SOIL BIOCHEMICAL RESPONSES TO INTERMITTANT TILLAGE ON SASKATCHEWAN LOW DISTURBANCE CROPPING SYSTEMS AND ETHIOPIAN VEGETATIVE TERRACES USED IN HILLSLOPE AGRICULTURE

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ABSTRACT

The pursuit of agricultural sustainability is necessary to ensure global food security into the future. To achieve sustainability, production systems around the world use different approaches. Utilizing several biological and physical indicators, this study investigates two agricultural production systems and assesses how management has affected the long-term health and sustainability of the soils. The first study assessed the effect of variable intensities of tillage on three Saskatchewan soils under low-disturbance (LD) management for the ten years prior to tillage. The soils represented were in the Grey, Black and Brown soils zones at sites located near Tisdale, Rosthern and Central Butte, Saskatchewan, respectively. A completely randomized block design utilized four treatments of varying tillage intensity. Samples were taken in spring before planting and after harvest at all sites. The soils were analyzed for microbial indicators of health by assessing dehydrogenase, urease, protease, and alkaline phosphatase activities. Microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and microbial quotient nitrogen (MQN) also were analyzed. Traditional soil nutrient and physical parameters were measured. The tillage intensities affected each parameter differently likely due to the differences in litter quality at each site. The high intensity tillage treatment decreased dehydrogenase activity at Tisdale at May, while in Rosthern dehydrogenase activity was increased in the moderate intensity tillage treatment and decreased by the high intensity tillage treatment. At Central Butte no effect was detected until October when dehydrogenase activity was increased by the low and moderate tillage intensity treatments. Protease and urease activities were affected at Rosthern only where the moderate intensity tillage treatment decreased activity relative to the control treatment. Soil physical parameters were not affected by tillage intensity; however nutrient levels were impacted by the increasing tillage intensity. Specifically, NO_3^- was reduced at Tisdale and was increased at Rosthern. Phosphate levels were reduced by the high tillage intensity in Rosthern whereas, with increasing tillage, the opposite occurred at Tisdale and Central Butte. The responses were strongly influenced by site characteristics, especially soil zone, organic matter content and surface litter abundance and quality. These effects were short-term, having no long-term impact on the agricultural sustainability or health of the soil, although knowledge of litter condition and quality is agronomically beneficial in order to predict soil responses to intense tillage events.

The second part of the study was to assess the success of grass terraces on preserving the soil health of hillslope farm plots with Oxisolic soils in southern Ethiopia. Soil erosion has a devastating impact on hillslope agriculture in Ethiopia causing severe land degradation. An adjacent terraced and unterraced hillslope was chosen and sampled, along with a second unterraced slope for comparison. These soils were analyzed for dehydrogenase, alkaline phosphatase, and urease activities, as well as total C and total N. The plots above the terraces [terraced upper and unterraced upper] had higher urease activities than the plots below [terraced lower and unterrraced lower]. The impact of a vegetative strip that had formed a terrace 20 years ago was still evident in consistently higher alkaline phosphatase, urease, and dehydrogenase activities than the other plots. Simple methods of erosion prevention on erosion prone hill-slopes indicated that vegetative strips leading to terracing have a positive effect on soil health and functionality, promoting the long-term agricultural productivity and sustainability of these landscapes.

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2l	Site 2; lower slope
2u	Site 2; upper slope
ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
ANOVA	Analysis of variance
BD	Bulk density
C	Carbon
C:N	Carbon to nitrogen ratio
CO_2^-	Carbon dioxide
DNA	Deoxyribonucleic acid
GDP	Gross domestic product
h	Hours
ha	hectare
HPO_4^{-2}	Secondary orthophosphate
$H_2PO_4^{-2}$	Primary orthophosphate
H_3PO_4	Orthophosphoric acid
K	potassium
kg	Kilograms
LD	Low disturbance
LSD	Least significant difference
min	Minutes
MB	Microbial biomass
MBC	Microbial biomass carbon
MBN	Microbial biomass nitrogen
Mg	Megagrams
MQ	Microbial quotient
MQN	Microbial quotient nitrogen
N	Nitrogen
NH_3	Ammonia

NH_4^+	Ammonium
NO_3^-	Nitrate
O_2	Oxygen
OM	Organic matter
Phosphorus	P
PO_4^-	Phosphate
rev	Revolutions
rpm	Revolutions per minute
S	Sulfur
sec	Seconds
SOM	Soil organic matter
Tl	Terraced-lower slope
Tu	Terraced-upper slope
TOC	Total Organic carbon
Ul	Unterraced-lower slope
Uu	Unterraced-upper slope

1.0 INTRODUCTION

The global population has expanded in the last five decades at an unprecedented rate, from approximately 2.5 billion at the beginning of the Green Revolution to over 6.5 billion today and is projected to be over 9 billion by 2050 (UN, 2005). The global agricultural land base is under incredible pressure to produce food to feed the burgeoning population. This pressure will intensify as populations continue to expand despite the limitations of a finite agricultural land resource base. Currently, in many areas, especially in those which are heavily populated, agricultural expansion into marginal lands is occurring out of necessity to feed local populations. This can cause catastrophic land degradation, which in turn threatens to drastically reduce future agricultural productivity. In order to ensure global food security, we need methods of increasing agricultural productivity while maintaining a productive and healthy land resource base. Unfortunately, it is often the developing, over-populated countries, those that can least afford to lose agricultural productivity, which are exerting the most pressure on their land base and destroying soil productivity as a result.

Globally, the status of the sustainability of agricultural production is variable. In recent decades measured progress towards sustainability has been made in the developed world, whose systems recognize that the preservation of the soil resource is key to maintaining a productive and healthy agroecosytem. Farmers in developed nations typically use low disturbance (LD) technology that minimizes soil disturbance and works to sustain and increase the soil's 'health' or condition and functionality. These systems utilize many resources in the forms of capital, technology, and knowledge. Due to the elimination of tillage, production in LD agriculture depends heavily on fertilizers and herbicides which require large amounts of capital to finance. As well, the technology used (the farm implements) is designed for large operations of thousands of acres and is therefore extremely costly.

Much of the agricultural production in the developing world is conducted without using the high input strategies of the western world. There, technology, knowledge and, most of all, capital is severely limited, making LD farming difficult or next to impossible. Populations in many developing nations, especially in east Africa, are huge and struggle to maintain food security. Because of this, most agricultural production is small scale for sustenance or, at best, a local market, and continued population pressure pushes agriculture into lands that have severe

limitations and marginal productivity. Naturally, the lack of capital, technology and awareness creates a reliance on low cost methods of production utilizing frequent and intensive cultivation. The usual problems presented by intensive cultivation of soils are magnified in marginal agricultural lands, creating disastrous land degradation over incredibly short periods of time.

Obviously, the adoption of LD management systems to such small scale-farms is difficult without investment from abroad, meaning that methodologies need to be developed for the specific demands and limitations of agricultural production on marginal lands in order for any type of widespread adoption to occur. These methods need to be both economically viable and effective at preserving the soil resource, at the same time as being economically attractive in the short-term in order to appeal to small-scale and sustenance farmers.

Soil health is defined as "the continual capacity of soil to function as a vital living system, within ecosystem boundaries, to sustain biological productivity, promote the quality of air and water environments and maintain plant, animal and human health" (Pankhurst et al, 1997). Therefore, in order to evaluate management strategies for agriculture, it is necessary to consider the effect of those strategies on the health of the soil. By assessing soil health using biochemical properties along with subtle changes in physical properties, the long-term effects of any management strategy can be observed and extrapolated from a relatively short time-frame. This type of evaluation is necessary in order for global agricultural productivity to be maximized as well as sustained through careful maintenance of the finite soil resource.

In this study, two agricultural systems are assessed. One is under LD management in Saskatchewan, where reliance on high cost inputs is leading to consideration of intermittent tillage as an option to reduce dependence on capital. The other is under traditional intensive tillage in a small-scale production system in the highlands of southern Ethiopia, where a huge population exerts pressure on a relatively small, fragile land base. Land degradation in the form of large-scale water erosion threatens the productivity and sustainability of agriculture, along with the food security of the growing population.

The objectives of this study are three fold: (1) to assess the significance of short-term variation in tillage intensity on soil biochemical properties indicative of soil health; (2) to assess the agronomic impact of intermittent tillage treatments of varying tillage intensity in long-term LD management systems in three soil zones in Saskatchewan; and (3) to assess the impact of

contour vegetative strips as a prevention measure against large-scale erosion loss and its subsequent impact on soil health in southern Ethiopian highland soils.

2.0 LITERATURE REVIEW

2.1 Soil health

Soil health is defined as "the continual capacity of soil to function as a vital living system, within ecosystem boundaries, to sustain biological productivity, promote the quality of air and water environments and maintain plant, animal and human health" (Pankhurst et al., 1997). This definition describes soil as a living entity carrying out functions necessary for the survival of the ecosystem. This study focuses on the functionality of soil in terms of its ability to sustain a productive agroecosytem, and the effect of varying degrees of tillage on that functionality.

In order to evaluate its overall health, it is necessary to understand how well the soil performs its vital functions and transformations. Larson and Pierce (1991) likened the assessment of soil health to a medical examination where a specific set of parameters are examined to develop a picture of the human condition. They suggest that a defined set of parameters should be adopted and standardized for assessing soil health, including methods and processes for evaluating these parameters (Larson and Pierce, 1991). Measurable properties which influence the capacity of the soil to perform agronomic and environmental functions can be indicators of soil quality (Acton and Padbury, 1993). To assess soil functionality, it is necessary to define attributes which are sensitive to management practices and vital to the ability of the soil to perform to its full agronomic and environmental potential.

