic and have bulk density in the range of 1.3 to 1. 5 Mg m^{-3} (Izaurralde et al., 1995b). The description of the two cropping systems and nutritive amendments applied at the Breton Classical Plots is shown in Table 2.1. Samples were collected at the beginning of the growing season in 1995 and 1996 (refer to Appendix I and II for a layout of the series, as well as cultivation practices). In the growing season 1995, a preliminary study of active carbon was carried out on soils cropped to wheat in both rotations and fallow soils but soil organic carbon, and light fraction were only measured. A summary of rotation phases and analyses carried out during both 1995 and 1996 is shown in Table 2.2. Soil samples were collected prior to cultivation on May 8, 1995 from series A and both phases of series E in plots 1, 2, and 3.

On May 16, 1996 soil samples were collected from each of the plots 1, 2, and 3 located in Series A, B, C, D, and F of the 5-yr rotation and east and west portions of Series E of the 2-yr rotation. Samples were collected from the limed half of the plots in series of the 5-yr rotation. The whole plots of the 2-yr series are limed. In 1995 the plots were sampled before cultivation but the plots were cultivated before sampling in 1996.

Table 2.1 Description of Breton Classical Crop Rotation and Nutritive Amendments.

Rotation	*Rotation Phase*	*Nutritive Amendment*	*Series*	*N added per rotation cycle (kg/ha)*
WOBHH	Wheat	control	A	0
	Wheat	manure	A	175
	Wheat	fertilizer	A	50
	Oats	control	B	0
	Oats	manure	B	175
	Oats	fertilizer	B	50
	Barley	control	F	0
	Barley	manure	F	175
	Barley	fertilizer	F	50
	Hay_yr 1	control	C	0
	Hay_yr 1	manure	C	175
	Hay_yr 1	fertilizer	C	0
	Hay_ yr 2	control	D	0
	Hay_ yr 2	manure	D	175
	Hay_ yr 2	fertilizer	D	0
Wheat-Fallow	Wheat	control	EW	0
	Wheat	manure	EW	91
	Wheat	fertilizer	EW	91
	Fallow	control	EE	N/A
	Fallow	manure	EE	N/A
	Fallow	fertilizer	EE	N/A

Soil cores were obtained to a depth of 15 cm using a 25-mm diameter probe. In addition during spring 1995, composite samples from each plot were obtained by randomly sampling ten cores from the limed half of the plots and mixing them in plastic bags. Three plots were sampled in three series for a total of nine samples in 1995. In 1996, three to five cores in the limed portion of the plots were taken to form a sub-sample and placed in a plastic bag. All seven crop phases were sampled and three plots within each series; from each plot three sub-samples were collected and separate analysis was done on individual sub-samples for a total of 63 samples. Samples were taken to the lab and stored at 4°C, and biological analysis was carried out within 24 hrs of sampling. Samples for analysis of light fraction organic matter and potentially mineralizable carbon were air dried, crushed and sieved (2 mm screen). Organic residues remaining on the screen were discarded.

Table 2.2. Summary of phases sampled and analysis carried out during the years 1995 and 1996 at Breton Classical Plots

Year	*Crop Rotation*	*Phase*				
1995	2-yr	Wheat	SOC	LFC		
	2-yr	Fallow	SOC	LFC		
	5-yr	Wheat	SOC	LFC		
1996	2-yr	Wheat	SOC	LFC	Co	Bio C
	2-yr	Fallow	SOC	LFC	Co	Bio C
	5-yr	All phases	SOC	LFC	Co	Bio C

Density Fractionation

Light fraction organic matter (LFOM) was determined using the method of Janzen (1987) with some modification. Thirty grams of sieved soil were placed in 50 ml NaI with a specific gravity of 1.70 (±0.01) g cm^{-3}. Soil was dispersed by placing on a rotary shaker for thirty minutes and sediment was allowed to settle for a period of 48 hours. The supernatant solution was removed by suction. Light organic matter fraction collected on filter paper was rinsed with 0.01 M $CaCl_2$ solution plus deionized water, dried at 70°C for 12 hours and weighed. Samples were crushed using a steel ball crusher, and analyzed for carbon and nitrogen content using an automated combustion technique(Carlo Erba, Milan Italy).

Microbial Biomass

Microbial biomass (MB) was determined using the fumigation extraction method (Voroney et al., 1993). Six 20-grams samples of soil were taken and placed in 50 mL beakers. Three portions were fumigated with purified chloroform and three were left as controls. After 24 hours, beakers were repeatedly evacuated followed by replacement with fresh air to ensure removal of residual chloroform. Extractable carbon was determined by shaking soils with 100 mL 0.5 M K_2SO_4 for 30 minutes on a rotary shaker and filtered through a Whatman No. 42 filter paper. Unfumigated soil samples were extracted at the same time as those fumigated. The extracts were stored at -15°C until analyzed: soluble carbon was measured on the ASTRO 2001 soluble

carbon analyzer (ASTRO , Texas USA). Biomass C was calculated as the difference between the C extracted from fumigated and non-fumigated samples divided by a Kc factor of 0.25 (Voroney et al., 1993).

Carbon mineralization potential

Carbon mineralization potential (Co) was determined on samples from 1996 using the method outlined by Biederbeck et al. (1994). The soils were incubated in the dark at 22 °C for 90 days, with a pre- incubation period of 10 days. Three portions (50 grams) of soil were re-wetted to 60% field capacity equivalent to 26% gravimetric water content (Rutherford, personal communication). Beakers with soil samples were individually placed inside 1.6 L kerr jars with 20 ml 0.25 M NaOH. CO_2 evolved was trapped in the alkali solution: three kerr jars were incubated without soil to determine CO_2 in air and this was subtracted from the samples prior to calculating soil respiration. A five mL aliquot was titrated with 0.10 M HCl to determine excess base after adding 2 mL 2M $BaCl_2$ to precipitate CO_2 out of solution. The initial weight of beaker plus wet soil was recorded and over the incubation, any loss in weight was monitored and replaced by adding de-ionized water. On average it was found that 0.5 mL water every two weeks were sufficient to keep the weight constant.

Soil respiration was calculated as follows :

mg of CO2-C = [(B - V) NE]* A

where B = volume (mL) of acid needed to titrate NaOH in the jars from the controls

V= volume (mL) of acid needed to titrate the NaOH in the samples

N = normality of the acid

E = equivalent weight , E = 6 to express results as mg of CO2-C .

where A is the multiplication factor based on the aliquot titrated (Anderson, 1982).

Results

Total carbon

Soil organic carbon content in the 5-yr rotation was higher than the 2-yr rotation. Total C content in 1996 growing season (Table 2.3) showed similar trends to results during 1995 (data not shown). In all phases of the continuous cropping system carbon content was between 12.8 to 24.4 g C/kg soil while the WF rotation ranged from 7.8 to 17.6 g C/kg soil. These results were similar to the long term averages (Izaurralde et al., 1995a). The carbon content was highest in the continuous cropping system for both growing seasons and on average soil organic carbon was about 1.5 times higher in the continuous cropping system than the 2-yr wheat-fallow. In the WF rotation, the fallow phase had a higher soil organic carbon since it had been cropped to wheat the previous growing season. On the other hand the wheat phase has been fallow for the last 16 months.

During 1996 there were slight differences within the 5-yr rotation. The hay crop phases had slightly higher soil organic carbon (Table 2.3) since these have received the least amount of cultivation. Within rotation soil organic carbon was highest in the manure amended plots for all phases of the 5-yr rotation (WOBHH) and the 2-yr WF rotation. Manure is both a nitrogen source and a rich carbon substrate.

Microbial biomass C

Microbial biomass showed the same general trends as soil organic carbon and light fraction organic matter between the 5-yr and the 2-yr rotations (Table 2.3). Microbial biomass C in the fertilizer and manure amended treatments of the 5-yr rotation ranged from 280 mg C/kg soil to 670 mg C/kg soil. There was no significant difference between the three nutritive treatments in the 5-yr rotation. Microbial biomass C in the control and fertilizer ranged from 70 mg C/kg soil to 110 mg C/kg soil and were lower than manure treatment (Table 2.3). On average, microbial C was about 50 % lower in the 2-yr (WF) rotation compared to the 5-yr rotation. Microbial biomass C was the smallest carbon pool sampled and is the most dynamic of the active carbon pools that were sampled. In all cases, biomass C accounted for less

Table 2.3 Total organic carbon, microbial biomass C, and % of total C in biomass C in two cropping systems and different amendments at Breton during Spring 1996. The standard deviation is indicated for each treatment.

Cropping system	*Amendment*	*Organic Carbon g C/kg soil*	*Biomass C g C/kg soil*	*% total C*
WOBHH	control	13.67	0.26 ± 0.23	1.90 ± 1.67
	manure	22.38	0.39 ± 0.03	1.76 ± 0.15
	fertilizer	15.61	0.48 ± 0.08	3.10 ± 0.49
WOBHH	control	14.82	0.29 ± 0.14	1.96 ± 0.95
	manure	20.30	0.37 ± 0.14	1.85 ± 0.69
	fertilizer	16.41	0.28 ± 0.04	1.69 ± 0.24
WOBHH	control	12.99	0.21 ± 0.07	1.59 ± 0.56
	manure	22.30	0.33 ± 0.07	1.49 ± 0.30
	fertilizer	17.04	0.42 ± 0.21	2.45 ± 1.26
WOBHH	control	14.34	0.27 ± 0.01	1.87 ± 0.07
	manure	24.41	0.43 ± 0.01	1.75 ± 0.03
	fertilizer	17.19	0.28 ± 0.03	1.65 ± 0.17
WOBHH	control	12.81	0.45 ± 0.09	3.48 ± 0.71
	manure	20.83	0.67 ± 0.24	3.21 ± 1.14
	fertilizer	16.19	0.33 ± 0.11	2.04 ± 0.69
WF	control	8.47	0.10 ± 0.02	1.20 ± 0.26
	manure	17.06	0.35 ± 0.18	2.07 ± 1.03
	fertilizer	7.98	0.11 ± 0.05	1.44 ± 0.67
WF	control	7.78	0.11 ± 0.03	1.43 ± 0.39
	manure	12.56	0.28 ± 0.08	2.21 ± 0.63
	fertilizer	9.43	0.07 ± 0.01	0.74 ± 0.13

than 3.5% of total organic C.

Within the 5-yr rotation there were no differences among crop phases. Control plots in the 5-yr rotation, often had microbial C content similar to or higher than the fertilizer or manure amendments (Table 2.3); for example the forage (2nd year) was 0.45, 0.67 and 0.33 g C/kg soil in the control, manure and fertilizer amended soils respectively.

It is important to note that the variability of biomass is higher in the 5-yr rotation than the 2-yr rotation. Standard deviation in the 5-yr rotation ranged from 0.01 to 0.24 g C/kg soil. In the 2-yr rotation, variability for manure was 0.18 and 0.08 g C/kg soil in the wheat and fallow phase respectively while in fertilizer and control

treatments variability was less than 0.05 g C/ kg soil. The variability was higher when there were missing samples.

Expressing biomass C as a proportion of soil organic carbon did not reveal a significant trend suggesting that the biomass was controlled by other environmental factors.

Light Fraction Organic Matter

Light fraction organic matter during spring 1995 is shown in Table 2.4. In general, the light fraction organic matter was higher in the 5-yr rotation; the fallow phase of the 2-yr rotation had about half the light fraction of the wheat in the 5-yr rotation. The 5-yr wheat phase control had 3. 97 (± 0.27) g LFOM /kg soil and the 2-yr wheat phase control had 2.70 (± 0.40) g LFOM /kg soil (Table 2.4).

The portion of total C in the form of LF C was 6.07% , 6.03% and 8.52% for the control, manure and fertilizer treatment in the 5-yr rotation. In the 2-yr rotation the proportion of light OM carbon ranges between 3.02 and 5.83 % of total C.

Table 2.4 Mass of light fraction organic matter, amount of carbon in light fraction and the mass of carbon per kg soil as well as the fraction (%) of total carbon in two cropping systems at Breton, Alberta during spring 1995. Standard deviation have been included and are based on four sub-samples.

Cropping systems	*Rotation*	*Dry weight*	*Carbon*		
	Phase	g /kg soil	g LFC/ kg LF	mg C/kg soil	% LFC of TOC
Wheat (5-yr)	control	3.97 ± 0.27	225	893	6.07 ± 1.84
	manure	4.92 ± 0.23	253	1246	6.03 ± 1.11
	fertilizer	5.44 ± 0.11	284	1545	8.52 ± 0.61
Wheat (2-year)	control	0.87 ± 0.13	262	228	3.02 ± 1.73
	manure	2.70 ± 0.40	271	731	5.73 ± 3.13
	fertilizer	2.02 ± 0.29	243	490	5.83 ± 3.45
Fallow (2-year)	control	1.31 ± 012	293	386	4.08 ± 1.27
	manure	2.91 ± 0.58	240	698	3.41 ± 2.83
	fertilizer	1.43 ± 0.19	243	348	3.44 ± 1.88

Table 2.5. Light fraction organic matter content in two cropping systems at Breton. Alberta during spring 1996. Samples were collected after cultivation and have been collected from all phases of the two rotations.

Cropping system	*Treatment*	*Dry weight*		*Carbon*	
		g /kg soil	g/ kg LF	mg /kg soil	% total carbon
WOBHH	control	1.07	305	326	2.38
	manure	0.15	272	42	0.19
	fertilizer	1.82	301	549	3.52
WOBHH	control	0.44	300	133	0.90
	manure	0.76	289	220	1.08
	fertilizer	0.84	297	250	1.52
WOBHH	control	1.96	271	534	4.11
	manure	1.78	307	548	2.46
	fertilizer	2.73	253	693	4.07
WOBHH	control	1.09	263	287	2.24
	manure	1.95	281	548	2.63
	fertilizer	3.97	284	1130	6.98
WOBHH	control	1.30	335	437	3.05
	manure	1.19	314	373	1.53
	fertilizer	1.39	306	427	2.48
WF	control	0.55	258	143	1.84
	manure	0.37	294	110	0.88
	fertilizer	0.55	293	162	1.72
WF	control	0.13	--		--
	manure	0.62	302	187	1.77
	fertilizer	0.92	223	204	2.80

However, the variability is large so that manure amended soil in the 2-yr rotation is not significantly different from the 5-yr rotation.

During spring 1996 the absolute value and proportion (Table 2.5) of light organic matter content was lower than spring 1995; the variability of these samples could not be determined since the sub-samples were combined to form a composite sample. The trends for 1996 were different from 1995 in the WF rotation; light fraction organic matter increased from control to manure to fertilizer, while in 1995 manure amendment had the highest amount of light fraction organic matter. In the 5-yr rotation the cereal crops follow the same pattern as the previous year. However, the forage year 1 did not show difference among treatments while the forage year 2

had about 2.2, 2.6 and 7.0 % of total C as LFC in the control manure and fertilizer amendments, respectively. Light fraction organic matter ranged from 0.443 to 4.4 g light fraction organic matter kg^{-1} soil in the 5-yr rotation, while in the 2-yr rotation the mass of LFOM ranged from 0.10 to 0.20 g light fraction organic matter kg^{-1} soil. When this was converted to a percentage of total carbon, light fraction values ranged from less than 1% to 7% of total organic carbon. During spring 1996 the proportion of soil organic carbon which was in light fraction organic matter did not indicate a definite trend.

Potentially Mineralizable Carbon

Potentially mineralizable carbon (Co) was highest in the continuous cropping system with the barley and forages having the highest cumulative CO_2 evolved (Table 2.6). Co for manure amended treatment in barley was 1132 (± 123) mg CO_2-C/kg soil. and the lowest Co in the 5-yr rotation was 544 (± 40) mg CO_2-C/kg soil for oats phase in the control treatment. The wheat phase fertilizer treatment of wheat-fallow had the least amount of carbon mineralized in terms of g CO_2 -C/kg of soil which was 524 (± 33) mg CO_2-C/kg soil. The higher cumulative soil respiration generally reflected the greater soil organic carbon in the soil. Forages had the highest total soil organic carbon within the 5-yr rotation and the WF had the lowest soil organic carbon. In the 5-yr rotation Co ranged between 3.24% to 6.64% of the total organic C present. The Co in the 2-yr rotation ranged from 4.94% to 7.80% of total organic C in the soil.

Cumulative CO_2 losses followed a similar pattern in all cases (Fig. 2.1 a-g); a rapid mineralization phase was observed in the first three weeks then a decreased rate for the next 10 weeks. The continuous cropping system had higher emissions of CO_2 than the 2-yr rotation. The total values for the continuos system were as high as 1100 mg CO_2-C/ kg soil while the WF was about 50 percent less. The wheat phase in the 5-yr rotation did not show any difference among treatments while the 2-yr wheat had higher emissions in the manure phase.