2.2 Soil and litter variability

Conventionally tilled soils have litter distributed through the plough layer, whereas LD soils typically have a layer of crop residue or litter at the surface. The thickness of this layer depends on the climate, crop inputs, and the farm implements used to create, in many long-term LD soils, a significant measurable layer. This layer, left untouched, forms a gradient of material in various stages of decomposition. The most unaltered and fresh residues are at the surface, while the more decomposed materials are at the soil litter interface, where moisture and temperature are more favorable for microbial growth. This results in significantly greater levels

of microbial activity and other processes at the interface layer of LD soils than in conventionally-tilled soils.

The condition of the surface litter is very important. In agriculture systems with crop rotations some crop materials will be higher in protein or nitrogen (N) and others will be lower. This is represented by the carbon (C) to nitrogen (C:N) ratio. High-ratio materials such as cereal straw, have ratios over 30:1 making it difficult for microorganisms to metabolize. Other crops, especially legumes, have a C:N ratio of less than 30:1, making this material more easily degradable and making the N within easily accessed and mineralized (Bremer and van Kessel, 1992; Ocio et al., 1991). Although surface residues generally decompose more slowly than buried ones (Brown and Dickey, 1970), the N concentration of the remaining residues increases (Franzluebbers et al., 1994) relative to the buried ones. Usually higher N concentration leads to faster decomposition (Vigil and Kissel, 1991), but in natural environments the fluctuation in moisture and temperature might increase the resistance of N compounds to microbial decomposition, which could lead to higher N accumulation in soils (Franzluebbers et al., 1994)

2.3 Soil organic matter (SOM)

Several soil properties are often correlated with increasing soil quality. Total organic C, microbial biomass carbon (MBC), extractable carbohydrates, and macroaggragate stability were significantly higher in soils that were perceived by farmers to be of high quality (Weil and Magdoff, 2004). All are tightly bound to the condition of the SOM fraction. Soil organic matter benefits agricultural soils in several ways: (1) reduced erosion and runoff; (2) enhanced soil aggregation; (3) increased nutrient cycling; (4) improved water infiltration; and (5) improved water retention (Weil and Magdoff, 2004). When assessing the quality of an agricultural soil the contribution of the content of SOM is central to not only the agronomic capability of the soil but also its overall quality and health.

Soil organic matter provides the substrate for microbial activity, being a significant pool of organic nutrients that are readily mineralized. Urease, alkaline phosphatase, and uricase are soil enzymes that actively degrade SOM in agricultural systems, transforming nutrients from organic to inorganic forms that are plant-available. The role of the enzymes cycling plant nutrients is essential to maintaining the health and productivity of the soil.

Soil organic matter is responsive to management changes in long-term and short-term studies. Changes in soil management can alter the amount of SOM and in turn alter the biological functioning of the soil. Soil enzymes such as dehydrogenase, protease and alkaline phosphatase have higher activity under less intensive (or conservation) management systems than under conventional tillage systems, which correlates positively to long-term changes in SOM levels (Madejon et al., 2007).

Plant macronutrients, especially N, sulfur (S), and phosphorus (P), are found in SOM in abundance. Nitrogen can be present in abundant amounts. Depending on the type and quality of plant material, soils with a 3% SOM content can contain up to 3,000 kg of N per hectare (University of Minnesota, 2002). The importance of SOM is undeniable in maintaining the productivity, functionality and health of all agricultural soils.

2.4 Microbial biomass

The microbial biomass of a soil can be an earlier indicator of change in soil function due to its faster rate of renewal than SOM (Jenkinson and Ladd, 1981; Paul, 1984). Microbial biomass can be used to predict long-term changes in total SOM (Powlson and Jenkison, 1981; Powlson et al., 1987; Sparling, 1992). Under conventional tillage management, MB and SOM decline simultaneously (Sparling, 1992; Madejon et al., 2007).

Microbial biomass affects soil fertility and health (Insam et al., 1991). The amount of potentially available N was positively related to higher MB (Hart et al., 1986). However, the same relationship did not hold true for plant available P or plant yield (Sorn-srivichai et al., 1988), indicating that the MB may be more important in N mineralization than in P mineralization.

Microbial biomass was higher under cropped agricultural land compared to fallow, suggesting that rhizodeposition contributed to the MBC (Campbell et al., 1999). Microbial biomass carbon also underwent seasonal trends relating to precipitation, decreasing from May to July, increasing through August, and decreasing again after August (Campbell at al., 1999). Alteration of management from conservation tillage (“direct drilling”) to conventional tillage for three years changed a suite of factors in the top 5 cm of soil, including a reduction in MBC

(Pankhurst et al., 2002). These studies show that favourable environmental conditions, such as substrate abundance and moisture, enhance MB.

2.5 Microbial quotient

The microbial quotient (MQ) is the ratio of MBC to total organic C for one particular soil. This MQ serves as a better indicator of changing soil processes and health than measures of soil organic C (SOC) or MBC separately (Sparling, 1992). The microbial quotient can be used to make comparisons between different soils with different SOM levels. Microbial quotients are especially useful for comparing soils with similar mineralogy and observing trends over time; however, soils with different mineralogy are not successfully compared (Sparling, 1997). The different nutrient and water-retention capabilities of soils with different textures directly influences total MB. It is necessary to set target values from reference soils in order to come to a determination of the health of a particular soil, as there is no one value that dictates whether a soil is "healthy" (Sparling, 1997).

The MQ decreases in time if a soil is used unsustainably due to faster turnover of MBC than of SOM (Sparling, 1997). In contrast, if soil is rebuilding, there will be a greater proportion of MBC to total organic C causing the MQ to increase (Insam, 1989). This value will be higher than those in soils that have already met their maximal equilibrium.

Haynes and Tregurtha (1999) found that MQs in soils under long-term arable management increased from 1.1% under long-term agricultural management to 2.3% under long-term pasture. Sparling (1992) found consistently higher MQ values for pasture than arable land. Pankhurst et al. (2002) reported decreases in MQ from plots under direct seeding and stubble incorporation treatments compared to those seeded conventionally. The MQ increased progressively from conventional seeding to stubble incorporation through to direct seeding (Pankhurst et al., 2002).

In studying the effects of crop rotations microbial biomass, specific respiratory activity and mineralizable nitrogen, it was found that MBN was more relative to treatment effects than MBC (Campbell et al., 1992b). The incorporation of MBN in the MQ would possibly allow for more sensitive analysis of studies conducted in the short term.

2.6 Nutrient pools

2.6.1 Nitrogen

Nitrogen is an important plant nutrient for agricultural ecosystems. It is needed by plants to synthesize amino acids, DNA, and proteins that build new cell material (Havlin et al., 1999) and it is also used by plants for chlorophyll and carbohydrate utilization, building enzymes, and stimulating root growth and activity (Olson and Kurtz, 1982). Nitrogen is in very high demand in agricultural systems and is usually the most limiting nutrient to crop growth, and, on the Canadian Prairies, often the second most limiting factor to growth after water.

The N cycle functions by carrying out the necessary transformations of N in order to ensure an adequate supply of plant-available N in the soil. In agricultural ecosystems microorganisms play a significant role in this process whereby organic materials (plant and microbial residues or manures) are decomposed and organic forms of N are converted to plant available inorganic forms of N. Microorganisms also transform synthetic fertilizers from various chemical forms into plant useable forms. This process is called mineralization, and is mediated by microorganisms.

Mineralization has several pathways and one of the most predominant is ammonification. Ammonification is the process whereby organic N is transformed into the plant available form of N, ammonia (NH_3) (Cooper, 2005).

Enzymes such as urease and uricase are active in the soil, depending on the substrates and soil conditions, in carrying out mineralization processes like ammonification by actively mediating the conversion from organic N to inorganic N.

2.6.2 Phosphorus

Phosphorus (P) concentrations in plants range is between 0.1 and 0.5%. Phosphorus in plants is predominantly used for energy storage and transfer through adenosine di- and tri-phosphates (ADP and ATP). Phosphorus also is essential for seed formation and development of reproductive parts (Havlin et al., 1999).

Plants absorb P as primary orthophosphate, ($H_2PO_4^{-2}$), and secondary orthophosphate (HPO_4^{-2}) (Tisdale and Nelson, 1966). The levels of either orthophosphate form in the soil are determined by the soil pH which influences which form is made plant available. Generally, at pH 6, $H_2PO_4^-$ is most abundant while at pH 7 or higher HPO_4^{-2} is dominant (Tisdale and Nelson, 1966).

Plant available P in the soil is regulated by a complex buffering system whereby its level in the soil solution is buffered by the inorganic P and organic P fractions (Havlin et al., 1999). This means that as the soil solution P is depleted by plant absorption, the inorganic P (bound or precipitated on the soil surface) and the organic P (in microbes or organic molecules) replenish the solution P (Havlin et al., 1999). The greater the buffering capacity of a soil, the greater the ability the soil has to replenish and maintain the levels of solution P, allowing for a constant plant available supply of P.

The soil MB mineralizes organic P from the SOM converting it to inorganic plant-available forms. Soil enzymes involved in P degradation, such as alkaline phosphatase which is secreted by the MB, actively mineralize P from the SOM, transforming P into plant available forms. Soil enzymes, which can be secreted by microorganisms and plants or exists abiotically, ensure the supply of inorganic plant available P, and in doing so, play a vital role in the terrestrial P cycle.

2.7 Soil enzymes

At the ecosystem level, soils perform numerous transformations and functions that ensure the sustainability of the ecosystem. Soil enzymes act as the mediators and catalysts of important soil functions like decomposition of organic matter, mobilization of plant nutrients, N fixation, nitrification and denitrification (Dick, 1997). When considering the definition of soil health as the ability of a soil to perform necessary functions within the ecosystem, investigating these enzymes can give insights into the ability of the soil to carry out enzyme-catalyzed processes (Dick, 1997).

Soil enzymes can be difficult to study simply because of their nature of existence. Only small amounts can be extracted from soils, because strong extractants will denature them. In most cases enzymes are studied by looking directly at their activity in the soil. Enzyme activity

is measured by the rate of conversion of a known substrate into a known and measurable product. This has its own consequences, in that the assays used are kept under constant conditions (optimal pH, temperature, and ionic strength), which may not be representative of the soil in its natural state (Dick, 1997).