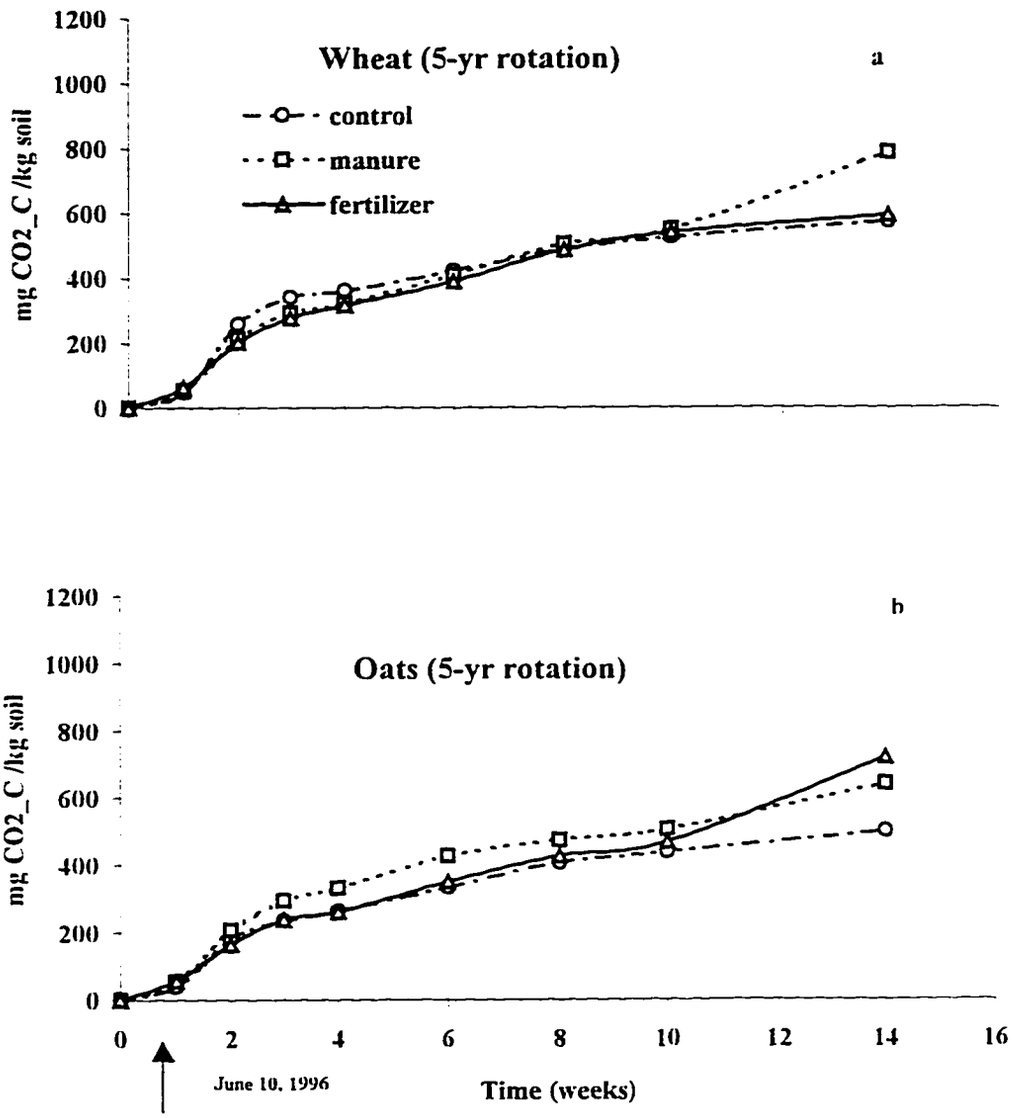
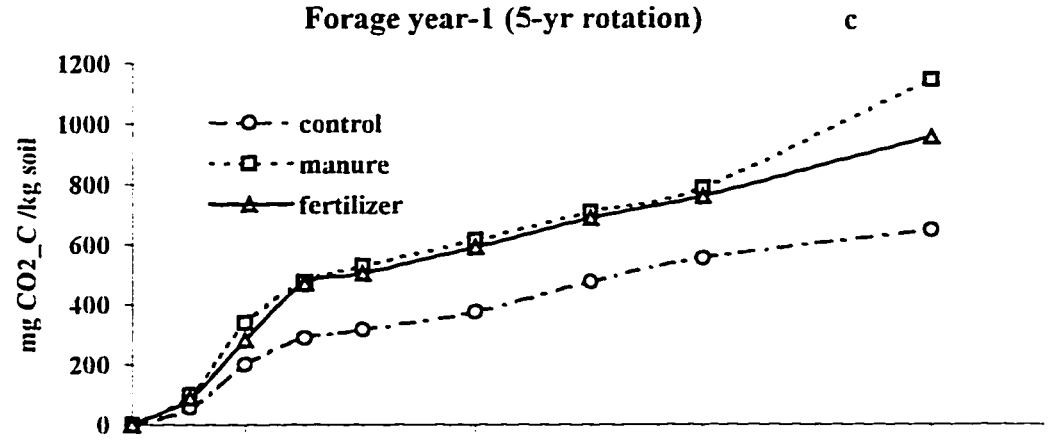
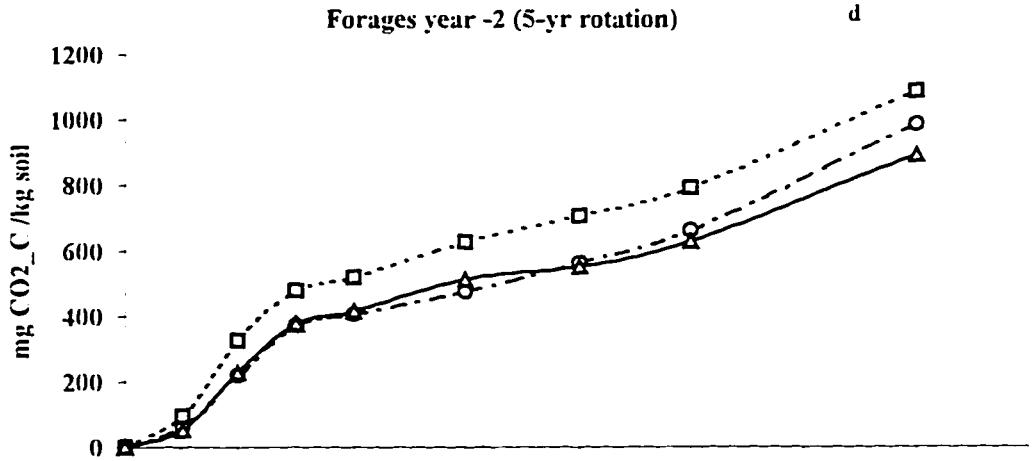
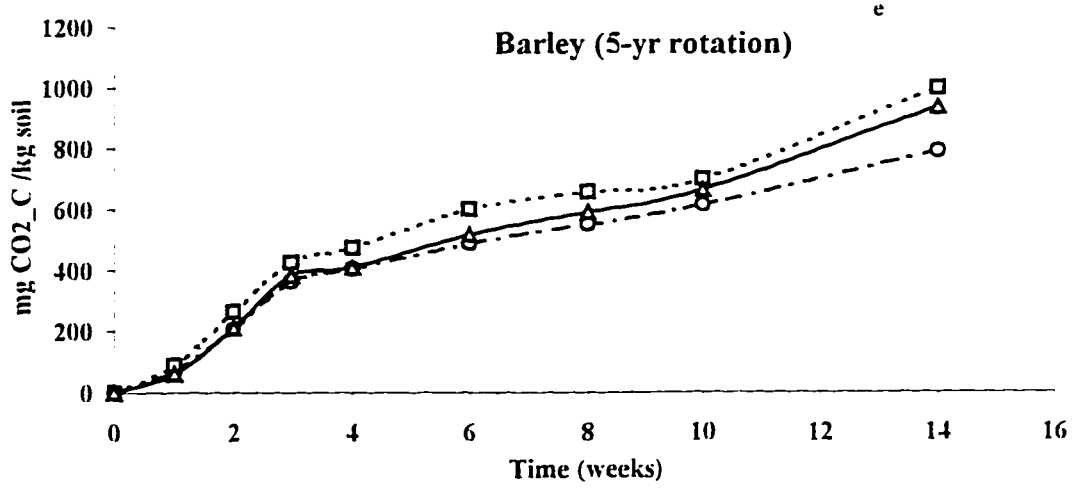


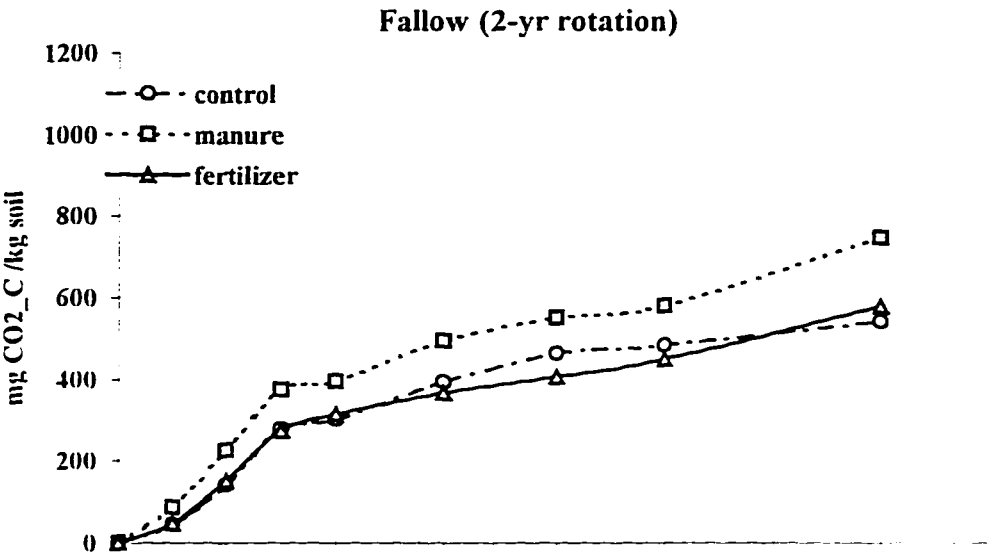
Figure 2-1(a-g) Potential carbon mineralization under two long-term cropping systems at Breton, Alberta. Incubation was done at 22 C for 14 weeks at 60% water holding capacity.


Forage year-1 (5-yr rotation)
c
1200
1000
800
600
400
200
0
mg CO2_C /kg soil
control
manure
fertilizer


Forages year -2 (5-yr rotation)
d
1200
1000
800
600
400
200
0
mg CO2_C /kg soil


e
Barley (5-yr rotation)
1200
1000
800
600
400
200
0
mg CO2_C /kg soil
0
2
4
6
8
10
12
14
16
Time (weeks)

f


Fallow (2-yr rotation)
control
manure
fertilizer
mg CO2_C /kg soil
1200
1000
800
600
400
200
0

g

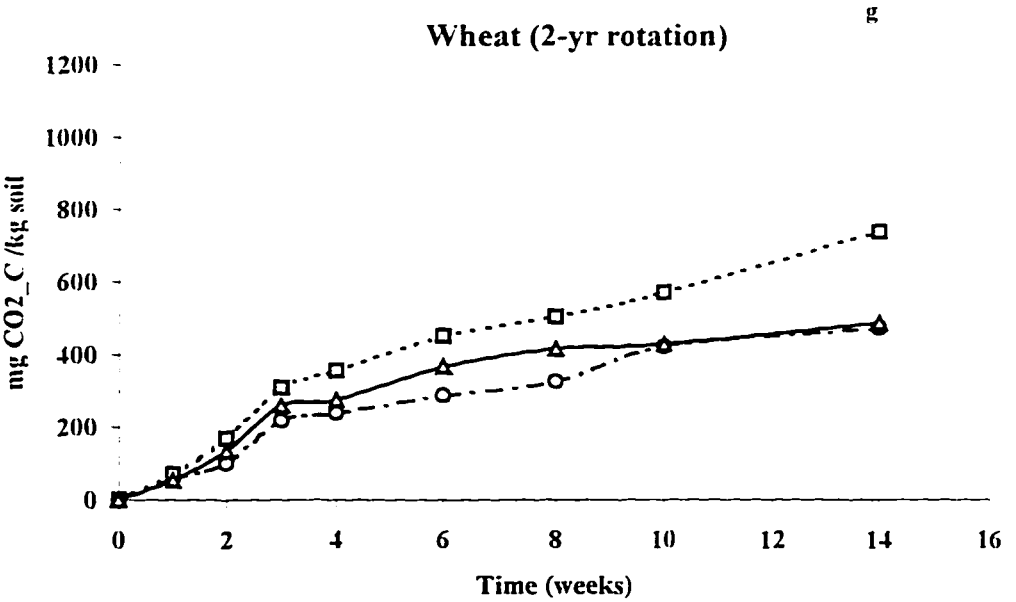

Wheat (2-yr rotation)
mg CO2_C /kg soil
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
16
Time (weeks)

Table 2.6 Potentially mineralizable carbon (Co), both as mg CO2-C/ kg soil and % of total organic C, and rate constant (k) for the Classical Breton Plots estimated from the first order model. Values in brackets are standard error.

Cropping system	*Amendment*	*Co*		*k*
		mg CO_2-C/ kg soil	**% total C**	**week^{-1}**
WOBHH	control	578 ±(36)	4.23	0.244 ±(0.037)
	manure	1000 ±(130)	4.47	0.092 ±(0.018)
	fertilizer	628 ±(48)	4.02	0.0174 ±(0.026)
WOBHH	control	544 ±(40)	3.67	0.168 ±(0.024)
	manure	657 ±(55)	3.24	0.171 ±(0.028)
	fertilizer	617 ±(82)	3.76	0.144 ±(0.034)
WOBHH	control	845 ±(71)	6.51	0.148 ±(0.023)
	manure	1046 ±(86)	4.69	0.139 ±(0.020)
	fertilizer	1132 ±(123)	6.64	0.103 ±(0.018)
WOBHH	control	872 ±(72)	6.08	0.144 ±(0.021)
	manure	940 ±(68)	3.85	0.194 ±(0.029)
	fertilizer	979 ±(99)	5.69	0.123 ±(0.021)
WOBHH	control	740 ±(44)	5.77	0.135 ±(0.014)
	manure	941 ±(79)	4.52	0.195 ±(0.033)
	fertilizer	980 ±(64)	6.05	0.168 ±(0.022)
WF	control	564 ±(59)	6.66	0.126 ±(0.023)
	manure	843 ±(62)	4.94	0.125 ±(0.016)
	fertilizer	525 ±(33)	6.58	0.189 ±(0.025)
WF	control	607 ±(44)	7.80	0.169 ±(0.025)
	manure	744 ±(48)	5.92	0.184 ±(0.025)
	fertilizer	600 ±(48)	6.36	0.161 ±(0.025)

Addition of manure to crop rotation led to higher CO_2 emissions than the fertilized treatments. This was not the case for the first 10 weeks in the wheat phase in the 5-yr rotation; all amendments were not different , yet after 14 weeks the manure amended treatment had the highest emissions and Co was significantly different 1000 (± 123) mg CO_2-C/kg soil. In the first three weeks emissions from the control plot are higher than the fertilized and manure treatments. however after six weeks all treatments are equal. Towards week 10. cumulative CO_2 in manure is higher than fertilizer and control treatments. In the two-year rotation. the trend is quite similar to the 5-yr rotation. Carbon evolved from manure amended soil was higher in both

phases after two weeks and this trend remained through out the incubation period. Emissions from the manure plots in fallow phase were slightly higher than from the wheat phase. In both phases control plots had the lowest emissions.

Discussion

Distribution of actively cycling carbon

The WF and WOBHH rotations studied in this work have been cultivated for over sixty years. Therefore the soil physical and chemical properties of these plots has been under the same management system and the plots should have similar properties in terms of pH. EC. CEC as these plots have been under similar management. However active soil organic matter is dependent on both short term and long term factors; consequently differences are observed in microbial biomass. light fraction organic matter and potentially mineralizable carbon. Soil organic matter trends in the two rotations suggest that the 5-yr rotation is accumulating carbon above the original carbon content of these soils. On the other hand the WF rotation has lost some of the organic carbon and the manure additions have been able to maintain the original carbon content. Originally, soil organic carbon of the Breton plots surface horizon (0-15 cm) was approximately 1.2 percent (Izaurralde et al.. 1995). Soil organic carbon in the Ap horizon from the 5-yr rotation ranged from 1.2 to 2.4%. while the WF rotation was between 0.8 % to 1.7% (Table 2.3). In the 2-yr rotation the control and fertilizer treatments. soil organic carbon content is less than 1% while the manure additions have maintained organic carbon levels at about 1.5%. This agrees with results from a long-term WF experiment in the Pacific Northwest. where losses of organic matter were increased by fallow systems and soil organic carbon levels were maintained by addition of manure (Rasmussen et al., 1980). Losses in SOM can be reversed by increasing the length of the crop rotation and converting to conservation tillage (Biederbeck et al., 1984; Larney et al., 1997).

During spring 1995 wheat (5-yr) had higher light fraction carbon content 3.97 (± 0.27) mg LFOM/ kg soil than the wheat and fallow phase of the WF (Table 2.4).

Light fraction organic matter was highest in the 5-yr rotation. Janzen et al. (1992) studied wheat-based rotations in the Canadian prairies and found that light fraction organic matter content increased with continuous cropping systems and forages.

Also addition of fertilizer and manure increase the amount of light fraction carbon relative to control plots. Addition of nutrients would stimulate root mass and increase the amount of root exudates contributed to the soil over the growing season

The 5-yr rotation has greater C inputs than the WF rotation; this corresponds with the soil organic carbon trends over the long term; and suggests that light fraction carbon is a sensitive indicator of management influences on soil organic carbon in agro-ecosystems (Janzen et al., 1992). Bremer et al. (1994) found that light fraction carbon ranged from 8% to 24 % of total soil organic carbon in a soil near Lethbridge. However, caution in interpretation of results must be exercised as light fraction organic matter is subject to temporal and vertical distribution, for example, Spycher et al. (1981) found that LF material increased by 50 to 100 % from spring to summer and fall in a forest soil.

Results from year 1 to year 2 of this study are quite different, it is difficult to draw comparisons between the two sampling periods as in the first year the plots had not been cultivated, while the second year sampling was carried out after cultivation had taken place. This cultivation may have redistributed light organic matter deeper in the profile causing a dilution effect, explaining why the concentrations are lower during 1996 than 1995. Another possibility is that cultivation causes changes in bulk density and ridging of the soil leading to errors in depth sampled. Furthermore, depending on type of cultivation implement used, an inversion of the soil is often observed (Larney, pers. comm.). The LFOM also varies with soil depth. For example, the amount of LFOM will depend on the plant biomass yields the previous growing season. Also, Spycher et al. (1981) reported that light fraction carbon accounted for 53 percent total C in the top 3 cm and about 24 percent in the lower horizon (63- 83 cm). In addition they found that light fraction carbon decreased from 53 percent of total C in the surface to about 24 percent in the lower horizons.

Microbial biomass accounted for less than 3.48% of total organic carbon in both crop rotations (Table 2.3). McGill et al. (1986) found that average microbial C accounted for 3.3 and 2.5 percent of organic carbon; also they found that the 0- 5 cm layer had a greater microbial C than the 5-15 cm layer. The concentration in the top 5 cm were higher possibly due to the time of sampling or due to the depth of horizon sampled as microbial biomass is higher in the surface (0- 5 cm) horizon. Our results report the average of the top 15 cm and are slightly lower. Microbial C in wheat (WOBHH) was about twice that of wheat (WF) (Table 2.3) and this observation is consistent with McGill et al.(1986). Collins et al. (1992) found that microbial C in a long-term crop accounted for about 4.3, 2.2, and 2.8% of organic carbon in grass pasture, annual cropping, and wheat-fallow, respectively.

Sparling (1992) indicated that microbial C is influenced by short-term and long term factors. McGill et al. (1986) observed seasonal fluctuations in microbial biomass dependent on short-term factors such as temperature and moisture levels: however, base levels of biomass remained constant and characteristic of the long-term rotation imposed. The data for the spring 1996 initial sampling from Breton (Table 2.3) supports this conclusion.

In previous studies researchers have observed a decrease in microbial C when studying effect of crop rotations and fertilizer treatments on microbial biomass (e.g. Ladd et al. 1994). Fertilizer treatment tends to decrease soil pH, and this may have accounted for decreased microbial biomass pool. In our study this decrease in pH was counterbalanced by addition of lime. Our results did not show any differences among treatment (Table 2.3) suggesting that the microbial biomass was dependent on other factors than the amendment. Another possibility may be a shift in the decomposer community towards fungal population which can exist under acidic conditions (Ladd et al., 1994) and the fumigation extraction method may not have been able to distinguish between different communities.

Potentially mineralizable carbon ranged from 3.24% to 7.80% of total organic carbon in both rotations. Cumulative carbon lost as CO_2 was highest in the 5-yr rotation (Figu 2.1 a-g) compared to the wheat-fallow system: this can be explained by

a larger pool of C in the 5-yr rotation . When considering the fraction of total carbon lost, the 5-yr rotation lost a smaller proportion. The continuous cropping system lost between 3.24% to 6.64% while the 2-yr rotation lost between 4.94% and 7.80% (Table 2.6). The trend then indicates that microorganisms in each rotation have been able to utilize different fractions of the organic matter pool. This suggest that if microorganisms are starved for carbon then they develop the ability to breakdown the more recalcitrant organic matter. Alternatively other components of microbial biomass are active in breaking down SOM.

Potentially mineralizable carbon was thehighest in the manure amendment, although, when expressed as a proportion of total organic C, the control plots lost the greatest fraction of total C. It is the treatment which has not received additional nitrogen which mineralizes the greatest portion of SOM. Again, this suggests that microbes have developed the capacity to use recalcitrant SOM as energy source: in the absence of additional carbon as manure or root exudates microbes have increased the potentially mineralizable fraction. In a greenhouse study native soil organic matter decomposition was delayed in the presence of high mineral N soils as compared to the decomposition rates in soils planted to the same crops but receiving smaller amounts of mineral nitrogen (Kuikman and Gorissen, 1993).

Active carbon indicators

Light fraction carbon, microbial C, and potentially mineralizable C were greater in the 5-yr rotation in terms of total amount per unit of soil; expressed as a fraction of total C for each phase the trends were not always the same. However, expressing the results as a fraction of total carbon present may be a better indicator of management effects. Soils at Breton are Luvisolic, with characteristic low organic matter content and have developed under more humid conditions leading to a more rapid decay of organic matter than the Chernozemic soils. In Ontario, Ellert and Gregorich (1993) compared proportions of organic matter in active pools of soils under forest adjacent to crop land. They found that cultivated soils had lower proportions of total C in light fraction.

Microbial biomass, the living fraction of soil organic matter has been suggested as a useful and more sensitive measure of change in organic matter status (Sparling, 1992). Carter (1986) used the chloroform fumigation incubation method (CFIM) to study the effect of tillage and crop rotation on soil biological properties. He found that introduction of arable crops and cultivation decreased microbial biomass in a wheat-fallow system in Vegreville, Alberta. The Ap horizon in wheat-fallow rotation had 69 kg microbial C ha^{-1} while a continuous wheat Ap horizon had 171 kg microbial C ha^{-1}. Similar results were found in Saskatchewan Chernozemic soils (Campbell et al., 1991). In New Zealand the $C_{microbial}$ / $C_{organic}$ ratio was tested as an indicator of management effects on SOM in pasture soils and arable land. The ratio was between 1 to 4% of organic C, and pasture soils had consistently a higher ratio than arable soils (Sparling, 1992). However, the absolute values were erratic in certain soils and the trends were dependent on soil texture, mineralogy, and cropping history. In some cases, the trend of microbial C was opposite to total C. In Australia, a study to determine the influence of agronomic practices on plant yields and soil properties over five years found that biomass was affected by agronomic practices (Ladd et al., 1994); however, biomass trends did not consistently relate to changes in the concentration of SOM. Differences found between rotation in the early years converged over the 5-yr period, while the differences remained constant for total C and N (Ladd et al., 1994). Addition of fertilizer in these long term trials has shown a decrease in microbial population (Ladd et al., 1994). They concluded that microbial C was influenced by both short term and long term factors.

In our study we conclude that microbial biomass is not significantly different within the 5-yr rotation; differences between the 2-yr rotation are not significant. The microbial biomass is very small carbon pool and is overly sensitive to environmental factors; however our results agree with previous work of McGill et al. (1986) which concluded that microbial biomass remained constant when averaged over time and was a function of cropping system. Seasonal variations of microbial biomass were similar to those observed by McGill et al. (1986). In terms of light fraction results from spring 1995 indicate that continuous cropping accumulates carbon in the light

fraction while the 2-yr rotation decomposes a greater portion of light fraction. This was the case for potentially mineralizable carbon in 1996. The differences in light fraction carbon, microbial C, and potentially mineralizable C observed were a function of crop, cultivation practice and previous cropping history which make up the management of this agro-ecosystem.

The results of this study indicate that SOM content at Breton Classical Plots is increasing in the WOBHH rotation; and that manure additions are able to maintain higher SOM contents in the WF rotation. It was shown that small biologically active pools are dependent on short term factors imposed over management which can confound the use of active carbon pools as indices of SOM trends. Therefore it is best to sample several times over the season to account for environmental variables.

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Chapter 3. Seasonal Dynamics of Carbon Dioxide Emissions, Microbial Biomass, Mineral N from Gray Luvisolic soil under Long-Term Crop Rotations at Breton, Alberta

Carbon dioxide accounts for 50 to 60 percent of the increase in radiative forcing of greenhouse gases contributing to global warming. Although fossil fuel burning and activities associated with its extraction are significant contributors to global warming, agricultural activities account for about one quarter of the increase in global warming. Global soil and plant respiration contributes about 68 Gigatons (Gt) C yr^{-1}, an order of magnitude higher than the 5.7 Gt C yr^{-1} (1987) released to the atmosphere though fossil fuel burning and industrial sources (Bowden, 1993). The current release of CO_2 due to conversion of land to agriculture is estimated to be in the range of 0.6 to 2.6 Gt C yr^{-1} (Duxbury et al., 1993).

Carbon dioxide exchange between the atmosphere and agricultural systems is an important component of the carbon cycle (Rochette et al., 1992). In soil, organic matter is transformed by soil biota into a wide variety of compounds or returned to the atmosphere as CO_2. Decomposition of soil organic matter and respiration of the vegetation are the major contributing processes of CO_2 release from terrestrial systems to the atmosphere (Kuikman and Gorissen, 1993). Carbon dioxide fluxes are controlled by biotic processes and modified by abiotic factors such as climate and management. Management of agro-ecosystems changes soil micro-environment and indirectly affects soil respiration.

The rate of CO_2 evolution from the soil is a function of the activity of soil microorganisms, soil invertebrates and plant root respiration (Wildung et al., 1975). Estimates of microbial respiration contribution to total soil respiration are difficult to separate from root respiration. Microbial activity is dependent on available carbon, and in cultivated ecosystems fresh residues are greatest when decay potential is highest (Buyanovsky et al., 1987). Microbial population can be twenty times higher in the rhizosphere than in bulk soil (Walton et al., 1994). Roots and rhizosphere organisms account for approximately 20 to 25 % of below-ground respiration (De Jong et al., 1974).

In the field microbial biomass will vary depending on substrate availability, therefore it will change according to changes in root mass and quantity of exudates. In addition, biomass is very sensitive to changes in its micro-environment. Consequently soil respiration in the field is dependent on the dynamic interactions between soil biota and its environment.

Furthermore, the amount of CO_2 released from the soil is determined by plant root respiration. Tate et al. (1993) estimate that fine roots respiration account for 23 % of total respiration in an old growth temperate forest. About one-third to two-thirds of the photosyntate translocated to the roots are used in respiration (Lambers et al., 1992). The proportion varies through out the growing season and depends on the kind of plant species. In addition, the growing root tip will have a higher energy demand and will respire more actively than the rest of the plant (Lambers et al., 1992).

Soil respiration is the result of physiological processes dependent on adequate water and temperature status in the environment. The dynamics of CO_2 are influenced by soil and air temperature, moisture (Buyanovsky and Wagner, 1983; Rochette et al., 1992), and soil properties (De Jong, 1981). There is significant interaction between soil moisture and temperature to control CO_2 evolution rates consequently quantifying relationships between soil respiration and environmental factors a very complex problem, particularly under field conditions.

The rate of CO_2 emission is dependent on temperature but mathematical relationships between temperature and rate of CO_2 evolution have not been well established. Field studies indicate that correlation between soil temperature and soil respiration decreases above 15°C because temperature has little effect on soil respiration (De Jong, 1974). Buyanovsky (1986) found that when accounting for variability in CO_2 evolved during annual cycles, soil temperature was most significant factor, and soil water content was second. Soil temperature was significantly correlated to soil respiration in a grassland soil only when soil moisture content was above 10 percent (Wildung et al., 1975). The Q_{10} factor, an indicator of the increase in biological activity for every increase of 10 °C, for soil respiration have been derived and range from 1.96 to 2.61

(Howard and Howard. 1993) to between 3 and 5 (Lessard et al.. 1994; Rochette et al. 1992).

Although soil moisture plays a significant role in respiration there is a range for certain soils in which moisture changes do not affect soil respiration rate. Lessard et al. (1994) found that CO_2 fluxes were not correlated to soil moisture content in a cultivated site nor in a forest. Edwards (1974) found that in forest soils where there was no moisture deficiency, water content was not statistically significant in accounting for soil respiration variability. In another study, Redmann (1978) compared the relationship between soil respiration to soil moisture and precipitation events; he found that soil moisture had a much lower level of significance than soil temperature or precipitation vs. soil respiration of a wheat ecosystem. He suggested that freeze-thaw and wetting-drying cycles may play a more significant role in controlling soil respiration fluxes.

In general. diurnal trends indicate that maximum respiration occurs mid-afternoon. and decreases during the night (Redmann. 1978; Rochette et al.. 1992). The rate of CO_2 evolution increases over the growing season. and peaks during the middle of summer. when crops are contributing carbon substrates to microorganisms and root respiration is at its peak. After the growing season. in late summer and early fall. peaks in soil respiration are observed when moisture and temperature are optimum to decompose plant residue. During winter. when soil climatic conditions are unfavorable to soil microorganisms and available carbon has been depleted soil respiration is at its lowest levels (De Jong. 1974; Buyanovsky 1983). Variability of soil respiration in the field occurs at a scale of less than 1 m (Rochette et al., 1991). and makes quantifying annual fluxes quite difficult. The measurement of soil respiration in the field is an essential link in the carbon cycle and with the monitoring of additional variables such as moisture and temperature it is possible to predict soil respiration rates.

Rochette et al., (1992) found soil respiration to be higher in a fallow field than in barley crop. however the fallow field had high manure application rates in the past. In a comparison of grassland soils de Jong (1981) compared fallow and cultivated sites and concluded that there was no difference between the two. A possible explanation for

higher CO_2 emissions is that fallow soils have warmer temperatures and higher moisture condition leading to accelerated organic matter decomposition.

The Breton plots have been under similar management for over sixty years and SOM dynamics have been studied in the past (Juma et al., 1997; McGill et al., 1986); however, these studies have focused on below ground soil carbon. There is a need to investigate the dynamics of CO_2 emissions from agro-ecosystems.

Measurements of CO_2 flux can be done both at the field level or in the laboratory; but no standardized method is available. Common methods for field measurement of CO_2 flux are the flow-through open chamber, closed chamber, soil wells, and towers. The chamber methods have been widely used and essentially trap gases in a head-space. The change in concentration can be analyzed using infra-red gas analyzers (IRGA). This method allows records to be taken directly in the field and requires less handling of the samples. Static chambers trap soil air in a head space. The CO_2 can be quantified by gas chromatograph, or an alkali trap can be used to capture CO_2 and quantification is carried out by titration. Infrared gas analyzers have been used extensively in photosynthetic studies and more recently are being used in evaluating soil respiration (e.g. Norman et al., 1992; Bekku et al., 1995; Rochette et al., 1997).

The objectives of this project were to: (1) compare methods between the two chamber techniques; (2) quantify soil respiration in cultivated experimental plots; (3) study the factors that influence rate of organic matter decomposition; and (4) compare the effect of nutritive amendments on soil respiration.

Materials and Methods

Site description

The site is located at Breton, 110 km SW of Edmonton. Soils and crop rotations have been described in Chapter 2. Briefly two cropping systems, WOBHH and wheat-fallow, have been established over sixty years ago. All phases of the rotations are present each year as series and each series has been sub-split to test nutritive amendments. For this study three amendments were selected: control, manure and fertilizer. The study was carried out for two growing seasons: 1995 and 1996. During 1995, a preliminary study

was carried out by sampling three crop phases at selected times over the growing season to determine whether differences in soil respiration could be measured. In 1996 all crop phases were sampled on a weekly basis from May to September. In addition, soil samples were collected once every three weeks and analyzed for moisture content, mineral N and microbial biomass.

Spring 1995 soil respiration using gas chromatography

Soil respiration was measured on July 12 and 19; August 02, 19, and 24; and on September 13, in series A, E_w, and E_f. An overview of the experimental site is given in Table 2.1. Soil respiration was determined using chambers as described by Hutchinson et al. (1981). Aluminum chambers were covered with insulating material and reflective sheets to minimize heat transfer. Gas sample chambers were inserted 2.5 cm into the soil surface to obtain a seal between chamber and soil. Gas samples were withdrawn using a 30 ml syringe at 0, 15 and 30 minutes. The samples were transferred to vacu-tainers previously evacuated to about 10^{-4} MPa and sealed with latex caulking. Gas samples were transported to the laboratory and analyzed using a VARIAN 3400 gas chromatogram. Soil respiration rate was calculated and expressed as g CO_2 m^{-2} hr^{-1}.

Soil respiration using IRGA 1996

Soil respiration was measured using SRC-1 soil respiration system which consist of a soil respiration chamber and the EGM-1 Environmental Gas Monitor (PP Systems, Haverhill MA USA). Measurements were carried out between 10 a.m. and 2 p.m. on a weekly basis. The EGM-1 contains an infrared gas analyzer which measures CO_2 in a closed circulation system. A fan attached to the roof of the respiration chamber gently stirs the air inside to ensure continuous mixing. Soil respiration is recorded based on the increase in carbon dioxide in chamber over a period between 24 seconds to 96 seconds. The rate of respiration is determined from the first derivative of a best fit quadratic for the increase in CO_2 concentration vs. time and is expressed as g CO_2 m^{-2} hr^{-1}. The SRC-1 is equipped with a soil temperature probe and the soil temperature at 5 cm depth was recorded.

The following formula was used to calculate respiration rate for both instruments:

Soil respiration (R) = $V(C- C_o)/At$

where R = Soil respiration rate (g CO_2 m^{-2} hr^{-1}); Co = CO_2 concentration at time zero: C = CO_2 concentration at time t; V = total system volume (m^3); and A = surface area exposed (m^2). The gas flux was expressed as g CO_2 m^{-2} hr^{-1}.

Seasonal soil microbial biomass

Microbial biomass was measured using the fumigation extraction method (Voroney et al., 1993). Details of method are given in Chapter 2. Briefly moist field samples were fumigated and extracted once every three weeks. Soluble carbon from fumigated and non-fumigated samples was measured using an ASTRO 2001 carbon auto-analyzer (ASTRO. Texas USA).

Mineral N was measured by extracting 10 grams of field moist soil with 50 ml KCl (0.5 M). Samples were frozen until analysis. and quantities of NH_4^+ and NO_3^- were measured using industrial methods 98-771W (Technicon. 1973) and 487-77A (Technicon 1977). respectively.

Soil moisture was determined gravimetrically. Ten grams of field moist soil were placed at 105 °C for 24 hours. The mass of dry soil and water was calculated and expressed as percent moisture (mass water/mass dry soil).

Results

Differences in soil moisture were not different among the various crop phases in the 5-yr rotation. In general soil moisture appeared to be slightly higher in the continuous cropping system than in the wheat fallow. Gravimetric water content ranged between 20 and 40 percent through out the growing season in the continuous cropping system and ranged as high as 35 percent in the forage phases (Fig. 3.1). The 2-yr rotation had moisture content between 15 and 25 percent. The fallow plots were slightly higher than the wheat phase in the two year rotation. In all phases moisture content increased after mid august when plant growth had ceased.