Another problem associated with measuring activity of soil enzymes is that the activity of the abiotic or extracellular enzymes cannot be separated from the activities of intercellular enzymes (Dick, 1997). This causes problems for using enzymes to predict the microbial activity of the soil, as the abiotic enzymes are not associated with living cells. Estimates of MB calculated based on enzyme activity far exceed the estimates of bacterial or fungal mycelia hypothetically able to exist in the soil (Ramirez-Martinez and MacLaren, 1966).

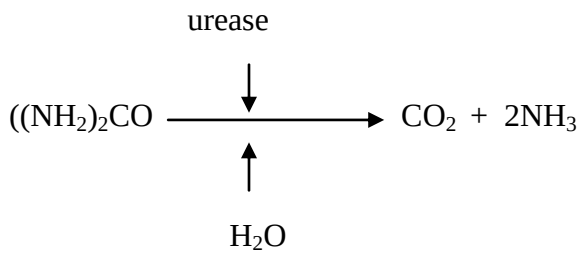
Urease, phosphatase, protease, and dehydrogenase are correlated with several microbial indicators (Laugesen and Mickelson, 1972; Laugesen and Mickelson, 1973). Alkaline phosphatase, amidase, and catalase were correlated with microbial respiration and total biomass, but not microbial plate counts in glucose amended soils (Frankenberger and Dick, 1983). There are many cases where microbial biomass was not closely correlated with enzyme activities. Often this is caused by a poor choice of assay or is because the enzyme has abiotic activity, making it difficult to correlate enzyme activity with MB, as the assay cannot distinguish between enzyme activities derived from living cells and non-living sources (Dick, 1997).

Cropping systems that returned higher levels of residues to the soil have shown elevated levels of enzyme activities over soils without returned residues (Jordan et al., 1995). Microbial stimulation in the rhizosphere due to improved physical condition of the soil caused by higher levels of organic inputs promotes microbial activity and further increases enzyme activities (Miller and Dick, 1995).

Conservation tillage systems that cause less soil disturbance have higher enzyme activities in the surface soil (Dick, 1984). Long-term conventional cultivation of soil depressed phosphatase and arylsulphatase by 49% and 65%, respectively (Gupta and Germida, 1988). Generally, farming systems that return crop residues to the soil and minimize tillage have higher enzyme activities across soils and climatic conditions (Kandeler and Elder, 1993).

2.7.1 Urease

The activity of urease in agricultural soils is very well studied and its importance understood. The enzyme urease acts both as an abiotic and biotic enzyme in the soil to accelerate the rate of conversion of urea into carbon dioxide (CO_2) and ammonia (NH_3) according to the following reaction:

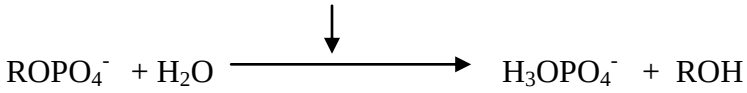


In LD agricultural systems, high amounts of organic residues accumulate on or near the soil surface. Without seasonal incorporation into the soil, the litter materials form a layer on the soil surface. As the litter layer thickens, the distance from the favourable microbial conditions of the soil-litter interface increases and decomposition processes slow. This causes an accumulation of degraded SOM to occur near the soil-litter interface (Dick, 1984). This build up of SOM produces a constant supply of energy to soil biota (Dick, 1984) and stimulates soil biological activity and thus soil enzyme activity (Dick, 1984). Urease activity in the 0- to 10-cm layer increased under no-till management compared to a conventional system (Bergstrom et al., 2000). Urease activity has been observed in LD soils 3.0 to 5.2 times higher than soils in conventionally managed systems (Dick, 1984).

Whereas no-till management increases soil urease activity, tillage reduces urease activity. Tillage induced reductions in enzyme activity typically occurs on all soils, most noticeably in the upper 10 cm (Bergstrom et al., 2000). Urease activity was reported to be significantly depressed under tillage systems compared to natural or LD systems (Roldan et al., 2005).

2.7.2 Alkaline phosphatase

Alkaline phosphatase is one of the primary catalyzers of the hydrolysis of esters and anhydrides of H_3PO_4. This process mineralizes P from SOM, transforming P to inorganic plant available forms (Rice, 2004).



Microorganisms in the soil release extracellular phosphatase into their environment. This is done through cell lyses, cell leakage or active exudation (Tadano et al., 1993). Excreted from plant roots, fungi and microorganisms, phosphatases in the soil increase when P levels become deficient (Tadano et al., 1993). Alkaline phosphatase is unique among other phosphatases in that it is believed to originate exclusively from soil microorganisms, as it has not been found to exist in higher plants (Juma and Tabatabai, 1977; Tabatabai, 1994).

In agricultural systems, phosphatase activity, along with other enzyme activities is strongly correlated to SOM content. Areas within a field with higher SOM values, had higher rates of phosphatase activity (Bergstrom et al., 2000). In studies where the effect of tillage on enzyme activity is observed, enzyme activity is highest under no-tillage or minimum-tillage treatments with high organic residue inputs (Bergstrom et al., 1998; Bergstrom et al., 2000).

Alkaline phosphatase activity tends to correlate with microbial activity likely because of its microbial origin (Kandeler et al., 1999a). Therefore, in tillage studies the activity of alkaline phosphatase is greatest in treatments with the greatest amounts of SOM, and in most cases this is the minimum or no-till treatment. A comparison of long-term cultivation of land under corn production to forested land and native grassland found significantly lower phosphatase activity in the soil under long-term corn production (Saviozzi et al., 2001). Gupta and Germida (1988) compared soils under cultivation for 69 years to adjacent native grassland and found decreased phosphatase activity under cultivation. Comparing phosphatase activities, including alkaline phosphatase, between no-till, chisel plough and moldboard plow treatments, enzyme activity was highest in the no-till and lowest in the moldboard plow treatments (the treatment having the most soil disturbance) (Deng and Tabatabai, 1995). Alkaline phophatase activity was 71% greater in 6-yr no-till treatments compared to 6-yr conventional tillage treatments (Carpenter-Boggs et al., 2003).

2.7.3 Protease

Soil protease activity has often been used as an indicator of total MB. It is often well correlated with microbial biomass due to its existence inside microbial cells and short life span as an extracellular enzyme (6 or 7 d) (Asmar et al., 1992; Nannipieri et al., 1978). In addition,

protease plays a role in the organic N-cycle in agricultural soils, degrading organic molecules and releasing inorganic N (Watanabe et al., 2003). Therefore, measurement of protease activity is a method for predicting soil N mineralization, and also soil microbial activity (Nannipieri et al., 1983).

Soil protease activity has been researched in order to observe the effect of various management methods on soil biochemical activity and overall soil quality. A comparison of native forest, grassland and cultivated soils (Saviozzi et al., 2001) found that the native soils had maximal levels of enzyme activity including protease, while the activity was depressed under long-term cultivation (Saviozzi et al., 2001). Protease activity fell with an increase in the intensity of soil management (Haynes and Tregurtha, 1999). Protease activity was greatest under long-term pasture and declined through no-till to conventional soil management. Soil protease activity appears to be responsive to soil management variations, especially long-term management strategies. This demonstrates a correlation, as other enzymes have, with SOM and MB, but also it may serve as an indicator of potential N-mineralization occurring due to the role of protease in the organic N-cycle.

2.7.4 Dehydrogenase

Dehydrogenase is unique among enzymes in that it does not have abiotic activity. Because dehydrogenase is active only within viable cells, it is a reliable indicator of soil microbial activity and therefore it is the most widely studied indicator of soil biological activity (Dick, 1997).

Dehydrogenase acts to catalyse the dehydrogenation of organic compounds. The reaction releases hydrogen ions which are captured by oxygen. The general reaction is as follows:

$$XH_2 + A = AH_2 + X$$

This occurs where XH_2 is an organic molecule and A is the electron acceptor, usually oxygen (O_2) (Davis, 2000). The result is hydrogen (H_2) bound to the electron acceptor, and the organic molecule devoid of hydrogen and ready for further degradation and use by the cell.

Dehydrogenase activity has been analyzed in several studies examining the effect of tillage and land-use on soil biochemical properties. Comparing adjacent fields of conventional and LD, showed dehydrogenase activity to be reduced by intensive and reduced tillage in comparison to LD tillage (Bergstrom et al., 1998). Soils under no-till, conventional, pasture and

forest management were found to have dehydrogenase activities correlated with other enzyme activities and organic C, confirming dehydrogenase as a reliable indicator of microbial activity in the soil (Jimenez et al., 2002).

Other studies have found the correlation between dehydrogenase and microbial activity to be insignificant (Frankenberger and Dick, 1983; Skujins, 1978). Compounds such as phenol oxidases, which commonly exist in soils, can act as alternative hydrogen acceptors reducing dehydrogenase activity (Howard, 1972). Anions, such as nitrate, also reduced measured dehydrogenase activity, suggesting that nitrates served as alternative hydrogen acceptors. This means that conventional 2,3,5-triphenyltetrazolium chloride (TTC) assays may underestimate microbial activity in some soils (Bremmer and Tabatabai, 1973).

Nonetheless, dehydrogenase is still considered a reliable indicator of microbial activity in soils, and continues to be widely used in soil biochemical research. Although it may not be as accurate as once presumed, nevertheless the characteristics of the enzyme, more specifically its lack of extracellular activity, make it a more reliable indicator of microbial processes and a predictor of forthcoming changes in soil physical parameters.