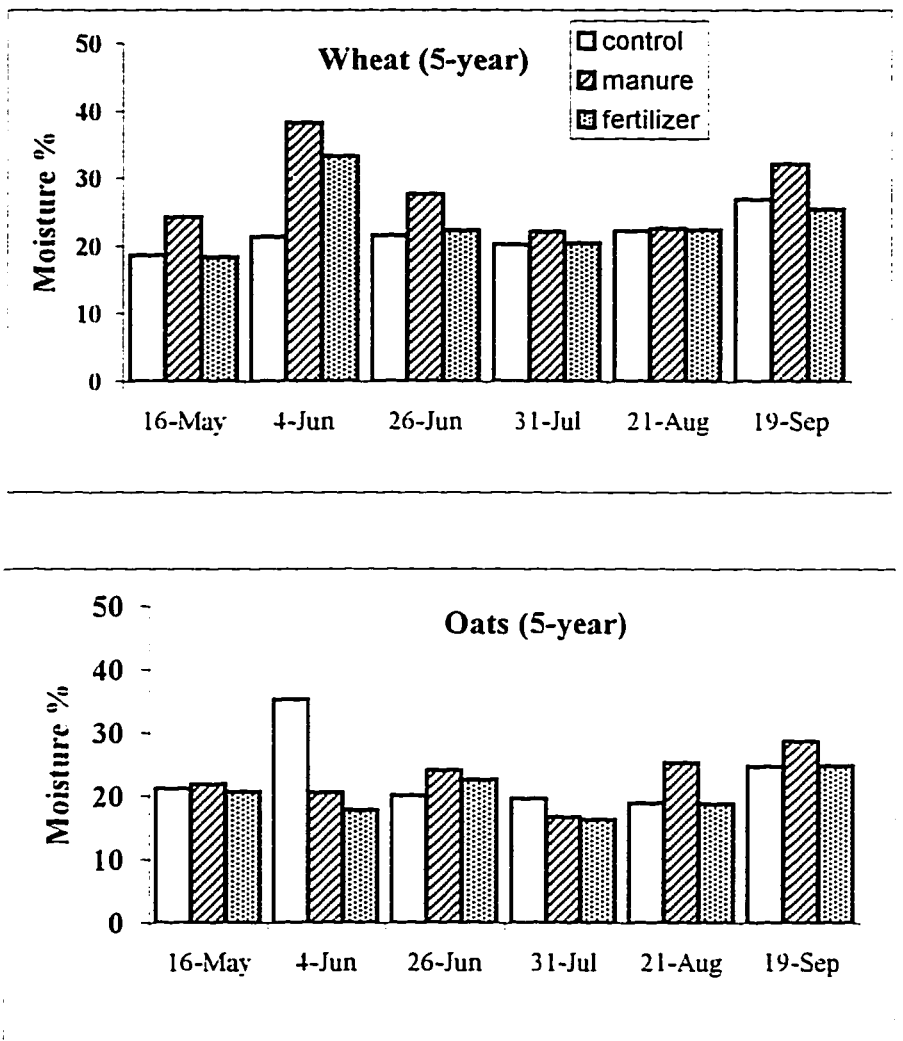
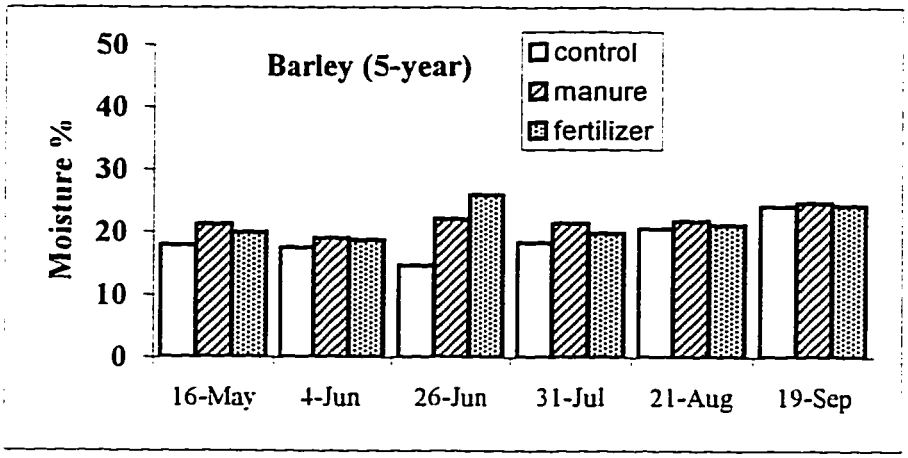
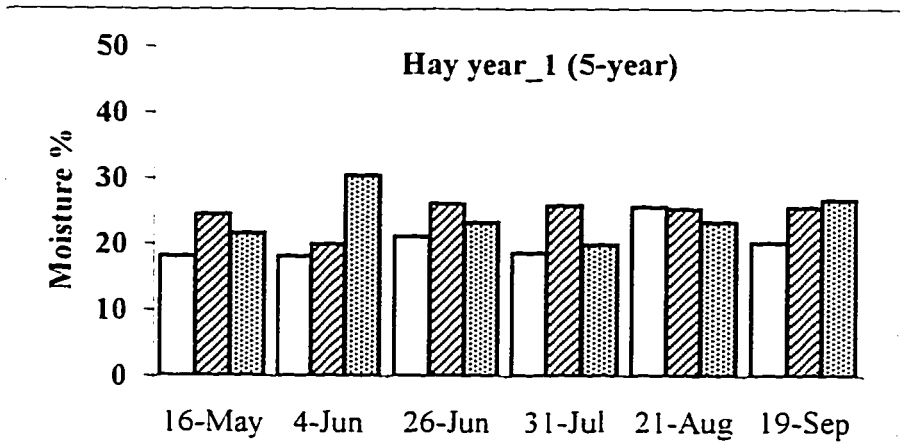
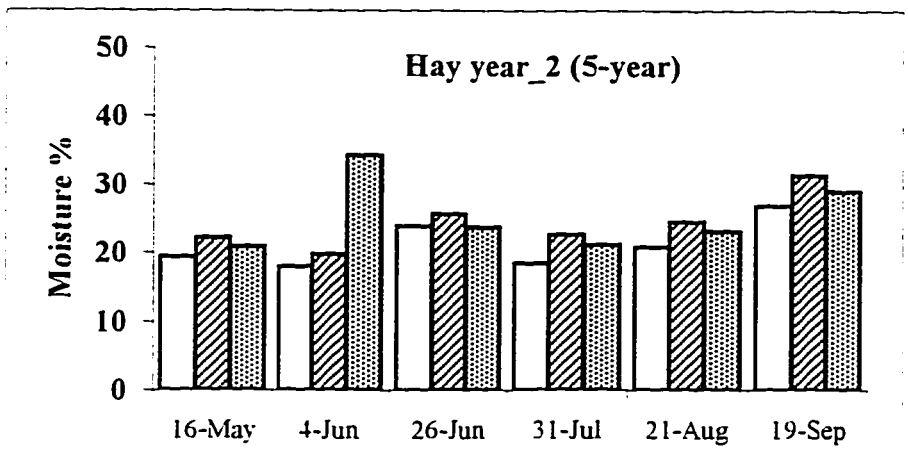
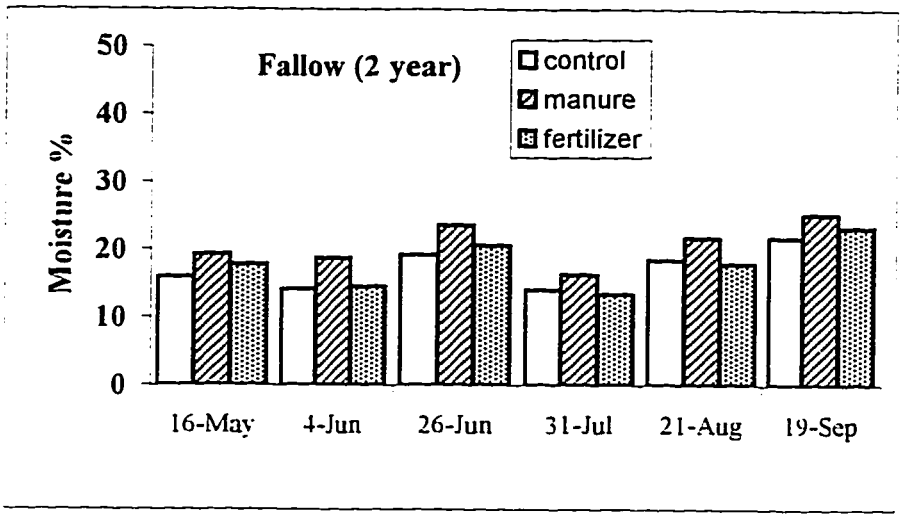


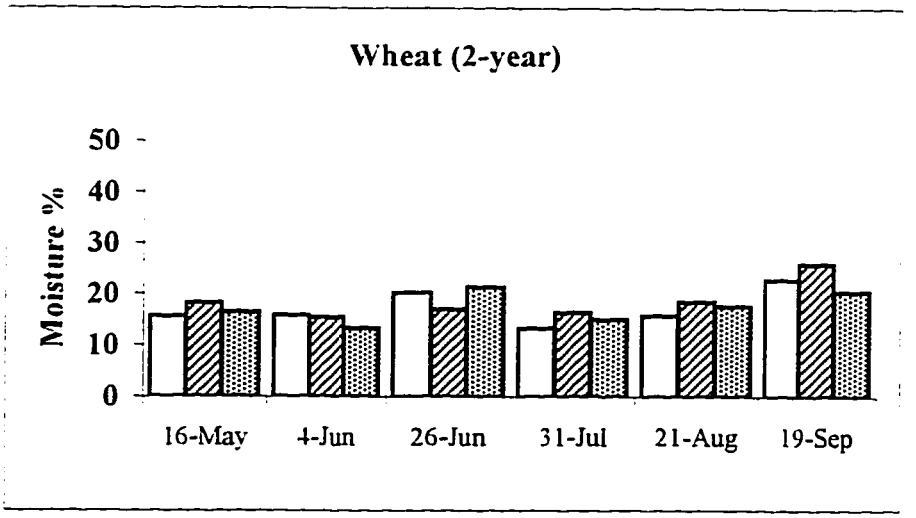
Figure 3.1. Soil moisture content (0-15 cm) during the 1996 growing season. Control, manure, and fertilizer amended plots were sampled for all the phases of the 5-yr (wheat, oats, barley, hay_1, and hay_2) and the 2-yr (wheat-fallow) rotations.


Barley (5-year)
control
manure
fertilizer
Moisture %
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay year_1 (5-year)
Moisture %
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay year_2 (5-year)
Moisture %
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Fallow (2 year)
control
manure
fertilizer
Moisture %
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Wheat (2-year)
Moisture %
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep

The addition of manure appears to have increased the capacity to hold water as generally the manure amended plots had slightly higher moisture content. However in early spring and at mid-summer the moisture content was the same in all three amendments. Organic matter has a high water holding capacity and is also a substrate for microbial decomposition.

Soil respiration during 1995 using the Hutchinson chamber indicated that wheat in the continuous cropping system had the highest CO_2 emissions, while the lowest values were measured in the fallow treatment of the wheat fallow rotation (Fig. 3.2). The respiration rates were highest during the months of July and early August which corresponds to period of greater plant activity. Soil respiration on July 19, 1995 in the wheat (5 year) fertilized plots was about 0.474 g CO_2 m^{-2} hr^{-1}. In the 2-yr cropping rotation manure amendment usually results in greater respiration than fertilizer and control plots. Coefficient of variations ranged from less than ten percent to eighty percent.

The 2-yr rotation had respiration rates which were at times less than 50 % of the continuous cropping system. During the month of July the respiration rates were as high as 0.4 g CO_2 m^{-2} hr^{-1} and after crop had been removed the respiration rates decreased to about 0.15 g CO_2 m^{-2} hr^{-1}. There were no differences in the CO_2 emission rates after the crop had been harvested. During the July 12 sampling the wheat crop had higher respiration rates than the fallow phase but during the other dates the rates were similar.

The comparison of Hutchinson chambers with EGM-1 indicate that the respiration rates obtained with EGM-1 are higher. Fig 3.3 is a regression of the data obtained using the two methods. The relationship indicates that IRGA readings are significantly higher almost four fold (Y= 0.2642X, r= 0.63**, n=30). Table 3.1 is a comparison of GC measurements during the 1995 and 1996 season. The magnitude of soil respiration obtained using the GC method were similar during both seasons. The IRGA readings follow the same trend with manure being higher followed by fertilizer then control treatments. Absolute values are much higher, therefore the data for 1996 growing season have been corrected to reflect the trends observed during 1995.

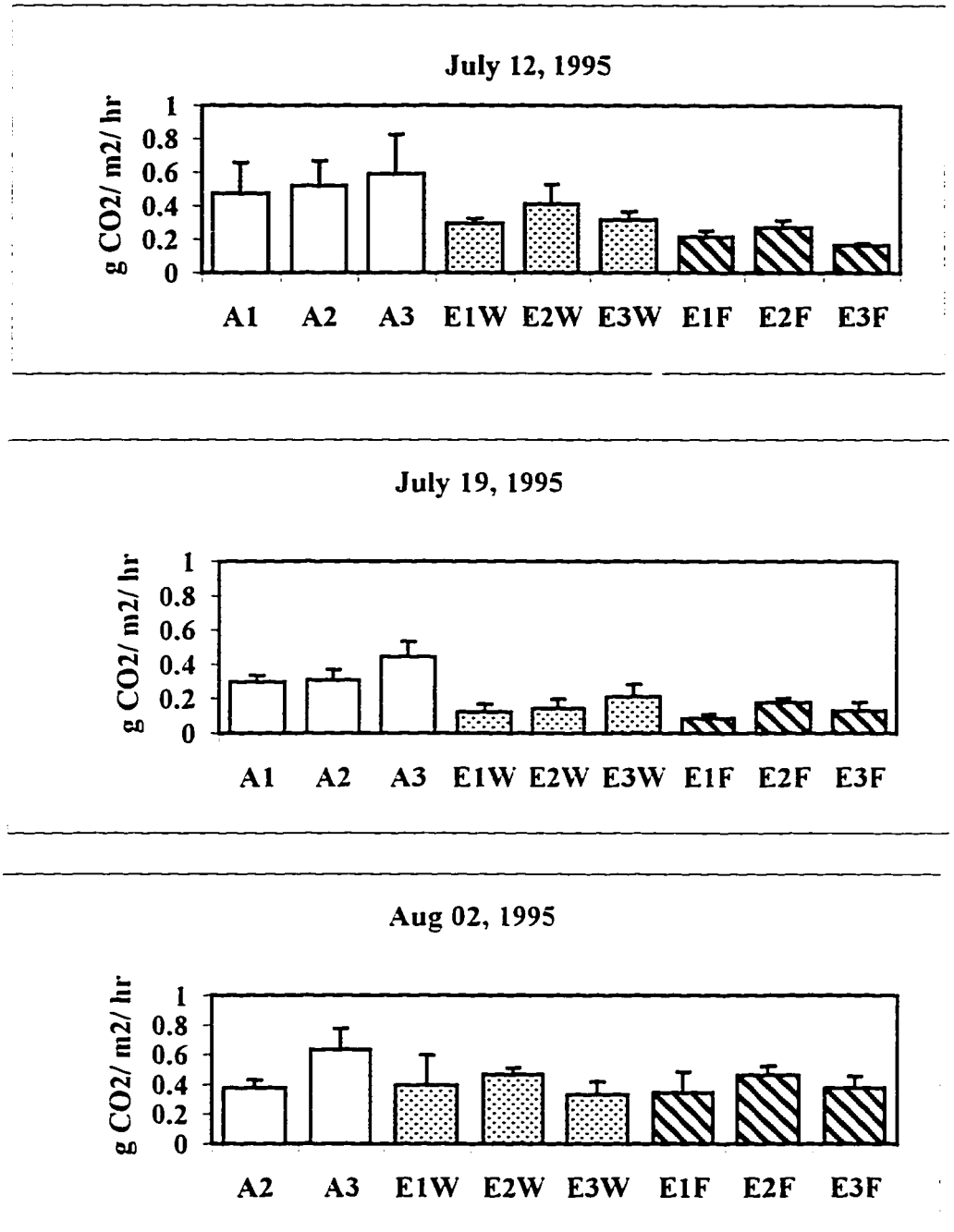
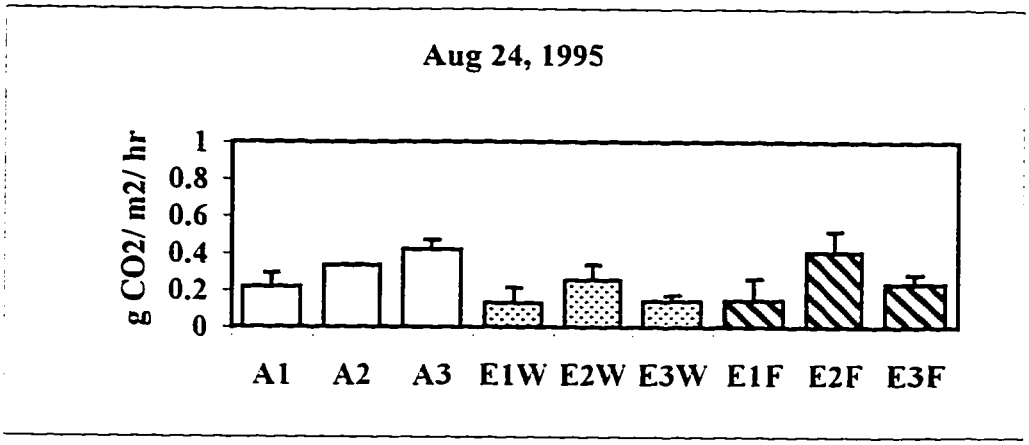
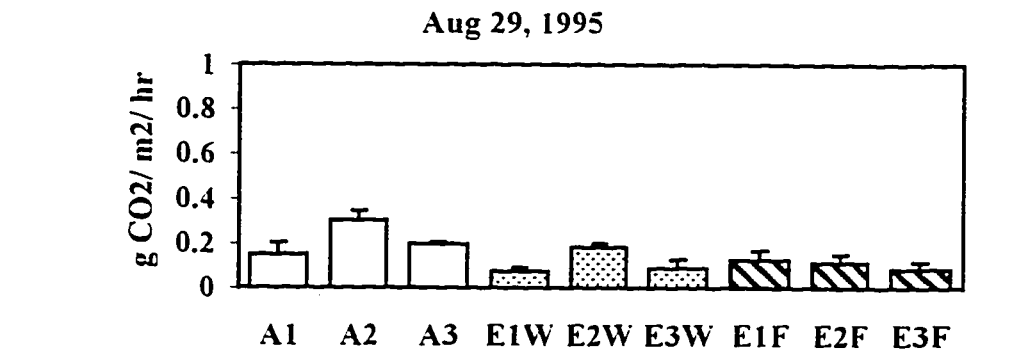
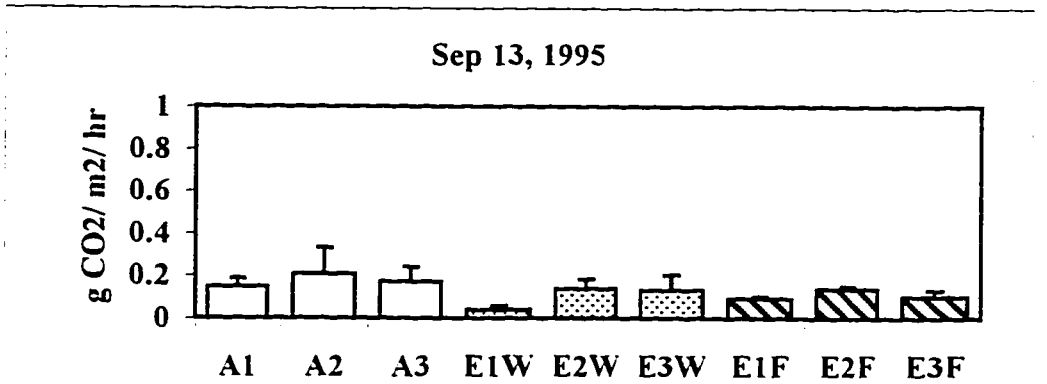


Figure 3.2. Soil respiration in the wheat phase of the 5-yr rotation (A1-A3), and the 2-yr rotation (E1W-E3W) and the fallow phase of the 2-yr rotation (E1F-E3F) at selected dates during the 1995 growing season. The numbers (1, 2, and 3) correspond to control, manure and fertilizer amendments respectively.