Soil microorganisms react quickly to environmental stresses by changing activity, biomass, and community structure (Schloter et al., 2003). Collectively, urease, phosphatase, protease, and dehydrogenase give insight into the status of the soil nutrient cycling, as well an indication of the microbial functioning, allowing for evaluation as to the health of the soil. Used together, and when combined with indictors of overall microbial community like MB, these enzymes provide for assessment of the effect of the short-term alterations in soil management and prediction of the long-term result on soil functionality and health. This allows for consideration of management techniques in terms of their effect on a soils agricultural potential and future sustainability in both the short and long-term.

2.8 Tropical soils: the Ethiopian comparison

Ethiopia, typical of East Africa, has such a large population that it has far outstripped the productivity of its agricultural land base, forcing farming out of more sustainable and productive areas (the fertile Rift Valley) and higher into mountainous highlands. The national economy of Ethiopia is highly dependant on agriculture, which comprises 42% of the GDP (2003/2004) and

accounts for 80% of the total Ethiopian employment (MoFED, 2004). The highlands, where the abundance of the population pressure has been exerted, comprise 44% of Ethiopia's land area, 95% of its cultivated area and 88% of its population (Kruger et al., 1996). Highland agriculture has existed for centuries in parts of Ethiopia, but the recent push into marginal land with steeper slopes, more erodible soils, and poorer fertility is causing landscape degradation on a scale previously not seen.

It is not surprising that soils in tropical regions are physically different from soils in temperate regions. The combination of climate, mineralogy and ecology makes tropical highland soils susceptible to large scale erosion after cultivation. Rainfall events are often more intense in tropical regions, contributing to ecologically devastating erosion. The higher humidity and temperature accelerate microbial decomposition, reducing the half-life of SOM and thereby the protection it provides. The removal of the tropical vegetative cover allows rainfall to impact directly on the soil surface, destroying its structure and promoting surface runoff. The steepness of the slopes worsens the situation, especially since expansion into marginal areas means farming steeper and more inaccessible mountain sides. Many highland soils have a fine textured mineralogy originating from volcanic ash which is easily erodible by intensive rainfall events. These factors, manageable in areas considered suitable for agriculture, combine and compound with one another in marginal areas to create a scenario that is very difficult to manage even with all available resources, and disastrous where technological, financial and strategic resources are limited.

The amount of rainfall received in Ethiopia between 1960 and 2002 ranged from 615 mm to 1742 mm annually, and is highly dependant on elevation. The southern highland areas near Sodo and Awassa have mean annual values between 1000 mm to 1250 mm over the 40 year period (Cheung et al., 2008). Most rain falls during the two rainy seasons: the Belg, from March to May and the Kiremt, from June to September. It is not the high annual rainfall which necessarily causes landscape-scale erosion, but the intensity of the rainfall events. Under natural tropical conditions much of the energy of rainfall is absorbed by vegetation in the canopy or litter on the soil surface. Depending upon the amount of precipitation, the canopy can retain 20% to 80% of rainfall (Mohr et al., 1972). When forests and other vegetation are removed and ploughed for agriculture the soil is left exposed. The full velocity of the raindrops impacts the bare soil surface destroying aggregation, forming a fine compacted crust which impedes

infiltration and promotes surface runoff (Ross, 1993). In this way, short but intense rainfalls can cause devastating erosion events in agricultural areas where soil is conventionally tilled and void of vegetation and litter.

Climates in tropical areas also tend to increase SOM turnover. Warmer and more humid atmospheric conditions combined with abundant precipitation create a favorable environment for microbial decomposition (Ross, 1993). While temperate soils experience seasonal periods where microbial function is severely limited by temperature and moisture, in tropical areas the temperature is almost constantly above 10ºC, providing no constraint to microbial activity. However, this is not always the case, because many tropical soils will experience seasonality in moisture if not temperature. Prolonged periods of excessive drought can reduce SOM turnover to rates similar to those found in more temperate regions. The labile SOM pool is usually smaller than that of temperate soils due to the warmer and wetter soil conditions and faster turnover of SOM (Duxbury et al., 1989; Ross, 1993). In situations where tropical soils are deforested and then tilled intensively they lose SOM rapidly (Piccolo et al., 2008). In either case the smaller and more fragile SOM pool of tropical soils provides less aggregation and structure, creating a soil highly susceptible to water erosion.

Along with vegetative cover, slope is the most significant factor in soil erosion. The erosion rates of nutrient and SOM in fallow and corn fields increase with slope angle (Lal, 1976). Upper slope positions suffer organic C loss while level depressions accumulate it (Gregorich et al., 1998). In Ethiopia upslope areas generally have lower nutrient levels than lower slope positions due to the erosional processes on hillslopes (Alemayehu, 2007; Wolde et al., 2007). In highland agricultural soils that have low SOM levels, lack of vegetative canopy, and surface litter and increased slope, it is difficult to manage soil erosion and maintain a sustainable production system.

Land degradation caused by large scale erosion depletes the agricultural productivity of land through plant nutrient pool and SOM losses. The most common soils in the humid tropics are Oxisols, which are high in iron and are typically highly weathered and acidic with very low nutrient retention ability. Because of their nature, these soils will have low amounts of SOM and small nutrient reserves making them fragile and not very resilient. In tropical marginal agricultural land any loss of plant nutrients or SOM is devastating for both soil quality and

agricultural productivity, given that the farmland is already limited in terms of agricultural production.

To truly understand the full soil quality spectrum it is necessary to examine the microbial functioning of the soil, especially as this relates to nutrient transformations and availability (Pankhurst et al., 1997). Soil enzymes are mostly secreted by microorganisms that mediate and catalyze many ongoing soil biochemical transformations including nutrient cycles, and the degradation, mineralization and formation of SOM (Acosta-Martinez et al., 2007). Therefore, any compromise in the ability of the soil to conduct these essential transformations can be reflected by the activity and abundance of the microorganisms and the enzymes responsible for them (Dinesh et al., 2004).

Most studies of soil enzymes have been conducted in temperate zones, and little information is available on enzyme activities in tropical soils (Chander et al., 1997; Cleveland et al., 2003). What information exists on the effect of deforestation and subsequent cultivation proves that the activity of key enzymes is suppressed under cultivation. In the conversion of Indian wet tropical forest to cultivation, microbial activity was suppressed in addition to the activity of the enzymes involved in the cycling of C, N, P and S (Pankhurst et al., 1997). Oxisols, Utisols and Inceptisols in a tropical watershed in Puerto Rico featured the same suppressed enzyme activities under cultivation compared to pasture and forest areas (Acosta-Martinez et al., 2007). In Bangladesh total and active microbial biomass and total organic C and N were all reduced in cultivated soils versus reforestation and grass (Islam and Weil, 2000). It is known that P is deficient in tropical soils, especially acidic Oxisols. Not surprisingly the activity of phosphatases is significantly reduced by the low soil pH of acidic Oxisols (Acosta-Martinez et al., 2007). Assessment of key soil enzymes provides valuable information about the status of the biochemical functioning of the soil. But its true benefit, compared to traditional physical parameters, is often in detecting changes in soil management and land use and in detecting these changes earlier and more efficiently than traditional physical analysis (Ndiaye et al., 2000).

3.0 INTERMITTENT TILLAGE EFFECTS ON SOIL BIOCHEMICAL PROPERTIES OF CONTINUOUS LOW DISTURBANCE CROPPING SYSTEMS IN SASKATCHEWAN

3.1 Introduction

The use of conservation tillage practices has gained wide acceptance across the Canadian Prairies. Land area under no-till, or low disturbance crop production totaled 30% of Canada's farmed acreage in 1996 (Ward, 2002). In Saskatchewan low disturbance management has been more widely adopted than in the rest of Canada with 16 million acres or 50% of the seeded acreage being managed this way (SCCC, 2001). Conventional tillage had been the preferred tillage method until the mid to late 1980s' when the benefits of the low disturbance (LD) farming system became evident to prairie cereal, oilseed and pulse producers.

The reason for the shift from conventional to LD was the realization of the soil conservation and economic benefits the LD system offers. Reducing tillage operations conserves soil quality by increasing the amount of soil organic matter (SOM), improving water infiltration, conserving moisture and reducing erosion by tillage, wind and water (PFRA, 2003). Levels of SOM are increased under LD because the absence of tillage reduces litter decomposition and allows organic residue to build up on the soil surface. Under conventional tillage systems, on the other hand, residue degradation is accelerated because of residue incorporation and aeration of the soil, providing a microclimate more conducive to decomposition processes (Six et al., 1999). These and other benefits of LD systems are a result of maintaining an abundance of crop residue on the soil surface, which decreases erosion and leaves root channels open, allowing for better infiltration and improved structure (SSCA, 2005).

Although the benefits for soil conservation are obvious, the economic aspects of LD cropping are not. Farmers save fuel and labour costs by reducing or eliminating tillage passes, but in turn they are faced with higher quantities of expensive inputs of fertilizers and herbicides. Producers are subject to greater risks associated with the price fluctuations of these inputs (Zentner et al., 2002).

Tillage traditionally has been a useful tool to control weed populations, increase soil warming, and release nutrients within the soil. Therefore with continued pressure on producers

to manage expenses, the option of using tillage occasionally in a long-term LD cropping system could be a means of managing and reducing financial risk and dependency on herbicides and fertilizers. However, the use of tillage in a LD system brings into question the obvious concern about using tillage in a production system that was designed to eliminate it because of its detrimental effect on the physical and functional health of the soil. The possibility that occasional tillage may be harmful to a LD soil, is unstudied and needs to be addressed in order for intermittent tillage to be considered a sound practice which is both economically beneficial and environmentally sustainable. In this study the effect of different tillage intensities within a 10 year no-till cropping system was evaluated in terms of the biochemical properties of the soil that are indicators of soil health and agronomic potential. The effects of various intensities of tillage were analyzed throughout the growing season by examining short-term changes in microbial reaction and soil functionality.

The objectives of this study were two-fold: (1) to assess the significance of short-term variation in tillage intensity on soil biochemical properties indicative of soil health within LD cropping systems in Saskatchewan; (2) to assess the agronomic impact of intermittent tillage treatments of varying tillage intensity on long-term LD management systems in Saskatchewan.

3.2 Materials and methods

This study looks at the effect of intermittent tillage in continuous low disturbance direct seeding systems, more commonly called no-till cropping systems. The plots were tilled at three different tillage intensities, leaving one no-tillage control. This design should reveal the positive or negative effects of tillage on the biochemical properties of agricultural low disturbance soils. The soils were sampled in May and October and analyzed for various soil biochemical indicators in order to determine the impact of the tillage on the no-till agricultural system.

3.2.1 Study sites

The three sites were selected as a part of a related project lead by Dr. Mike Grevers (ADF# 2003112-000274; Baan, 2007). The sites chosen were representative of the three major soil zones in Saskatchewan where LD agriculture is practiced. One site was located in each of the Dark Brown, Black, and Grey soil zones. Each site had been under no-till management for at least ten years before the treatments were applied. Tillage was conducted in the fall of 2004 and

spring of 2005. The plots were then managed as part of the surrounding field by the cooperating farmer under the same conditions of the low disturbance cropping system for the remainder of the study.

3.2.1.1 Tisdale

The Tisdale site is located at GPS coordinates N 53.01678^{o} and W 103.94934^{o} and legal land location SW2-47-14-W2. The land was under a low disturbance cereal oilseed rotation for the 12 years before the study. It is located in the Grey soil zone and is mainly a Dark Grey wooded Eldersly soil with orthic Tisdale soils on lower slopes and through the depressions (Saskatchewan Institute of Pedology, 1985). It is gently sloping with some 5% but mostly 2 to 5% grades, of hummocky nature. The soil texture of the research site is a medium silty clay loam to clay loam.

In May 2005 the site was seeded to canola (*Brassica napus* L. cv. Millenium) at a rate of 5.6 kg ha^{-1}, and fertilized with 67.2 kg N ha^{-1}, 22.4 kg P_2O_5 ha^{-1} and 22.4 kg S ha^{-1}. The crop was seeded using a Flexicoil 5000 airdrill with 7.5 cm Stealth Single-Shoot openers. One-half of the N was placed in between the seed row as anhydrous ammonia (NH_3) with the remainder of the N placed in the seed row as urea along with the 11-52-0 P_2O_5 and S. The previous year this site had been under a wheat crop that left abundant fresh, unaltered residue on the soil surface (Fig. 3.1).

3.2.1.2 Rosthern

The Rosthern site is located at GPS coordinates N 52.66821^{o} and W 106.21182^{o} and legal land location of SW3-43-02-W2. It was continuously cropped for 12 years prior to the implementation of this study using a cereal oilseed rotation. It is located in the Black soil zone and is of the Hamlin Orthic Black soil association, in a shallow lacustrine plain with a knoll and depression pattern (Saskatchewan Institute of Pedology, 1985). The slope class is 2 to 5% gently sloping or roughly undulating. The texture is a medium loam.

The crop grown in 2005 was canola (*Brassica napus* L. cv. Banner) seeded at a rate of 6.2 kg ha^{-1}. The crop was fertilized with a blend containing 56 kg N ha^{-1}, 22.4 kg P_2O_5 ha^{-1} and 11.2 kg S ha^{-1} using a Seed Hawk air-drill equipped with 1.27 cm knife openers. The previous year this site had been under barley that left abundant fresh, unaltered residue on the soil surface (Fig. 3.2).

Figure 3.1. Tisdale research site in fall 2004, after implementation of tillage treatments

3.2.1.3 Central Butte

The Central Butte site is located at GPS coordinates of N 50.72770^{o} and W 106.41588^{o} on legal land location NW30-20-3-W3. The site was cropped under a low disturbance cereal chem-fallow rotation for 10 years before the study. It is located in the Brown soil zone with soils ranging from Brown Solod to Brown Solodized Solonetz typical of the Kettlehut association and from Orthic Brown to Calcareous Brown Chernozem, of the Ardill soil association (Saskatchewan Insitute of Pedology, 1978) The Kettlehut parent material is moderately fine textured, moderately calcareous saline shale and modified glacial till. The Ardill association is moderately fine textured, moderately calcareous, shale modified glacial till. The soil surface texture is loam. Landscape features moderately stoney glacial till plains with knolls and depressions, gently sloping or undulating topograhy.

In the spring of 2005 the plot and the field surrounding were seeded to hard red spring wheat (*Triticum aestivum* L. cv Prodigy) using a John Deere air seeder with 40- cm sweep-type

cultivator shovels. The crop was seeded at a rate of 94 kg ha $^{-1}$ and fertilized with 18.8 kg N ha^{-1} and 17.4 kg P_2O_5 ha^{-1}. The previous season the site was chemical fallowed, and had a low amount of weathered cereal crop residues on the soil surface (Fig. 3.3).

Figure 3.2. Rosthern research site in fall 2004, after implementation of tillage treatments

3.2.2 Experimental design

A completely randomized design was used at each of the sites with four treatments replicated four times. Each plot was 7.3 m x 15.2 m. In the corners of each site radiometric detection devices were buried 30 cm to 60 cm below the surface to enable the corners to be located after field operations. In this way the plot did not interfere with the operations of the farmer, thereby ensuring the experiment accurately reflected field management strategy and environmental conditions.

Figure 3.3. Central Butte research site in fall 2004, after implementation of tillage treatments.

3.2.2.1 Treatments

The tillage treatments used were designed to reflect a minimum tillage control, relative to low, moderate, and a high tillage intensity management strategy. The difference between treatments is predominantly a difference in the intensity of tillage used. All treatments were lightly disturbed once during seeding, including the control, while the others were tilled in either the fall of 2004 or spring of 2005. The control was not tilled other than through the necessary disturbance needed for seed placement. The low intensity treatment was tilled once in spring 2005 prior to seeding and the moderate intensity treatment was tilled once in fall 2004 and once in spring 2005. Both were tilled with a 1.8 m-wide cultivator with 30-cm sweeps with 30-cm row spacing down to a depth of approximately 8 cm and at a speed of 6.4 km h^{-1}. The high intensity tillage treatment received the same tillage as the moderate intensity treatment, except, that it received an additional pass from a tandem disc to the same depth (Baan, 2007). This

treatment represents an extreme perturbation, beings beyond the incremental graduation in tillage intensities seen through the first three treatments.

3.2.2.2 Soil sampling

Soils were sampled in 2005 at the end of May and in October before freeze up. Samples (10 cm depth and are 7 cm in diameter), were taken systematically using a five sample grid pattern to ensure equal representation of the soil condition from each plot (Fig. 3.4).

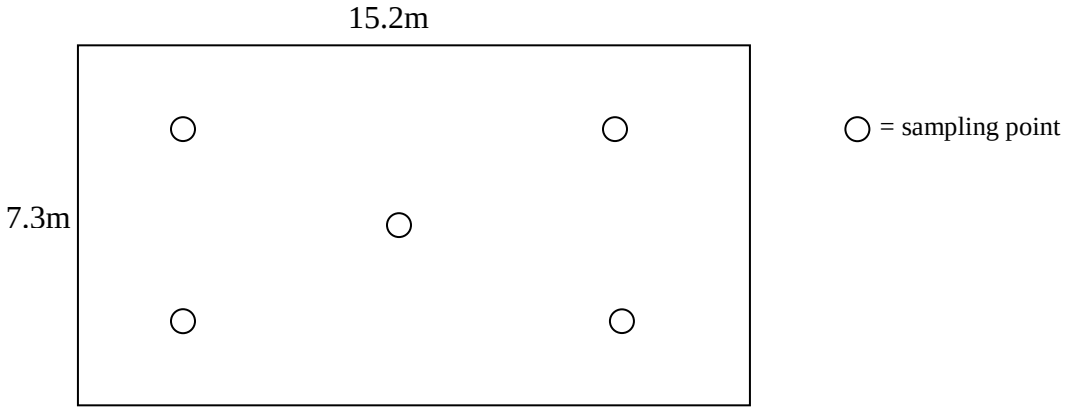


Figure 3.4. Soil sampling design of treatment plot used in Central Butte, Rosthern and Tisdale.

The five samples from each plot were combined into a composite and then two sub-samples were taken. One was stored in a cold room at 5 ^{o}C and the other was stored in a -20^{o}C freezer. The frozen samples were kept in order to preserve them for enzyme activity and microbial biomass analysis. The samples kept at 5 ^{o}C were used for nutrient analysis.

3.2.3 Soil analysis

3.2.3.1 Nutrient analysis

Five grams of field moist soil were weighed into an Erlenmyer flask and 50 mL of 2.0*M* KCl was added. The solution was shaken on a reciprocating shaker for 30 min (Kenney and Nelson, 1982). The solution was filtered with Whatman® #454 filter paper, and stored in plastic vials at 4°C until the extract was analyzed for NO_3^- and NH_4^+ using the Technicon Autoanalyzer II (Labtronics Inc, Tarrytown, NY).

Soil P analysis was done by the modified Kelowna soil P and K extraction method (Qian et al., 1994) used on high pH soils throughout the western prairie provinces. Thirty millilitres of a solution containing 0.25*M* HOAc, 0.25*M* NH_4OAc, and 0.015*M* NH_4F with a pH of 4.9, were mixed with 3 g of soil and shaken on a rotary shaker for 5 min at 200 rpm. The mixture was filtered with Whatman® #454 filter paper and stored at 4°C until they were analyzed colorimetrically using a Technicon Autoanalyzer II.

3.2.3.2 Soil enzyme analysis

Dehydrogenase activity was measured by the 2,3,5-triphenyltetrazolium chloride (TTC) method which uses TTC as an NAD^+ inhibitor (Casida, 1977). The exclusion of oxygen favours the transfer of electrons to the TTC, reducing the TTC to the red triphenyl formazan (TPF) (Pepper and Gerba, 2004). Six grams of soil were placed in a glass vial with a 100*M*m TRIS buffer (pH 7.6) and 6 mL of TTC solution. The samples were incubated for 24 h at room temperature, and then filtered and rinsed with 50 mL methanol. The conversion of TTC to TPF was measured by examining its optical density at 485 nm wavelength with a Thermospectronic Spectronic 20D+.