Aug 24, 1995
g CO2/ m2/ hr
1
0.8
0.6
0.4
0.2
0
A1 A2 A3 E1W E2W E3W E1F E2F E3F


Aug 29, 1995
g CO2/ m2/ hr
1
0.8
0.6
0.4
0.2
0
A1 A2 A3 E1W E2W E3W E1F E2F E3F


Sep 13, 1995
g CO2/ m2/ hr
1
0.8
0.6
0.4
0.2
0
A1 A2 A3 E1W E2W E3W E1F E2F E3F

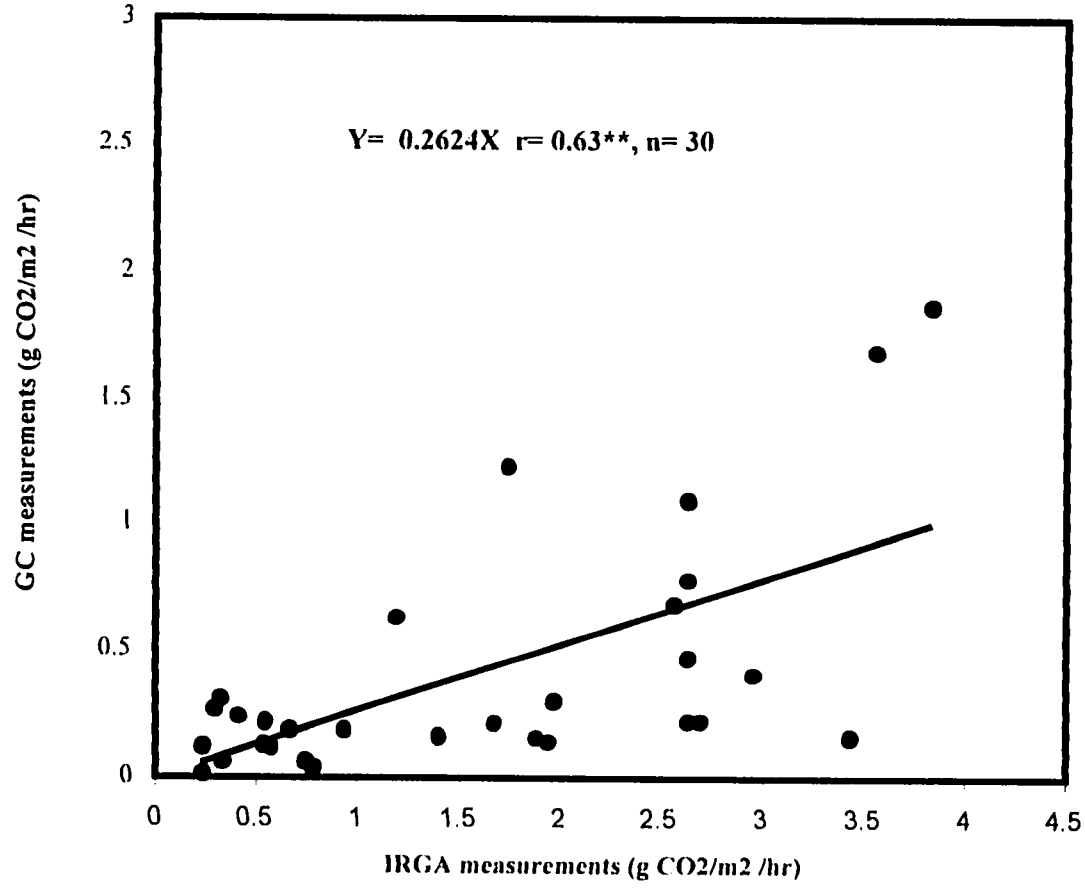


Figure 3.3. Soil respiration measurements using a portable infra-red gas analyzer (IRGA) and gas chromatograph (GC) in the fallow phase of the 2-yr (wheat-fallow) rotation on June 21, 1996

Table 3.1 Calibration of methods of measuring soil respiration in the field .

Treatment	*Gas Chromatogram*	*Gas Chromatogram*	*IRGA*
	July 12, 1995	June 21, 1996	June 21, 1996
	g CO_2 m^{-2} hr^{-1}		
E-fallow-control	0.213 (0.0352)	0.121 (0.077)	0.573 (0.53)
E-fallow-manure	0.271 (0.0403)	0.917 (0.550)	2.64 (1.03)
E-fallow-fertilizer	0.165 (0.0110)	0.216 (0.0550)	1.54 (1.01)

Soil respiration measurements are averages of three samples (standard deviation is in brackets).

Seasonal soil respiration rates are low during spring when there are no crops growing and temperatures are cool. Figure 3.4 indicates that temperatures increased through out the summer as soil warmed up and there is increased plant root respiration. After the middle of June (week 6) and up to mid July (week 10) there is a peak in activity and later on towards the end of the growing season respiration decreases.

Soil respiration at the beginning of the 1996 growing season was less than 0.1 g CO_2 m^{-2} hr^{-1} in the cereal crops and the forage crops had slightly higher respiration rates at about 0.17 g CO_2 m^{-2} hr^{-1}. The respiration rate in the continuous cropping system remained at this rate for the following five weeks and afterwards increased to as much as 1.0 g CO_2 m^{-2} hr^{-1} in the oats and barley phases. However the second year forage had crops growing from early spring consequently plant root respiration were contributing more CO_2 and respiration rates were higher than the rest after the first week of June (week 4).

The wheat and oat phases of the five year crop rotation had slightly higher respiration rates than the hay crops after 4 weeks and continued to increase up to as much as 1.1 g CO_2 m^{-2} hr^{-1} after six weeks. The variability of the measurements increased at higher values and consequently the differences are not significant.

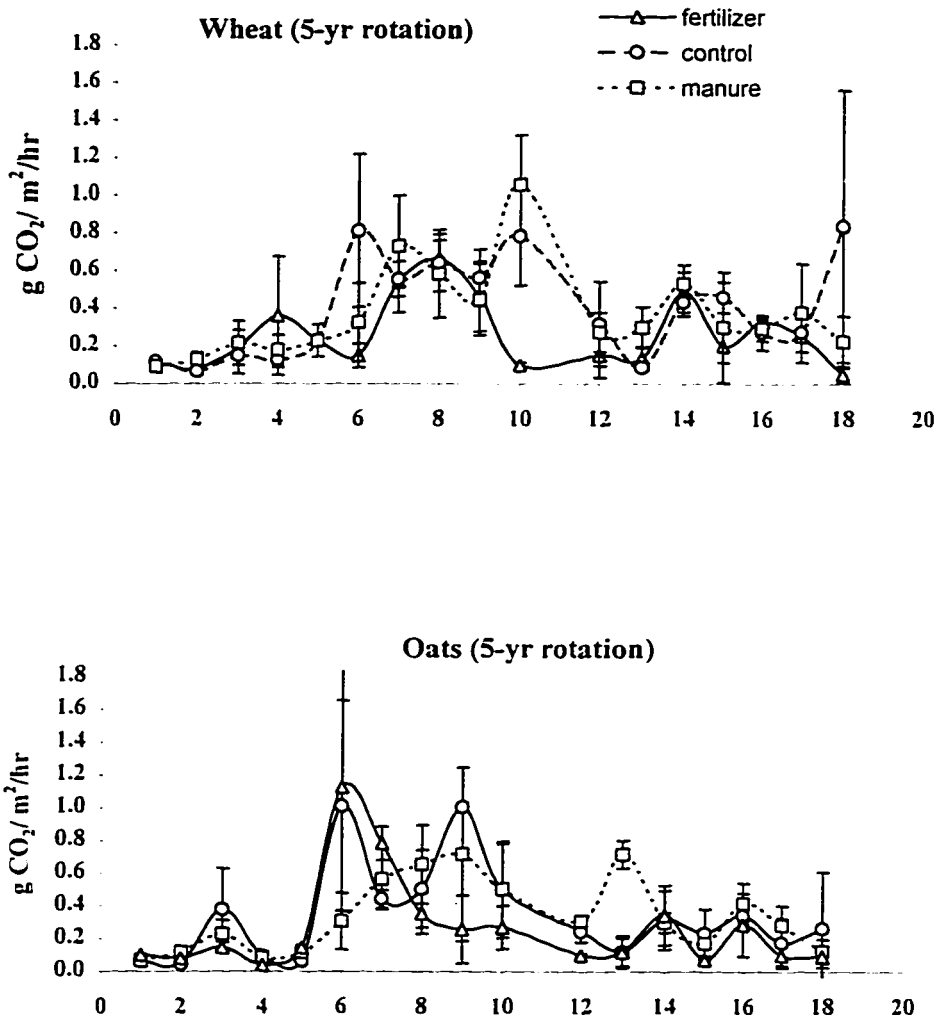
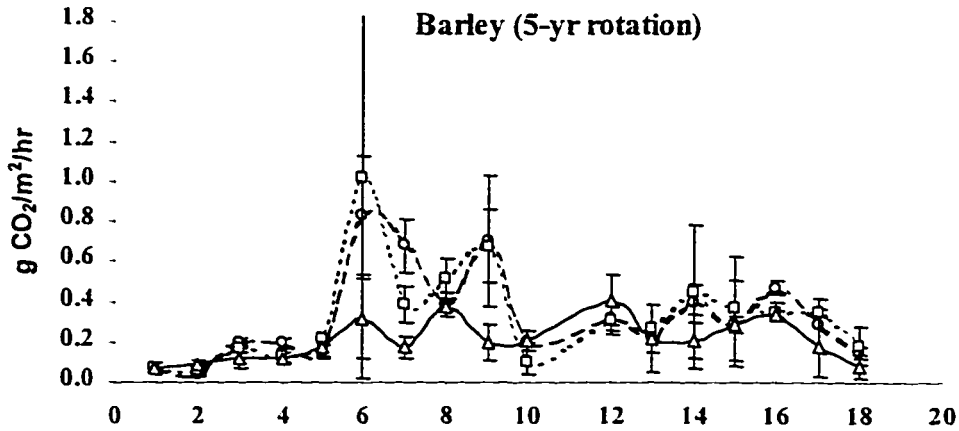
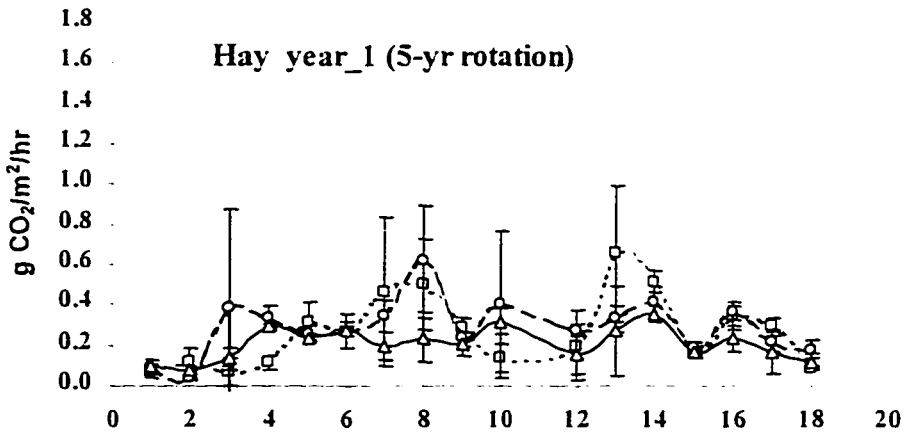
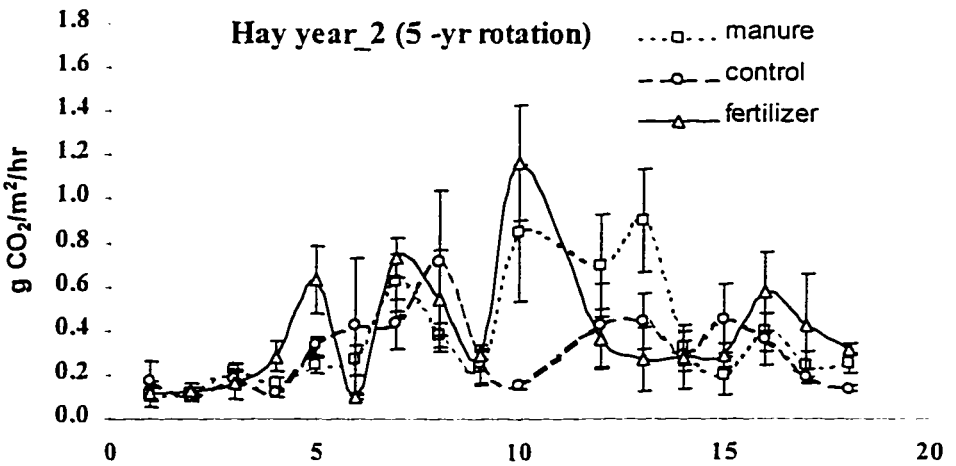
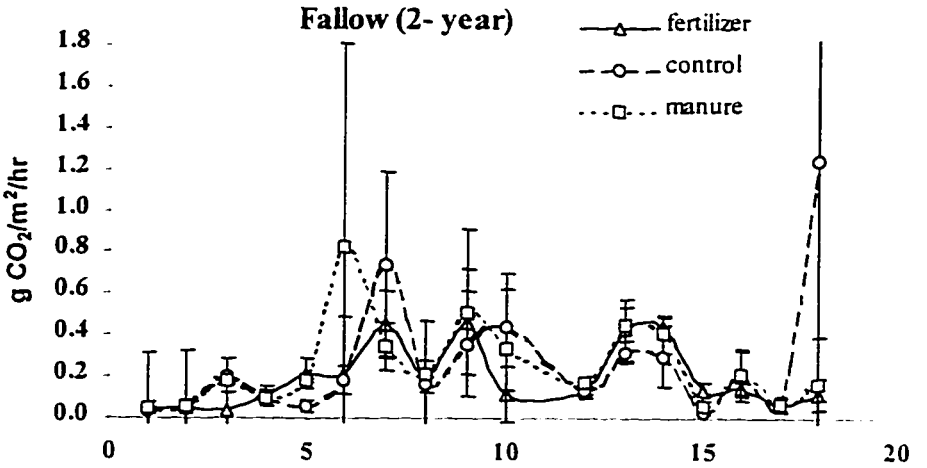


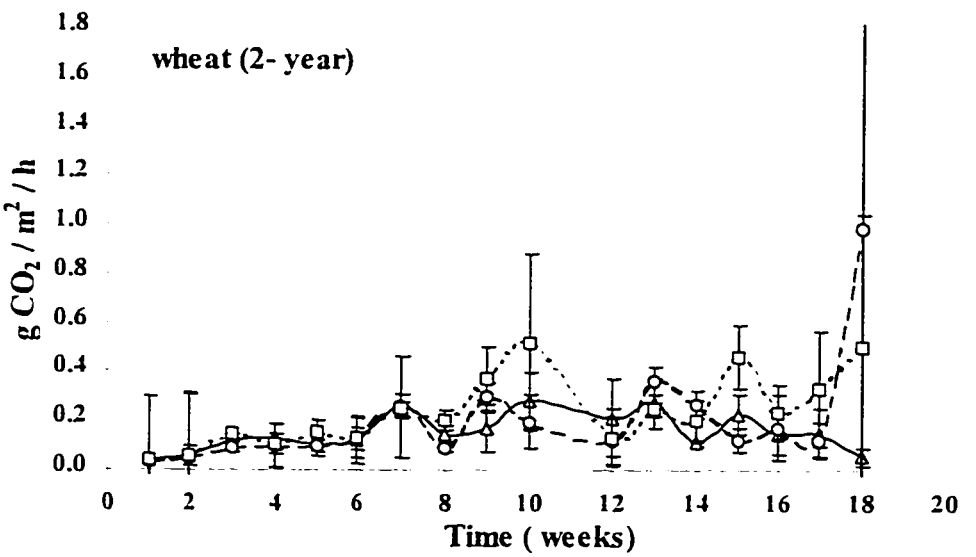
Figure 3.4. Soil respiration measured with a portable infra-red gas analyzer (EGM-1) during the 1996 growing season. Control, manure, and fertilizer amended plots were sampled for all the phases of the5-yr (wheat, oats, barley, hay1, and hay2) and the 2-yr (wheat-fallow) rotations.