Activity of alkaline phosphatase was measured using an artificial P (p-nitrophenyl phosphate) substrate mixed with the soil to promote hydrolysis and release of orthophosphate (Tabatabai and Bremmer, 1969). In this method 1 g of soil was incubated with a Modified Universal Buffer (MUB) at pH 11 and p-nitrophenyl phosphate for 1 h at 37°C in a stoppered flask. Then 1 mL of 0.5*M* $CaCl_2$ and 4 mL of 0.5*M* of NaOH was added before the entire suspension was filtered and the yellow color analyzed using a Thermospectronic Spectronic 20D+ at 420 nm wavelength.

Protease activity was determined using casein as a substrate and the subsequent release of amino acids was measured (Ladd and Butler, 1972). One gram of wet soil was mixed with 5 mL of 50*M*m, pH 8.1 TRIS buffer and 5 mL of 2% (wt/vol) sodium caseinate solution. The tubes were incubated at 50°C for 2 h. The reaction was stopped with 15% (wt/vol) trichloroacetic acid solution (TCA). The suspension was centrifuged at 10,000 to 12,000 rev min^{-1} for 10 min. Five milliliters of supernatant was mixed with 7.5 mL alkaline reagent and incubated for 15 min at room temperature. Before filtering, 5 mL of 33% (wt/vol) Folin-Ciocalteu was added. After the

solution was filtered the absorbance was measured after exactly 1 h at 700 nm wavelength with the Thermospectronic Spectronic 20D+.

Urease activity was estimated by the amount of NH_4 released when a 5 g sample of soil is incubated at 37°C for 2 h with 2.5 mL of 4.8% (wt/vol) urea solution (Kandeler and Gerber, 1988). After incubation, the sample was extracted with 50 mL KCl solution (74.5 g KCl, 10 mL 1 M HCl into 1000mL water), shaken for 30 min and filtered. The amount of ammonia was determined using 1 mL of the filtrate mixed with 9 mL distilled water and 5 mL of Na salicylate/NaOH(0.1*M*) solution (17 g Na-salicylate and 120 g Na-nitroprusside in 100 mL distilled water) and 2 mL of 0.1% sodium dichloroisocyanide solution. The mixture was incubated at room temperature for 30 min and the optical density was then measured at 690 nm wavelength using the Thermospectronic Spectronic 20D+.

3.2.3.3 Microbial biomass measurement

Microbial biomass was measured by the microwave (MW) irradiation method evaluated by Islam and Weil (1998) with modifications. The instrument used was 650-W household microwave (CEM MDS 2000, Matthews, NC) with a 2450 MHz magnetron when operating at high power in continuous mode. The energy output of the microwave was measured using 1000 mL of distilled water in a beaker and a thermometer measuring the temperature change over a 2 min exposure to high power using the formula (Neas and Collins, 1988):

$$P=C_pK\Delta Tm/t \qquad [3.1]$$

where P is the power absorbed by the water sample (J s^{-1}) ; C_p is the heat capacity of water (J mL^{-1} $°K^{-1}$); K is a factor (4.184) to convert thermal chemical cal mL^{-1} $°K^{-1}$ to watts (J s^{-1}); ΔT (°C) is the difference between final temperature and initial temperature of water; m is the mass of the water (g); and t is the duration (s) of MW energy application. The MW oven output power was calculated to be 2400-W.

Two 17 s bursts of 400 J g^{-1} were used on 25 g oven-dried equivalent (ODE) soil. The total energy exposure of the soil was 800 J g^{-1} (Islam and Weil, 1998). The measurements were performed on field moist soils that had been frozen in a -20°C freezer and thawed for the experiment. The soils were sieved through a 2 mm screen and brought to 80% water filled pore (WFP) space. Duplicate samples were prepared and incubated at room temperature in plastic

aerated vials for one week. After the incubation one sample was placed in the MW oven for two 17-s bursts and the other left as a control. Both samples were extracted with 100 mL 0.5 *M* K_2SO_4, shaken for 1 h at 150 rpm and filtered with Whatmann #2 filter paper.

The extracts were immediately frozen at -20 °C until analysis was conducted. The frozen extracts were thawed for analysis. Ten millilitres of the K_2SO_4 extract was mixed with 0.45 g K_2SO_8 and autoclaved for 1 h. The solution was cooled to room temperature and 0.2 g Devarda's alloy was added and incubated for 16 h. The solution was decanted and analyzed for NH_4^+ on the Thermospectronic Spectronic 20D+ (Thermo Fischer Scientific Inc., Waltham, MA).

Microbial biomass carbon was measured using the same frozen extracts. The samples were thawed and diluted 10:1 with double-distilled water and analyzed for dissolved organic C using a Total Organic Carbon Analyzer, TOC-5050A Shimadzu (Mandel Scientific, Guelph, ON).

3.2.3.4 Microbial quotient N

Microbial quotient N was calculated as a ratio of MBN to total organic N. Total organic N values were determined by subtracting total soil inorganic N from total soil N. Microbial quotient N was then calculated by dividing the MBN by total soil organic N.

3.2.3.5 Total carbon and nitrogen

Total C and N were analyzed using a LECO CNS-2000 (LECO Corporation, St. Joseph, MI). The samples were air dried and ground to pass through a 2-mm sieve and combusted in a sealed furnace at 1100 °C using a LECO CNS-2000 utilizing an infrared detector and thermal conductivity detector where N in various forms is reduced to N_2 by copper.

3.2.3.6 Statistical analysis

This experiment utilized a completely randomized design. Analysis of variance (ANOVA) was used to determine significance of treatments. Separation of the means was done using least significant difference (LSD) at $P = 0.01$. All statistical analysis was done using SPSS (2005).

3.3 Results

3.3.1 Particle size distribution and observations on litter

Soil particle size was measured on the soil in fall 2004 before the tillage treatments were implemented (Table 3.2). Silt fractions were dominant in Tisdale (43.4%) and Rosthern (41.7%), with sand dominant in Central Butte (40%). Tisdale had the highest percentage of clay (36.2%).

Each of the three sites had notable differences in litter condition and abundance (Table 3.1). Central Butte, being under chemical fallow in 2004, had a small amount of surface residue that was more than partially degradation. Rosthern was cropped in barley in 2004 and had abundant barley residue remaining by May 2005 sampling. Depending on treatment, the residue varied from fresh in the least disturbed treatments, to advanced stages of decomposition in the high disturbance treatments. In Tisdale, the litter layer was comprised mostly of wheat straw from 2004, but also other materials remaining from earlier than 2004. The litter at the Tisdale site was in all stages of decomposition.

Table 3.1 Types of tillage implements and tillage systems used by Saskatchewan farmers and the subsequent soil and residue incorporation resulting from each (Prairie Agricultural Machinery Institute).

Tillage system/ implement	% Soil surface disturbance	% Residue left after 1 pass	% Residue left after 4 passes
Low disturbance	< 30	-	-
Minimum disturbance	> 30	-	-
Full disturbance	100	-	-
Zero till	< 30	-	-
Minimum tillage	> 30	-	-
Conventional tillage	100	-	-
Wide blade cultivator	100	90	60-65
Tandem disc	100	35-65	5-15

Table 3.2 Soil pH and soil particle size distribution of sand, silt and clay measured in fall tillage treatments in Tisdale, Rosthern and Central Butte [adapted from Baan, (2007)]

Soil Particle Class	Tisdale	Rosthern	Central Butte
	-----Soil Particle Size Distribution (%) -----		
Sand	20.4	36.2	40.5
Silt	43.4	41.7	35.0
Clay	36.2	22.1	24.5
	---------- pH ----------		
	7.45	6.52	6.59

At both the May and October sampling dates, soils at Tisdale had the most moisture of the three sites (Table 3.3).

Table 3.3 Soil moisture percentage (wt/v) May and October 2005 in Tisdale, Rosthern and Central Butte (0-to-10cm).

Month	Tisdale	Rosthern	Central Butte
	----------Soil Moisture (% wt/v) ----------		
May	18.9	18.1	15.1
October	21.2	17.8	15.0

3.3.2 **Total carbon, organic carbon, and nitrogen**

Total C was not affected by tillage intensity in May or October of 2005 at any of the sites (Table 3.4).

Table 3.4 Total C under minimum, low, moderate and high disturbance tillage in May and October 2005 in Tisdale, Rosthern and Central Butte (0- to -10cm).

	Tisdale		Rosthern		Central Butte	
Treatment†	**May**	**October**	**May**	**October**	**May**	**October**
	C (Mg C ha^{-1})					
minimum	28.31	30.91	27.90	29.70	15.84	17.33
Low	25.96	27.80	28.20	28.50	16.26	16.05
moderate	24.78	25.54	28.00	28.60	14.98	16.26
High	25.62	26.80	27.70	28.30	16.69	16.37
$LSD_{(0.10)}$‡	**NS§**	**NS**	**NS**	**NS**	**NS**	**NS**

† minimum: no tillage; direct seeding only; low: spring tillage; moderate: fall and spring tillage; high: fall, spring and spring disc tillage
‡LSD, least significant difference assessed at $\alpha = 0.10$
§NS, not significant at $\alpha = 0.10$

Total organic carbon (TOC) measured in the spring of 2005 after imposition of the tillage treatments was not affected by the tillage treatments at any of the sites (Table 3.5).

Table 3.5 Total organic C at 0-to-15 cm depth from soils under minimum, low, moderate and high disturbance tillage in May and October 2005 at Tisdale, Rosthern and Central Butte. Adapted from (Baan, 2007)

	Tisdale		Rosthern		Central Butte	
Treatment†	**May**	**October**	**May**	**October**	**May**	**October**
	TOC (Mg C ha^{-1})¶					
Minimum	16.92	10.35	15.08	14.36	7.68	7.59
Low	14.36	14.92	14.43	12.83	7.62	7.02
Moderate	13.62	12.35	14.28	12.84	7.12	7.23
High	15.71	14.86	13.74	12.56	7.12	8.13
$LSD_{(0.10)}$ ‡	**NS§**	**NS**	**NS**	**NS**	**NS**	**NS**

† minimum: no tillage, direct seeding only; low: spring tillage; moderate: fall and spring tillage; high: fall, spring and spring disc tillage
‡LSD, least significant difference assessed at $\alpha = 0.10$
§NS, not significant at $\alpha = 0.10$
¶ 0- to -15 cm depth

Total N was not affected by tillage treatments in May and October 2005 (Table 3.6). Reflective of the soil zone, total C and total N decreased from Tisdale to Rosthern and further in Central Butte, revealing a north to south gradient of decreasing soil total N and C content.

Table 3.6 Total N at 0- to -15 cm depth in soils under minimum, low, moderate and high disturbance tillage in May and October 2005 in Tisdale, Rosthern and Central Butte.

	Tisdale		Rosthern		Central Butte	
Treatment†	**May**	**October**	**May**	**October**	**May**	**October**
	----------N (Mg N ha^{-1})----------					
Minimum	3.39	3.45	3.21	3.50	2.15	2.30
Low	3.18	3.13	3.34	3.79	2.13	2.33
Moderate	2.96	2.88	3.21	3.52	2.07	2.27
High	3.05	3.03	3.20	3.63	2.18	2.21
$LSD_{(0.10)}$ ‡	**NS§**	**NS**	**NS**	**NS**	**NS**	**NS**

† minimum: no tillage, direct seeding only; low: spring tillage; moderate: fall and spring tillage; high: fall, spring and spring disc tillage
‡LSD, least significant difference assessed at $\alpha = 0.10$
§NS, not significant at $\alpha = 0.10$

3.3.3 **Nutrient analysis**

Nitrate (NO_3^-) concentrations were affected by tillage intensity at all sites in May 2005 (Table 3.7). Nitrate decreased in the high intensity treatment relative to the minimum intensity control in Tisdale in May, while in Rosthern and Central Butte NO_3^- levels increased in the high intensity treatment relative to the minimum intensity control. Ammonium (NH_4), at Tisdale, decreased in the moderate and high intensity treatment relative to the minimum intensity control. Ammonium did not respond in May to tillage intensity at Rosthern and Central Butte sites.

Nitrate and NH_4^+ concentrations in October at Tisdale in the moderate tillage treatment decreased relative to the minimum intensity control while the others were unaffected (Table 3.7). Nitrate concentrations in both Rosthern and Central Butte were decreased by the low intensity treatment relative to the minimum intensity control and then increased by the moderate and high intensity treatments relative to the low intensity treatment. At Rosthern and Central Butte, NH_4^+ concentrations did not respond to tillage intensity in October.

Extractable phosphate increased in the high intensity treatment relative to all the intensity treatments in Tisdale in May and October. In Central Butte in May, PO_4 concentrations increased in the moderate and high intensity treatments relative to the minimum and low intensity treatments. In Central Butte in October, PO_4 concentrations decrease in the low and

moderate intensity treatment relative to the minimum intensity control, and then increases in the high intensity treatment relative to all lower intensity treatments (Table 3.6). Conversely, concentrations in Rosthern were reduced in the high intensity treatment relative to the minimum intensity control in both May and October.

Table 3.7 Soil nitrate, ammonium and phosphorus at 0-to-10 cm depth under minimum, low, moderate and high disturbance tillage of previously no-till sites in May and October 2005 in Tisdale, Rosthern and Central Butte.

	May 2005								
	Tisdale			Rosthern			Central Butte		
Treatment†	NO_3	NH_4	PO_4	NO_3	NH_4	PO_4	NO_3	NH_4	PO_4
	Kg N ha^{-1}								
Minimum	68.0	8.8	16.4	5.2	0.4	17.2	8.6	3.2	11.0
Low	66.6	9.8	17.2	5.2	1.0	16.2	9.4	3.1	10.8
Moderate	53.6	6.6	14.6	6.0	0.8	14.8	10.6	3.1	12.8
High	33.2	3.8	17.8	8.0	0.6	14.6	11.6	3.1	12.8
$LSD_{(0.10)}$ ‡	**15.4**	**5.4**	**2.2**	**0.6**	**0.2**	**1.6**	**1.6**	**0.6**	**1.2**

	October 2005								
	Tisdale			Rosthern			Central Butte		
Treatment†	NO_3	NH_4	PO_4	NO_3	NH_4	PO_4	NO_3	NH_4	PO_4
	Kg N ha^{-1}								
Minimum	5.4	2.0	17.6	3.8	1.0	14.4	3.2	0.8	12.8
Low	6.0	2.4	17.4	3.2	1.0	12.2	2.6	0.8	11.8
Moderate	4.2	1.4	17.4	4.2	1.2	11.0	3.6	0.6	11.8
High	6.0	2.2	21.2	4.2	1.2	11.2	3.4	0.8	13.8
$LSD_{(0.10)}$ ‡	**1.0**	**0.6**	**1.8**	**0.4**	**0.2**	**1.6**	**0.2**	**0.2**	**1.4**

† minimum: no tillage, direct seeding only; low: spring tillage; moderate: fall and spring tillage; high: fall, spring and spring disc tillage
‡LSD, least significant difference assessed at $\alpha = 0.10$
§NS, not significant at $\alpha = 0.10$

3.3.4 **Enzyme analysis**

3.3.4.1 Dehydrogenase

Tillage intensity affected dehydrogenase activity at the May sampling at Tisdale and Rosthern (Fig. 3.5). High tillage intensity reduced dehydrogenase activity relative to the minimum tillage intensity control treatment in Tisdale in May but the tillage effect was not statistically significant by October. Conversely, in Rosthern, the high tillage intensity treatment had higher activity than the low and moderate treatments in the spring and in October the minimum tillage intensity treatment increased relative to the others. In Central Butte dehydrogenase was unaffected until October when the moderate intensity treatment had higher dehydrogenase activity relative to the minimum tillage control and the high intensity treatment.

3.3.4.2 Alkaline phosphatase

Tillage intensity did not affect phosphatase activity at any of the sites in May or October (Fig. 3.6.) In comparing the levels of activity in May and October, phosphatase had higher activity across all the tillage intensity treatments in May than in October in Tisdale. The opposite occurred in Central Butte and Rosthern where alkaline phosphatase activity was lower in May than October.

3.3.4.3 Protease

Protease activity was affected by tillage intensity in May and October only at Rosthern but the differences were minor (Fig. 3.7). In May the moderate intensity treatment decreased protease activity relative to the high intensity treatment. In October activity was decreased relative to both the minimum tillage control and the high intensity tillage treatment. The Central Butte and Tisdale sites had no treatment dependant effects with respect to protease. However, in both sites protease activity was visibly elevated in October relative to May across all tillage intensities.

3.3.4.4 Urease

Urease activity was affected by the tillage treatment at only the Rosthern site in May (Fig. 3.8). The moderate tillage intensity treatment decreased urease activity relative to the control treatment, but this effect was not detected by October. In Tisdale in May urease activity was lower in the moderate and high intensity treatments, although not signIficantly, possibly due to the highly variable nature of the data in Tisdale.

3.3.5 **Microbial biomass**

Microbial biomass N was affected by the variable tillage operations at Rosthern in October and Central Butte in May (Fig 3.9). Tillage intensity had no effect on MBN in Rosthern in May, but in October the MBN in the moderate intensity tillage treatment decreased relative the low intensity tillage treatment. In Central Butte the high intensity tillage treatment increased MBN over the low intensity treatment but MBN values were very low at both sampling times.