Barley (5-yr rotation)
g $CO_2/m^2/hr$
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20


Hay year_1 (5-yr rotation)
g $CO_2/m^2/hr$
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20


Hay year_2 (5 -yr rotation)
manure
control
fertilizer
g $CO_2/m^2/hr$
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20


Fallow (2- year)
fertilizer
control
manure
g CO2/m2/hr
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20

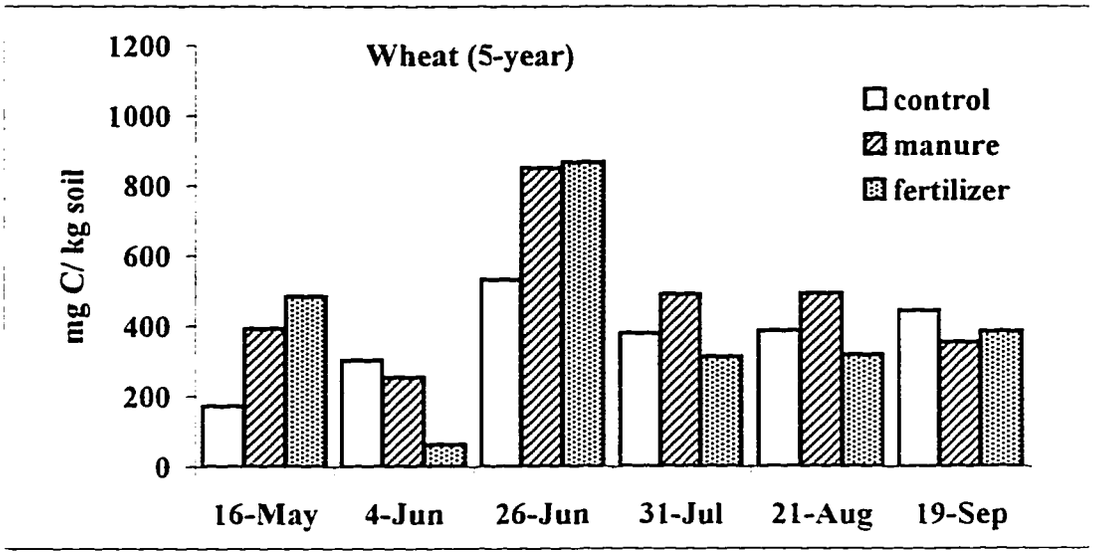

wheat (2- year)
g CO2 / m2 / h
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
10
12
14
16
18
20
Time (weeks)

Soil respiration decreased to less than 0.4 g CO_2 m^{-2} hr^{-1} in most series for the last week in August and first half of September.

The two year rotation followed a similar seasonal trend as the continuous cropping system with some slight variations which can be attributed to differences due to management. The wheat phase were consistently lower than the fallow phase in the first six weeks. Soil respiration in the wheat phase peaked at 10 weeks however, the respiration rate was less than 0.5 g CO_2 m^{-2} hr^{-1} significantly lower than the wheat in the continuous cropping system. In most measurements the two year cropping system had lower respiration rates than the continuous cropping system. Only towards mid-September did respiration rates reach more than 1.2 g CO_2 m^{-2} hr^{-1} during the season.

Soil respiration did not show significant differences due to the amendments in the continuous cropping system. There was a large variability in the measurements and at times the control treatments had respiration rates twice of manure and fertilizer. During week six , respiration rates for control, manure and fertilizer are 0.8, 0.4, and 0.2 g CO_2 m^{-2} hr^{-1} respectively in the wheat (fifth year). During week 13, the respiration rate in descending order has changed from week 6 and manure > fertilizer > control. In the 2-yr rotation the range of values was narrower and manure amendments had the highest soil respiration through out the growing season for most sampling dates.

Microbial biomass in 1996 was 2-3 times higher in the continuous cropping system than in the wheat-fallow system (Figure 3.5). Microbial biomass was low during spring and increased over the growing season. Peak microbial biomass was observed on June 26, 1996 in second year hay it was 1231 mg C/ kg soil. Although the sampling was carried out once every three weeks, it is possible that higher microbial population may have been missed. Biomass within the five year rotation was highest in the forages followed by the wheat phase. Oats and Barley phase had similar biomass C. As plant growth increased there was an increase in microbial biomass. There was an increase in microbial biomass after plant growth had ceased. Biomass in barley plots was less than 300 mg C/ kg soil during July 31 and on both dates sampled in August and September the biomass was between 200 and 500 mg C/kg soil. This probably correspond to root



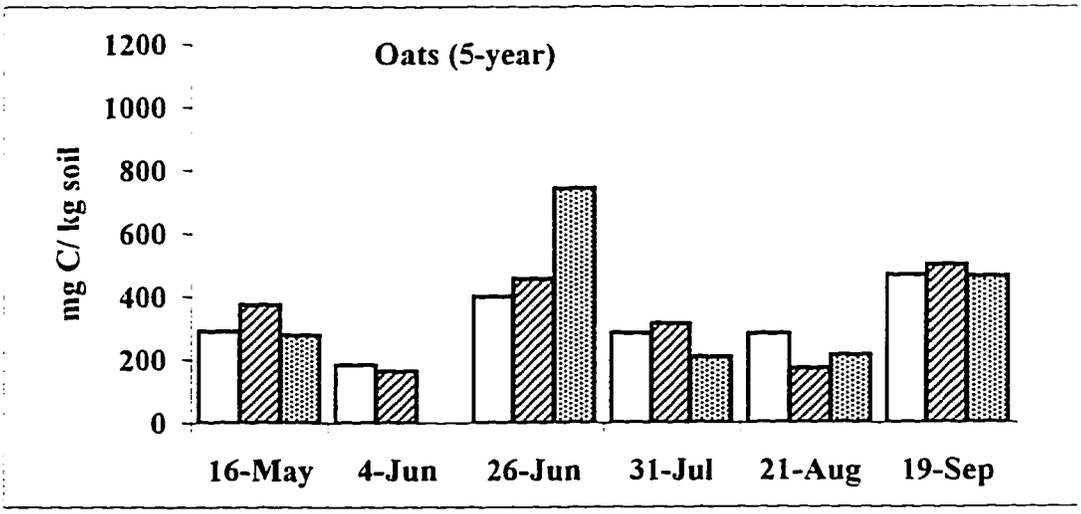
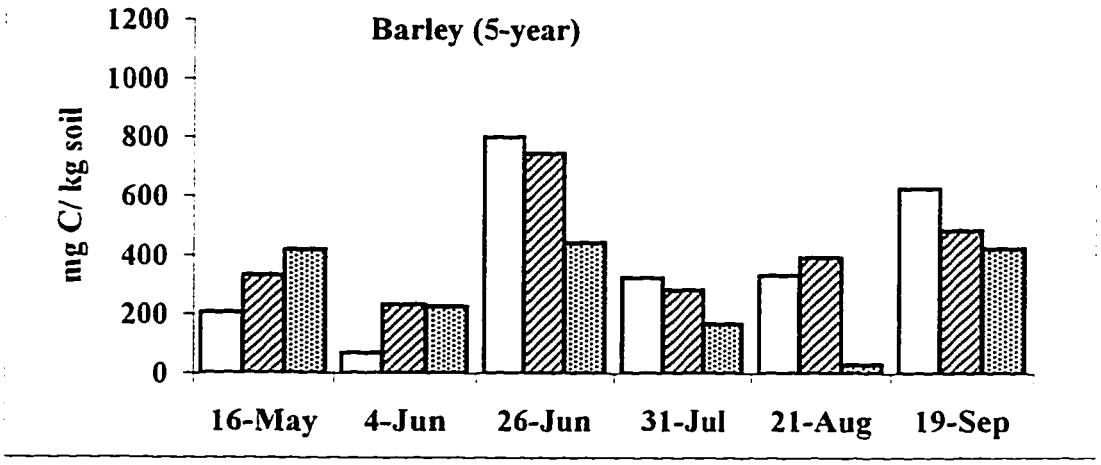
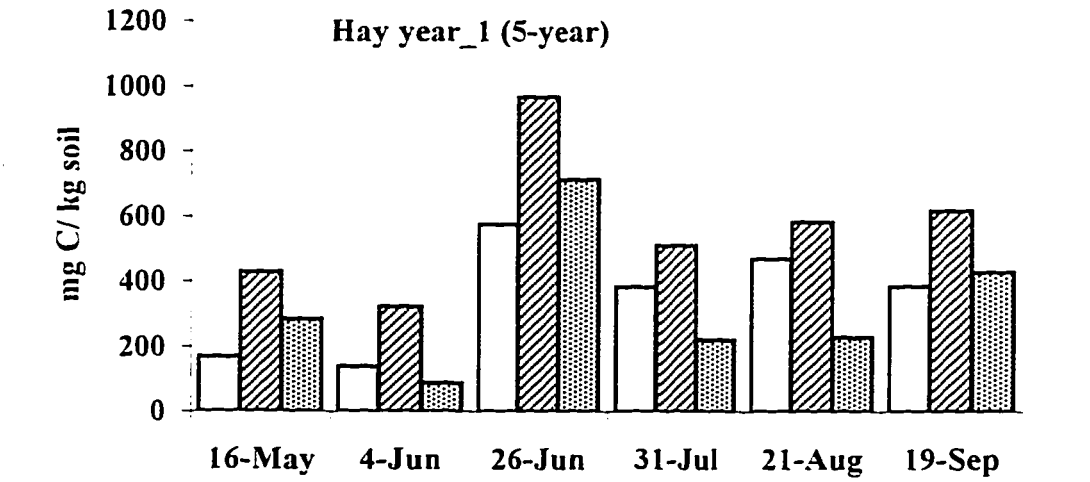
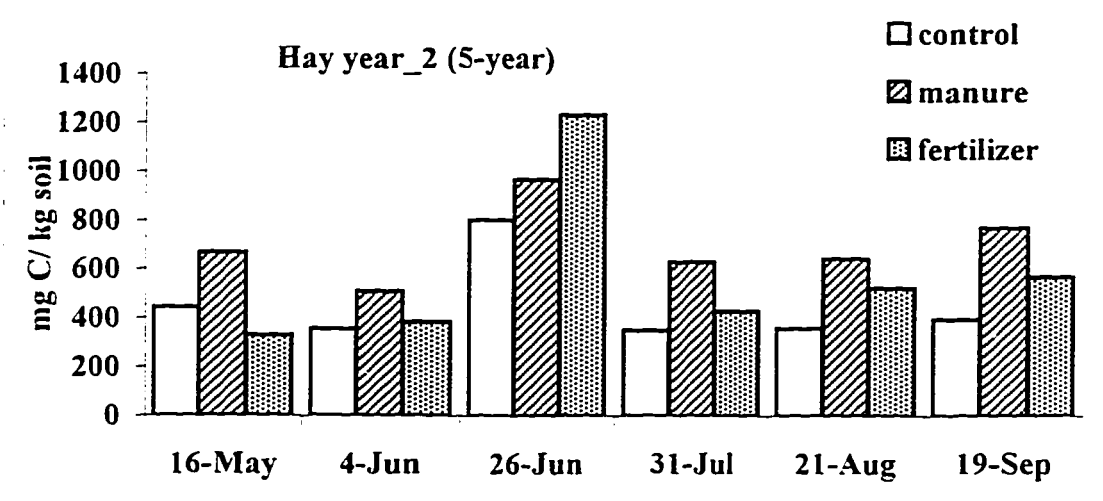
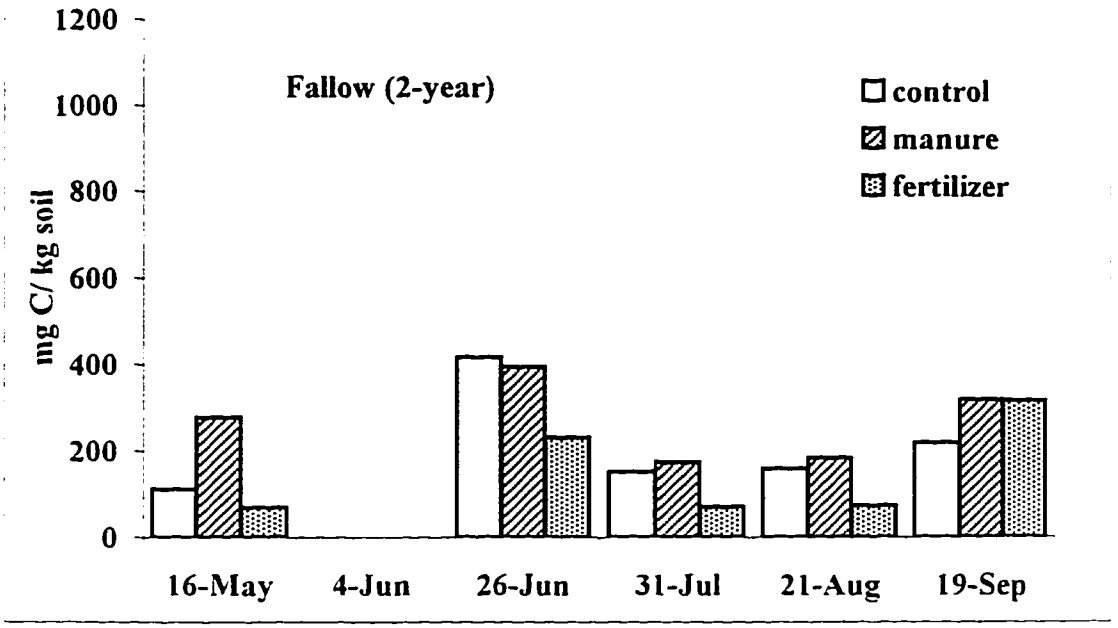


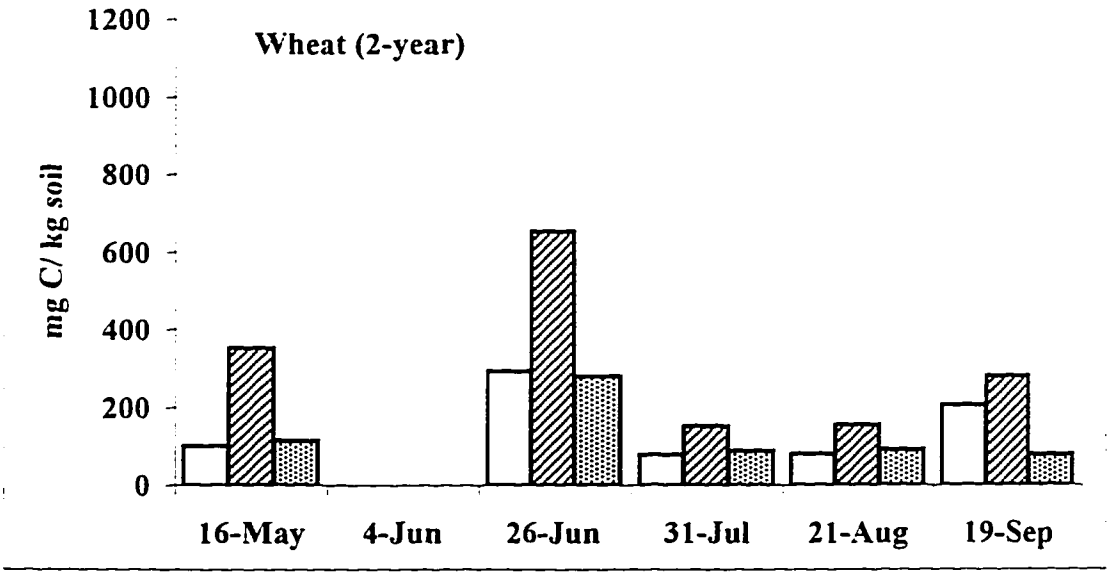
Figure 3.5. Soil microbial biomass during the 1996 growing season. Control, manure, and fertilizer amended plots were sampled for all the phases of the 5-yr (wheat, oats, barley, hay_1, and hay_2) and the 2-yr (wheat-fallow) rotations.


Barley (5-year)
mg C/ kg soil
1200
1000
800
600
400
200
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay year_1 (5-year)
mg C/ kg soil
1200
1000
800
600
400
200
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay year_2 (5-year)
control
manure
fertilizer
mg C/ kg soil
1400
1200
1000
800
600
400
200
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Fallow (2-year)
control
manure
fertilizer
mg C/ kg soil
1200
1000
800
600
400
200
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Wheat (2-year)
mg C/ kg soil
1200
1000
800
600
400
200
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep

and residue decomposition; however, this increase in biomass was observed in both phases of the wheat-fallow rotation also.

Mineral N was highest mid May to early June when plant growth was minimal. Forage crops had the greater values and were as high as 55 mg N/ kg soil initially (Fig. 3.6). As plant demand increased, nitrogen levels decreased to less than 5 mg N/ kg soil by the end of the growing season.

Discussion

Comparison of methods

Comparison of soil respiration measured using different chamber techniques is difficult since measurements cannot be made simultaneously and at the same location. Spatial variability of soil respiration was shown to occur at a scale smaller than 15 cm (Rochette et al., 1991). The comparison of closed chamber using IRGA (EGM-1) and Hutchinson chambers indicates that soil respiration measurements are higher when measured using the EGM-1 (Fig. 2). Seasonal soil respiration for 1996 indicates values range from 0.17 to 1. 1 g CO_2 $m^{-2}h^{-1}$: in contrast the measurements obtained in 1995 were usually less than 0. 6 g CO_2 $m^{-2}h^{-1}$. The seasonal trend observed in 1995 is similar to 1996 where soil respiration was greater during the month of July and decreased by the 2nd week of September. During 1995, soil respiration on Sept 13 was less than 0.25 CO_2 m^{-2} h^{-1} and during 1996 by Sept 10 the values ranged from 0.20 to 0.40 CO_2 $m^{-2}h^{-1}$. Jensen et al. (1996) compared the EGM-1 with the alkali-absorption method and found that EGM-1 values were higher, both in arable land and forest soils; their comparison was done both in the southern and northern hemispheres. Rochette et al. (1992) comparing alkali trap vs. IRGA (LICOR) found that the alkali trap produced lower soil respiration rates than when using the IRGA method; our results were similar although the comparison was done with a gas chromatogram.

Both the alkali trap and GC require longer exposure times than the IRGA method. The longer exposure times would result in disruption of the CO_2 concentration gradient reducing the flux, thus resulting in lower respiration rates. As the flux gradient from the soil air to chamber air decreases the respiration rate decreases. Our data for GC showed

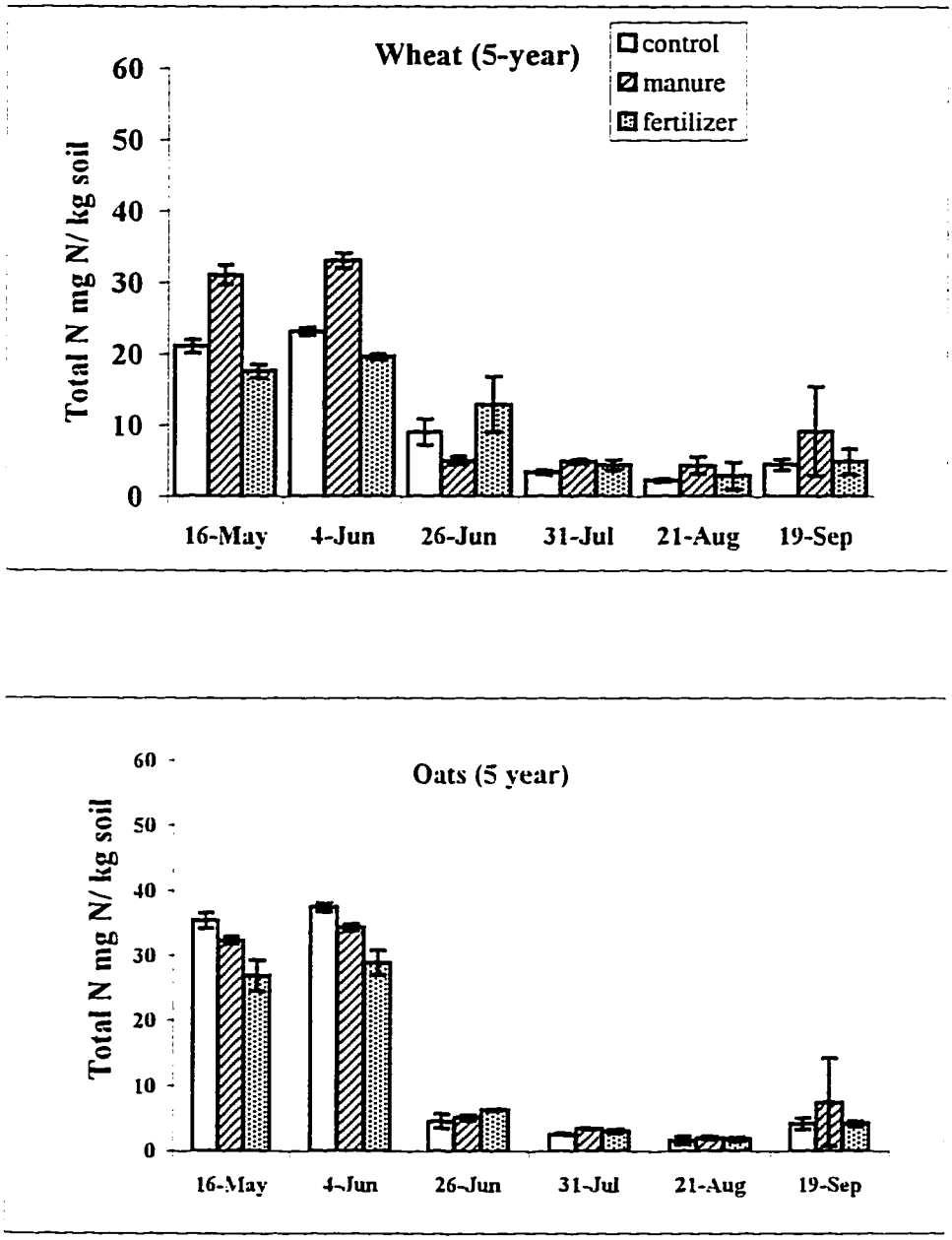
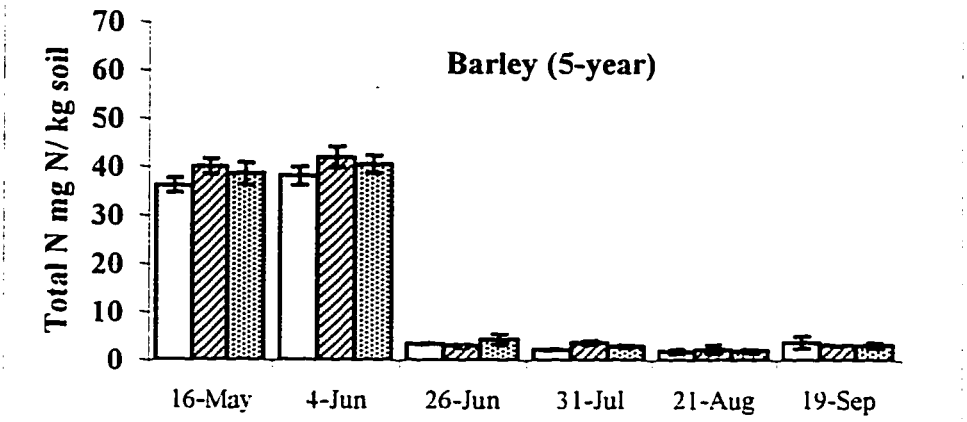
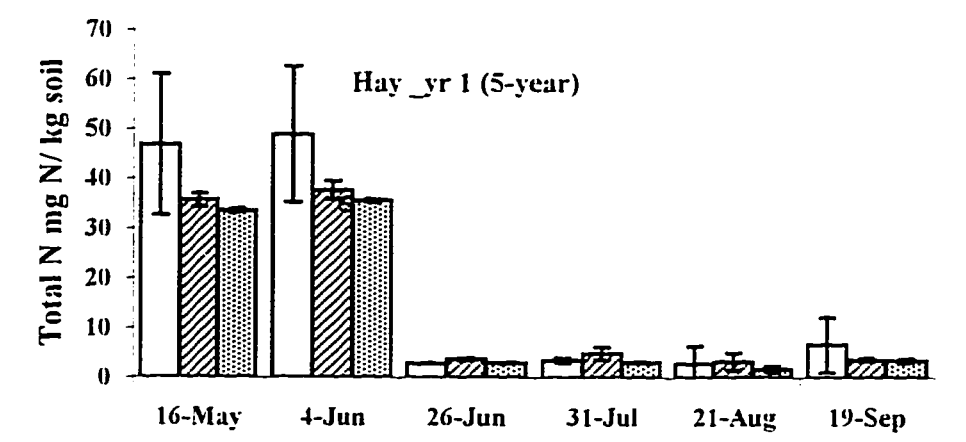
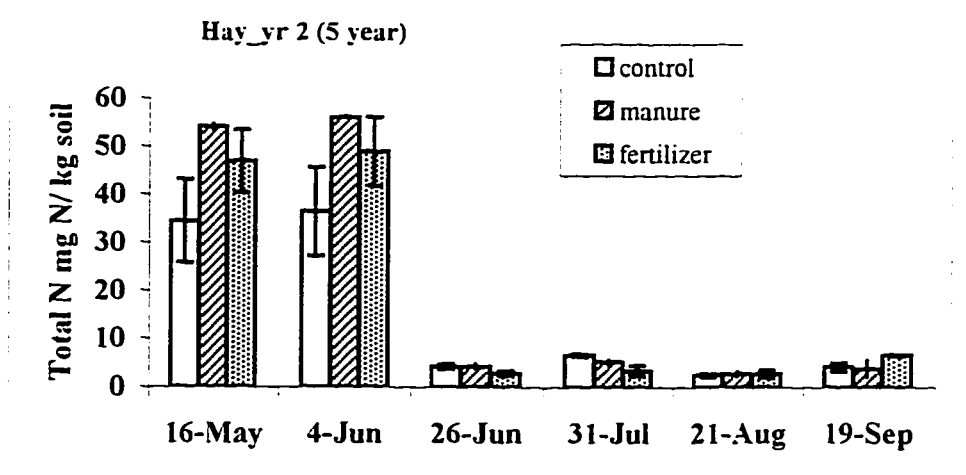
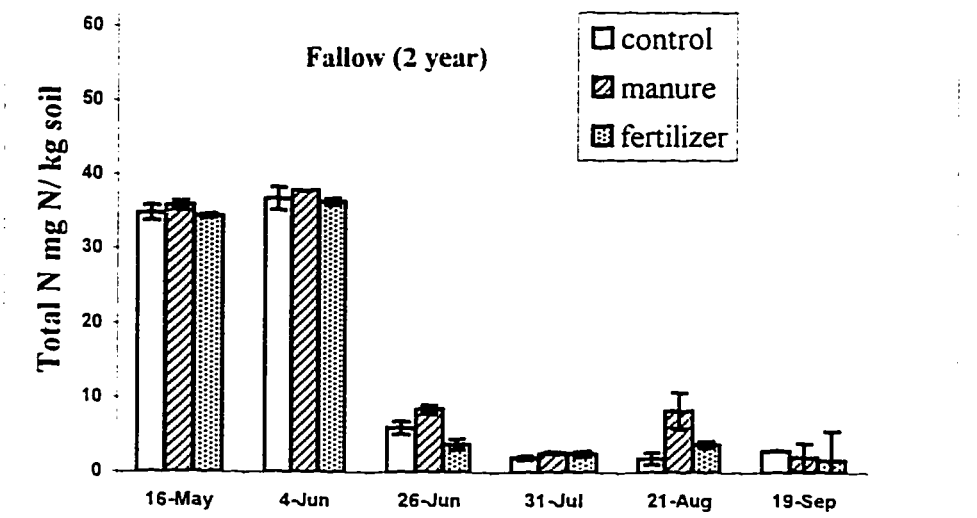


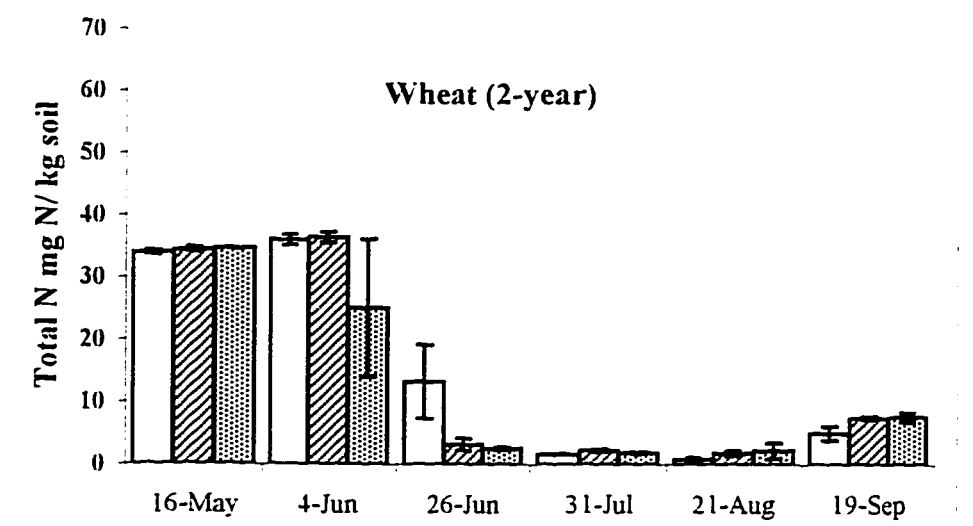
Figure 3.6. Soil mineral N during the 1996 growing season. Control, manure, and fertilizer amended plots were sampled for all the phases of the 5-yr (wheat, oats, barley, hay_1, and hay_2) and the 2-yr (wheat-fallow) rotations.


Barley (5-year)
Total N mg N/ kg soil
70
60
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay _yr 1 (5-year)
Total N mg N/ kg soil
70
60
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Hay_yr 2 (5 year)
control
manure
fertilizer
Total N mg N/ kg soil
60
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Fallow (2 year)
control
manure
fertilizer
Total N mg N/ kg soil
60
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep


Wheat (2-year)
Total N mg N/ kg soil
70
60
50
40
30
20
10
0
16-May
4-Jun
26-Jun
31-Jul
21-Aug
19-Sep

that in some cases the slope of the line in the time period 0- 15 minutes was greater than between 15- 30 minutes. This was not consistently the case, however at high respiration rates this would become a problem, as the concentration in the chamber air would increase and disrupt the natural concentration gradient between soil air and atmosphere. EGM-1 takes a reading within 96 seconds of placing the chamber on the soil and this minimizes disruptions to microclimate. Bekku et al. (1995) compared two IRGA systems, a closed chamber and an open flow through chamber, and found that measurement time were so short that disruption of soil CO_2 gradient was not a problem.

It is possible to incur in overestimation of soil respiration rates if mass flow of CO_2 -rich air from the soil is drawn into the chamber (Kanemasu, 1974; Bekku et al., 1995). This can occur due to pressure changes in the chamber: the Hutchinson chamber has a vent which is designed to stabilize pressure and prevent such mass flow from occurring. This effect was not studied in our experiment but may be a contributing factor in explaining the higher soil respiration rates observed with the EGM-1.

Crop rotation and nutritive amendment influence on CO_2 emissions

Seasonal soil respiration was quite similar in both long term cropping systems with maximum soil respiration mid June and early July. The amount of carbon respired by the wheat-fallow rotation was lower than the continuous cropping system. There was a lag in the wheat (2 year); maximum respiration rates occurred towards the end of July. The fallow phase was cropped to wheat and has the same seasonal pattern as the five year rotation. Winter wheat in Missouri had a similar seasonal pattern and respiration from a cultivated site was higher than for native prairie (Buyanovsky et al., 1987).

In a comparison of forest soils under cultivation and forested sites Beyer (1991) found that soil respiration in a Luvisol was higher during the growing season as plant growth and microbial activity was stimulated by N inputs. They observed an increase in soil respiration as the growing season progressed and this diminished in the fall as temperatures decreased and plants were no longer present. In contrast Buyanovsky et al. (1986) observed that 40% of total CO_2 evolved occurred in the 56 days following the harvest. Our data is for the period of may 16 to Sept 20 and shows peak respiration

during the growing season. However, it can be seen that the wheat phase (2 year) had lower rates of respiration early in the spring as most of the carbon had been lost from the system already. The wheat phase has been fallow for sixteen months prior so the amount of residue available for decomposition is minimal. In our study the effect of tillage was not studied however, this is a contributing factor in the decomposition of residues as they are incorporated after tillage enhancing the rate of oxidation.

In the continuous cropping system there is a greater amount of undecomposed residue and higher total organic carbon and nitrogen contributed to the soil through the various phases of the rotation. This cropping system contains both cereals and forage crops which have distinct rooting patterns and contribute different amounts of plant root respiration. The cereal crops such as wheat have about 90 percent of root mass in the top 20 cm (Buyanovsky et al., 1987). Fyles et al. (1988) found that oat plants had significantly higher shoot:root ratio compared to alfalfa, since alfalfa has a larger root mass than oats. Newton (1945) observed that root respiration in barley was less than wheat and that it varied with stage of growth. As a result difference in crop phases in the continuous cropping system are a function of the crop currently grown and also depend on the previous crop. For example wheat (five year) is grown after two years of forage and this results in higher respiration than the other two cereals (Fig 3.2).

Soil respiration at Breton plots did not show differences due to the nutritive amendments as in the field soil respiration is a function of soil moisture and temperature and biological factors. The total organic matter of the manure and fertilizer amended plots has increased significantly over the last 60 years (Juma, 1995). However, the temporal and spatial variability of CO_2 is too high and no differences were observed. In addition the effect of nutritive amendment is masked by overriding factors such as plant growth and physical factors.

Soil moisture in the five year rotation was influence by the amount of organic matter, and the type of plant growing. Forage crops had less than 30 % moisture content through out the growing season, while the wheat phase had as high as 40 % moisture. Manure amended plots had highest moisture in the oats, while control plots were highest in wheat phase. The two year rotation had higher water content in the fallow manure

amended plot. This difference was small and over all the water content was lower in the two year rotation than the five year.

Residue decomposition and further stabilization is mediated by microbial biomass: consequently soil respiration is dependent on microbial biomass. The five year cropping system has a greater microbial biomass and is able to mineralize more carbon. The microbial population is dependent on carbon and also responds to micro-environmental changes. These two factors are superimposed in the field (McGill et al. 1986).

Moisture during the growing season was not limiting to plant growth. moisture deficits rarely occur at Breton as 60 to 70 % of the precipitation occurs during the growing season (Bentley et al. 1971). Differences in plots were probably due to different root growing patterns which resulted in the soil profile being drier where roots explored a greater proportion of soil zone. Soil respiration is made up of microbial respiration and root respiration. Seasonal pattern of soil respiration reflected the increase in contribution from both sources as they are interdependent. As plants grow a portion of photosyntate is exuded into the rhizosphere and this supports greater microbial biomass. In addition. microbial death and organic matter decomposition releases nutrients which are taken up by plant roots leading to larger plant biomass. Therefore. as the growing season progressed soil respiration increased due to greater plant growth and higher microbial population. Soil mineral N decreased after the first week in June as it was taken up by plants. As the growing season progressed root exudates are rich in carbon and mineral N is immobilized in both plants and microbial population.

In conclusion, our field experiment shows that the method of measuring soil respiration needs to be calibrated in order to ensure that values are representative. The data obtained using GC were much lower than the IRGA technique. The reasons for the higher soil respiration could be due to disruption of CO_2 gradient using the Hutchinson chamber since they were in place for longer times. or pressure differences created by the IRGA chamber without vents and the use of a fan . Pressure changes may result in mass flow movement of CO_2 rich air . The seasonal trends observed follow those observed by

other researchers although differences due to climate and ecosystem inputs resulted in seasonal peaks of different magnitudes occurring at different times of the year.

Microbial biomass plays a significant role in mediating decomposition, and it increased over the growing season. There was an increase in microbial biomass following the period of plant maturity as root and residue decomposition increased. Mineral N was taken up by plants and remained low through out the growing season. Any mineral N released due to plant biomass decomposition would be immobilized by microbial biomass as they have rich carbon substrate. Consequently, through out the growing season no increase in mineral N was observed. This pool represents the readily available nitrogen which is used for plant growth and microbial mediated decomposition.

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Chapter 4. Synthesis

Historical trends and summary of the current work

The Breton Plots were established in 1930 to find "a system of farming suitable for the wooded soil belt". The experiment was designed to compare two cropping systems and test several soil amendments (fertilizers, manure, lime) within the two rotations. Originally, the experiment consisted of 5 blocks of land (Series A-E) which accommodated the 2 cropping systems, across which ran 11 strips with the various soil amendments. In 1938, an additional block of land was added (Series F) to expand the 4-yr rotation to a 5-yr rotation. Further, in 1941 the continuous wheat system (Series E) was split in half to create the present-day 2-yr rotation of Wheat-Fallow. The experimental unit is a series (i.e., a crop by soil amendment) which is not replicated. The crops for both the two rotations are grown every year but the individual treatments (crop by soil amendment) are not replicated (Juma et al., 1997).

Recently, Izaurralde et al. (1995) reanalyzed the historical sets of soil samples from the Breton Classical Plots for soil organic C using a LECO Carbon Determinator CR 12 (LECO Corp., St. Joseph, Mich.) and statistically analyzed the data. The organic C in control and fertilizer treatment in the 2-yr wheat fallow rotation was at a steady-state with soil organic carbon (SOC) at 1.1%. The manure treatment in the 2-yr rotation showed a steady increase (SOC = -20.9 + 0.011 x year, $r^2 = 0.64$, $p<0.06$) over the 55-year (1937-1992) period (Fig 4.1). The organic C in the control, fertilizer and manure treatments all showed significant linear increases (Fig. 4.1). Although, all the above-ground crop residues were removed, the 5-yr crop rotation showed significant increases in total soil C. This can be attributed to continuous cropping, inclusion of legumes in rotation and improved soil fertility in all the treatments.

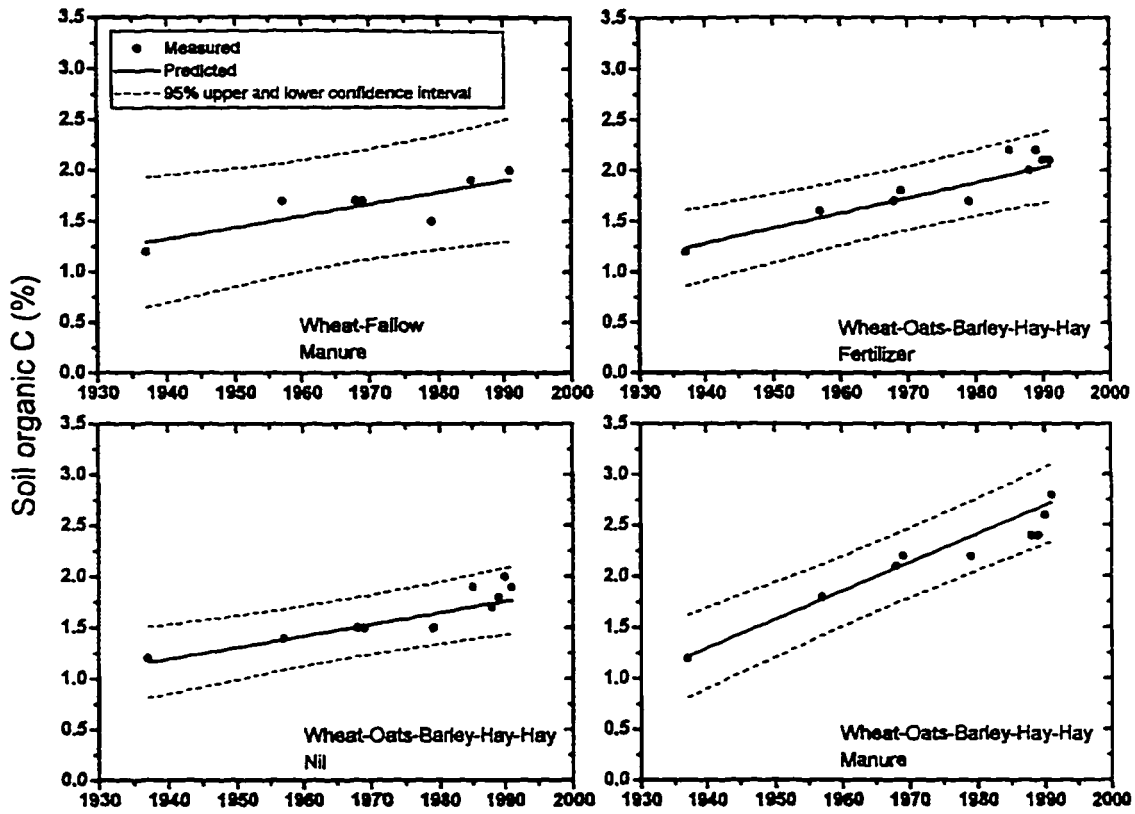

Figure 4.1. Relationship between soil organic C and time (year) for the 2-yr and 5-yr rotations amended with NPKS or manure or unamended at Breton plots, Alberta (1938-1991) (Izaurralde et al., 1995).

The above discussion shows that appropriate management of agricultural system can lead to increases in soil organic carbon. The change in carbon is often small and changes in total soil organic C often require long periods of time. In order to asses the impact of crop rotations on soil organic carbon, I measured labile organic matter in soil (Chapter 2) and the amount of carbon dioxide released from two differently managed agro-ecosystems (Chapter 3). Labile organic matter is an organic carbon pool with a fast turnover rate which has been used as an indicator of changes in soil organic matter (Campbell et al., 1992, Biederbeck et al., 1994). Light fraction organic matter, microbial biomass and potentially mineralizable carbon were measured under laboratory conditions. Light fraction organic matter is made up mainly of undecomposed plant residue and

microbial products. As residue decomposition proceeds, the density of organic matter increases and it becomes complexed with mineral particles.

Light fraction organic matter was higher in the 5-yr than the 2-yr rotation. During spring 1995 the fertilizer amendment resulted in greater amounts of LFOM than manure and control. However, in 1996 there were no clear trends established among amendments. Microbial biomass accounted for less than 3.2% of total organic carbon during the spring of 1996, although the 5-yr rotation had biomass about 50 % greater than the two year rotation. Potentially mineralizable carbon was measured for 14 weeks and it was found that in the 5-yr rotation the amount of CO_2 evolved was higher than the 2-yr rotation by about 30%. Given that the total amounts of organic carbon in the 5-yr rotation is higher then it can be expected that the amounts of carbon emitted is higher also. When compared as a proportion of total organic carbon the 5-yr rotation lost a smaller amount, about 4.4 % while the 2-yr rotation lost about 5.9 % of total SOM. This agrees with findings that systems with fallow lose organic matter faster than continuous cropping systems. McGill et al.(1986) concluded that the two year rotation was showing a net loss of carbon. Dinwoodie and Juma (1988) concluded that carbon cycled faster in Breton (Gray Luvisol) than at Ellerslie (Black Chernozem). Although labile organic matter accounts for less than 25% of SOM, it represent the readily available nutrient pool and accounts for much of the changes in soil organic matter in agricultural land.

Seasonal soil respiration was measured once a week during the 1996 growing season from May to September. Soil respiration in spring was about 0.05 g CO_2 m^{-2} hr^{-1} and increased as temperatures warmed up and plant growth increased. Peak values were observed towards the beginning of July. Respiration rate decreased as the plants matured. By September, soil respiration had decreased to less than 0.4 g CO_2 m^{-2} hr^{-1}. During the growing season in 1995 the similar trend was observed, soil respiration was highest mid-July and by early September soil respiration had decreased to less than 0.15 g CO_2 m^{-2} hr^{-1} in the selected plots that were sampled. Measurements of soil moisture showed no difference between rotations. Generally, moisture is often not limiting to plant growth at Breton. Mineral nitrogen was a function of crop growth and decreased rapidly as plants became established. Nitrogen levels decreased from about 60 mg N/ kg soil to less than

5 mg N/ kg soil after 3 weeks of plant growth.

Microbial biomass increased over the early summer and reflected the increased carbon sources from root exudates and sloughed off root mass. Seasonal trends between rotations indicate that microbial biomass is higher in the 5-yr crop rotation than the 2-yr rotation. However, biomass was quite variable and no differences were observed between amendments within the 5-yr rotation. These changes due to environmental factors were indirectly affecting soil respiration by influencing microbial respiration. The factors controlling microbial biomass are a combination of long-term management as well as short term dynamic factors such as temperature and moisture. Therefore, changes in microbial biomass due to amendments were difficult to quantify and they contribute to the variability in soil respiration. There is a great deal of variability in soil respiration and since carbon dioxide is the result of biological processes factors which affect biological activity that will indirectly affect soil respiration. Interactions between plant species and microbial activity may have resulted in variability in soil respiration in the field.

Discussion

The differences in light fraction carbon, microbial C, and potentially mineralizable C observed were a function of crop, cultivation practice and previous cropping history which make up the management of this agro-ecosystem. In order to separate the influence of each factor, environmental variables need to be removed from treatment. For example, wheat was planted after two years of forage, and the forage crops would have left the greatest amount of residue; in addition the forage crops were not in rows and would have received lowest tillage intensity in the rotation. Forages are nitrogen fixers and would have deposited a portion of nitrogen below ground. Consequently microbial activity would not have been nitrogen limited to the same extent as other phases of the rotation. Therefore the results observed in wheat phase could be due to residual effects from the forages. Alternatively it could be that wheat respired a greater portion of carbon per unit of photosynthates translocated than oats, barley or forages. Also, the time of sampling for the different parameters measured may not have

been optimum. Seasonal variations have been observed in terms of biomass (McGill et al., 1986) as well as light fraction (Spycher et al., 1981). The amount of mineralizable fraction would be higher at the end of the growing season prior to the fall rather than in spring.

Seasonal soil respiration was a function of plant root respiration and microbial respiration. As plant biomass increased, the portion of soil respiration due to plants increased accordingly. This was not uniform for all crop phases. In addition, the plant roots support microbial populations and as the root mass increases the rhizosphere would support greater populations. Thus, plants affect soil respiration both directly and indirectly by supporting pockets of microbial populations in discrete areas.

Actively cycling carbon is an important pool fundamental to understanding the potential for soils to sequester carbon and the processes which contribute to release of organic carbon to the atmosphere, and is consistent with the strategies described in Fig 1.2 (Lal et al., 1995). The Breton Classical Plots have undergone a change in land use which has been well documented since the beginning of the change in land use. Cultural practices at Breton have focused on residue management, fertility management and cropping systems. The original vegetative cover was characterized by forest and has been under cultivation for sixty years. Detailed records have been kept of inputs and outputs from this ecosystem as well as amount and nature of soil organic matter. The Breton Plots provide the only long-term study on Luvisolic soils in Canada. The aim of this thesis was to gain an understanding of short term dynamics of organic carbon in two differently managed crop rotations. This active carbon represents a large portion of carbon which is sequestered by crop rotations which are accumulating soil organic matter. The use of various parameters was carried out to gain an understanding of the various active carbon pools in the soil. Carbon dioxide measurements provided a measure of the decomposition occurring in situ over the growing season.

Conclusions

In summary, the use of a single parameter to measure the effect of management on soil organic matter can be misleading as was indicated by Ellert and Gregorich (1993). Continuous cropping systems had greater active carbon pools and reflected the influence of management. However, these small pools are sensitive to micro-climate changes and may not be responding to management changes but rather reflect short term environmental factors. Short-term environmental factors such as soil temperature, moisture, and freeze thaw cycles which influence the dynamics of labile organic matter are difficult to separate yet often account for a great proportion of variability (McGill et al., 1986).

Reduction of soil CO_2 efflux in the long term requires a move towards continuous cropping as it has been observed that summer fallow reduces native soil organic matter. The increase in cropping intensity may result in short term carbon emissions which are higher than a system relying on fallow but averaged over the longer term of the crop rotation there is a greater portion of carbon stored in the soil. Carbon sequestration in cultivated land is particularly challenging as the nature of management practices promotes decomposition. By cultivating the land, soil is mixed and organic matter is exposed and brought into contact with oxygen and microorganisms promoting decomposition. There is a period of time after crops have been harvested when the land is bare and this again promotes decomposition. However, in places where native soil organic matter content is low, agricultural systems can increase soil organic matter and contribute to carbon sequestration. The 5-yr cropping system has accumulated organic matter to a level higher than the original carbon content of the Luvisolic soil at Breton. Addition of manure and fertilizer resulted in significant increases in soil organic matter. Although the emissions from this cropping system were higher in the 5-yr tan the 2-yr cropping system, lab studies indicated that carbon cycled at a slower rate in the 5-yr rotation.

Future Studies

The present study focused on the short term dynamics of carbon cycling in Gray Luvisols in Central Alberta. In order to assess the biologically active carbon pools there is a need to measure light fraction organic matter at more than one stage of the growing season. The plant species had different growth patterns and the forages in particular had a longer growing season. Consequently, there are differences in light fraction organic matter which are due to growth stage rather than management.

Plant respiration is a significant component of total soil respiration. Plant species will respire at different rates as well as influence the rhizosphere and, depending on rooting patterns this influence will vary. The respiration of roots and that of microbes needs to be separated under field conditions. Furthermore, there is an increase in variability in respiration over the growth of the plant and there is a need to increase the number of readings in order to obtain a more representative value. Rochette et al. (1991) concluded that 190 readings were required to estimate the soil respiration within 10% of its mean value in a hectare early in the growing season and only 30 were needed at the end of the growing season. Temporal variation are important and need to be quantified particularly as little work has been done in the northern latitudes in Canada. The growing seasons are much shorter and average seasonal temperatures are lower.

Future studies require careful selection of sampling schedules, recognizing the various species which are present have different growth and possibly limiting the number of species studied. In addition the sampling schedule must be set up so that diurnal temperature changes do not influence the measurements of soil respiration. A selection of a limited number of plots is necessary to ensure that temperature changes are minimal and recognizing that there are going to be stages when the number of readings must be increased to ensure representative sampling.

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Appendix 1.

1995 BRETON PLOTS: Summary of Crops and Herbicides

Varieties:

Wheat	-Katepwa	**Red Clover**	-Altaswede
Barley	-Duke/Leduc	**White Clover**	-Dutch
Oats	-Cascade	**Bromegrass**	-Carlton
Fababeans	-Orion	**Fescue**	-Tall
Alfalfa	-Peace	**Field Pea**	-Tipu

Fertilizer:

Nitrogen	-Urea (46-0-0)
Phosphorus	-Treble superphosphate (0-45-0)
Potassium	-Potassium chloride (0-0-60)
Sulphur	-Elemental sulphur (0-0-0-90)
NPS	-Ammonium phosphate sulphate (16-20-0)
N	-Ammonium nitrate (34-0-0)
Lime	-Calcium carbonate
Non-plot	-Not fertilized

Herbicides:

Barley/Hay	-Embutox 626
Oat	-Refine
Wheat	-Triumph Plus
Barley	-2,4-D
Faba	-Poast

1995 BRETON PLOT CROP ROTATION AND FERTILIZER TREATMENTS

SERIES

F	E	D	C	B	A	
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	1
MANURE	MANURE	MANURE	MANURE	MANURE	MANURE	2
75-22-46-5.5	90-22-46-5.5	50-22-46-5.5	0-22-46-5.5	0-22-46-5.5	50-22-46-5.5	3
75-0-46-5.5	90-0-46-5.5	50-0-46-5.5	0-0-46-5.5	0-0-46-5.5	50-0-46-5,5	4
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	5
LIME	LIME	LIME	LIME	LIME	LIME	6
75-22-46-0	90-22-46-0	50-22-46-0	0-22-46-0	0-22-46-0	50-22-46-0	7
0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	8
75-22-46-5.5	90-22-46-5.5	50-22-46-5.5	0-22-46-5.5	0-22-46-5.5	50-22-46-5.5	9
75-22-0-5.5	90-22-0-5.5	50-22-0-5.5	0-22-0-5.5	0-22-0-5.5	50-22-0-5.5	10
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	11
OAT	WHT (east)	BLY/Hay	HAY-1	HAY-2	WHEAT	

Yr 1 - BARLEY
Yr 2 - FABA
Yr 3 - BARLEY
Yr 4 - FABA
Yr 5 - BLY/Hay
Yr 6 - HAY
Yr 7 - HAY
Yr 8 - HAY

* see 1982 guidelines for details
\+ all fertilizer on elemental basis kg/Ha

N

YR2	0-22-46-5.5	YR5	0-22-46-5.5	CG	90-22-46-5.5	13
CF	18-10-0-17	CF	18-10-0-17	YR8	0-22-46-5.5	14
YR7	0-22-46-5.5	CG	90-22-46-5.5	CF	18-10-0-17	15
YR6	0-22-46-5.5	YR1	0-22-46-5.5	YR3	0-22-46-5.5	16
CG	90-22-46-5.5	CF	18-10-0-17	YR4	0-22-46-5.5	17

Appendix 3.

1996 BRETON PLOTS: Summary of crops and herbicides

Varieties:

Wheat	-	Roblin
Barley	-	Leduc
Oats	-	Athabasca
Fababeans	-	Orion
Alfalfa	-	Peace
Red Clover	-	Altaswede
White Clover	-	Dutch
Bromegrass	-	Carlton
Fescue	-	Creeping Red

Fertilizer:

Nitrogen	-	Urea (46-0-0)
Phosphorus	-	Treble superphosphate (0-45-0)
Potassium	-	Potassium chloride (0-0-60)
Sulphur	-	Elemental sulphur (0-0-0-90)
NPS	-	Ammonium phosphate sulphate (16-20-0)
N	-	ammonium nitrate (34-0-0)
Lime	-	calcium carbonate
Non-plot	-	not fertilized

Herbicides:

Barley/Hay	-	Embutox 626
Oat	-	
Wheat	-	
Fababean	-	
Barley	-	Refine
Fescue & Roadways	-	2,4-D
Non-plot	-	2,4-D

1996 BRETON PLOTS CROPS AND FERTILIZER ROTATIONS

BLY/HAY	WHEAT (WEST)	HAY-1	HAY-2	WHEAT	OAT	
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	1
MANURE	MANURE	MANURE	MANURE	MANURE	MANURE	2
50-22-46-5.5	90-22-46-5.5	0-22-46-5.5	0-22-46-5.5	50-22-46-5.5	75-22-46-5.5	3
50-0-46-5.5	90-0-46-5.5	0-0-46-5.5	0-0-46-5.5	50-0-46-5.5	75-0-46-5.5	4
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	5
LIME	LIME	LIME	LIME	LIME	LIME	6
50-22-46-0	90-22-46-0	0-22-46-0	0-22-46-0	50-22-46-0	75-22-46-0	7
0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	0-22-46-5.5	8
50-22-46-5.5	90-22-46-5.5	0-22-46-5.5	0-22-46-5.5	50-22-46-5.5	75-22-46-5.5	9
50-22-0-5.5	90-22-0-5.5	0-22-0-5.5	0-22-0-5.5	50-22-0-5.5	75-22-0-5.5	10
CHECK	CHECK	CHECK	CHECK	CHECK	CHECK	11

YR3	0-22-46-5.5	YR6	0-22-46-5.5	CG	90-22-46-5.5	13
CF	18-10-0-17	CF	18-10-0-17	YR1	0-22-46-5.5	14
YR8	0-22-46-5.5	CG	90-22-46-5.5	CF	18-10-0-17	15
YR7	0-22-46-5.5	YR2	0-22-46-5.5	YR4	0-22-46-5.5	16
CG	90-22-46-5.5	CF	18-10-0-17	YR5	0-22-46-5.5	17