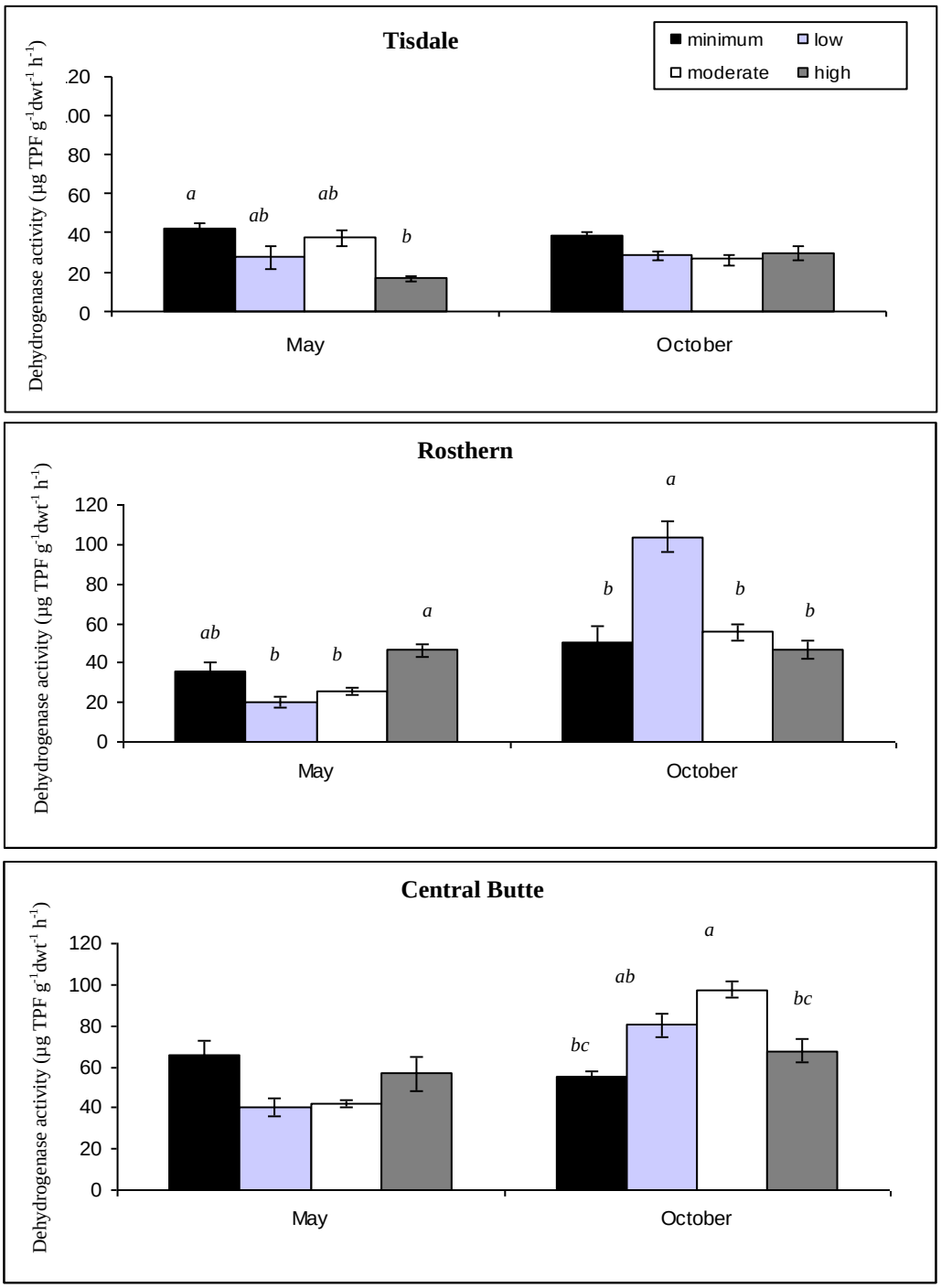


Figure 3.5. Dehydrogenase activity as measured by conversion of TTC to TPF as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage control but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

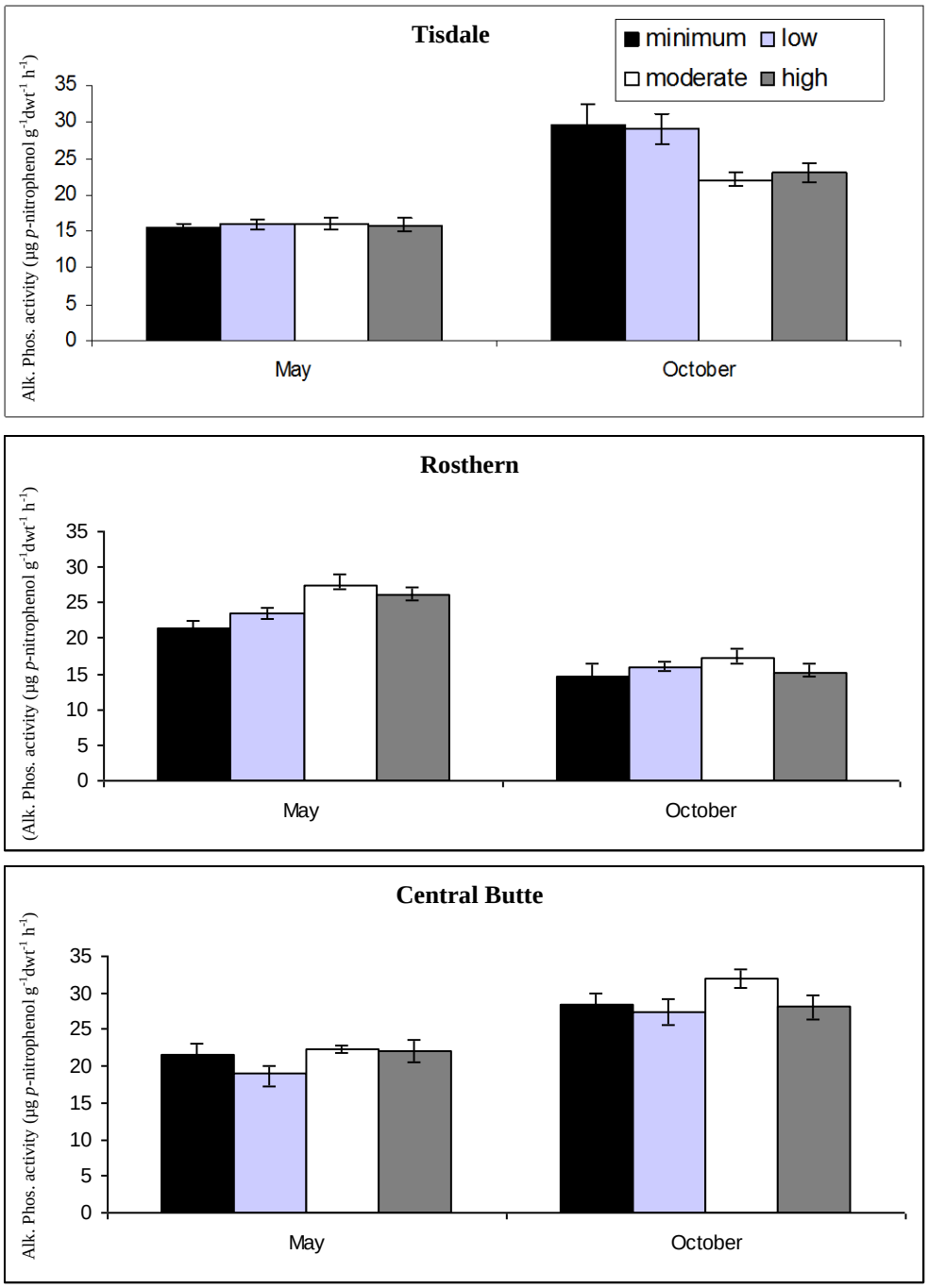


Figure 3.6. Alkaline phosphatase activity measured by release of p-nitrophenol from sodium p-nitrophenol phosphate as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. No significant differences were detected according to LSD. Error bars represent standard error.

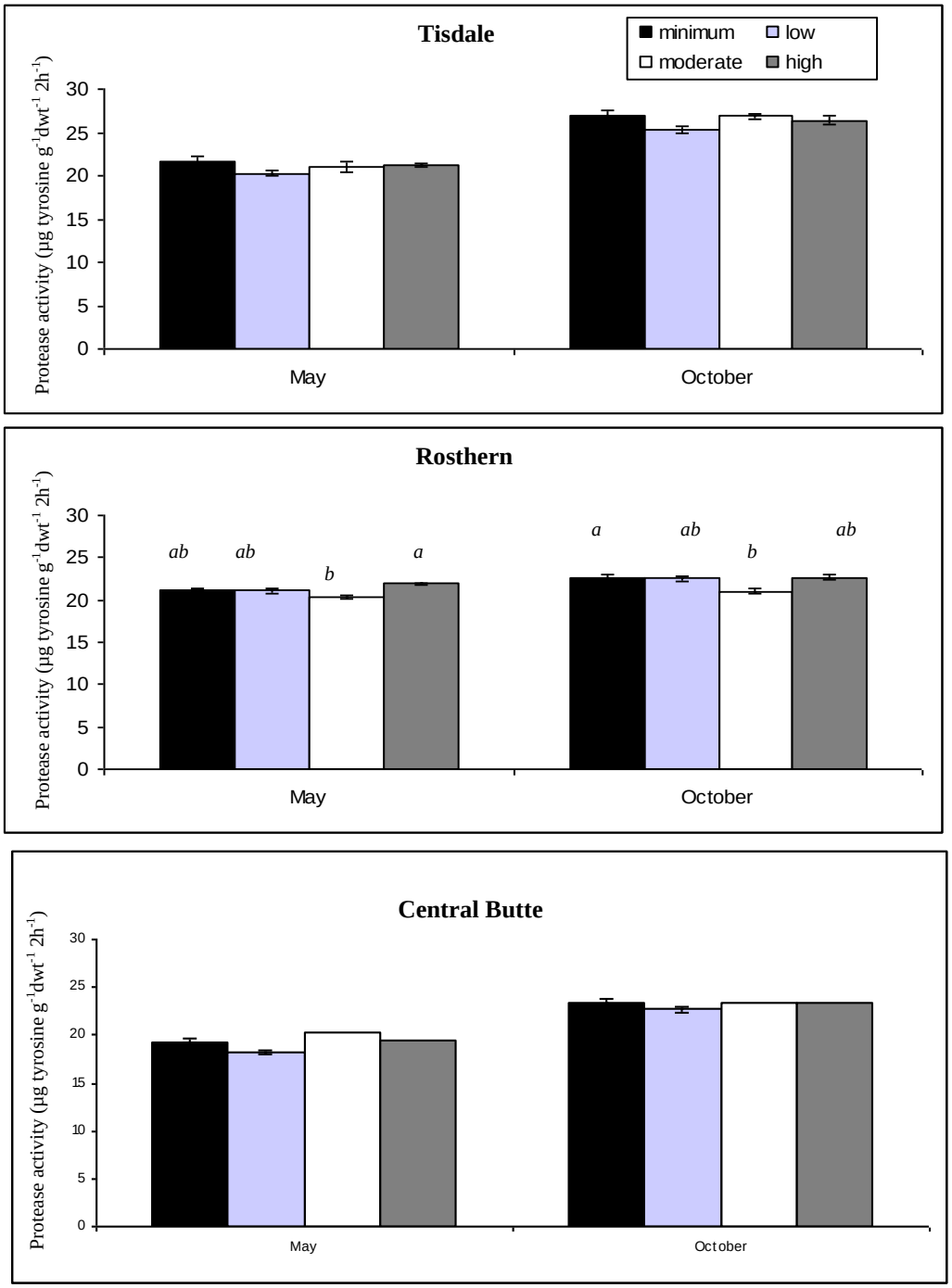


Figure 3.7. Protease activity measured by the conversion of casein to tyrosine as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

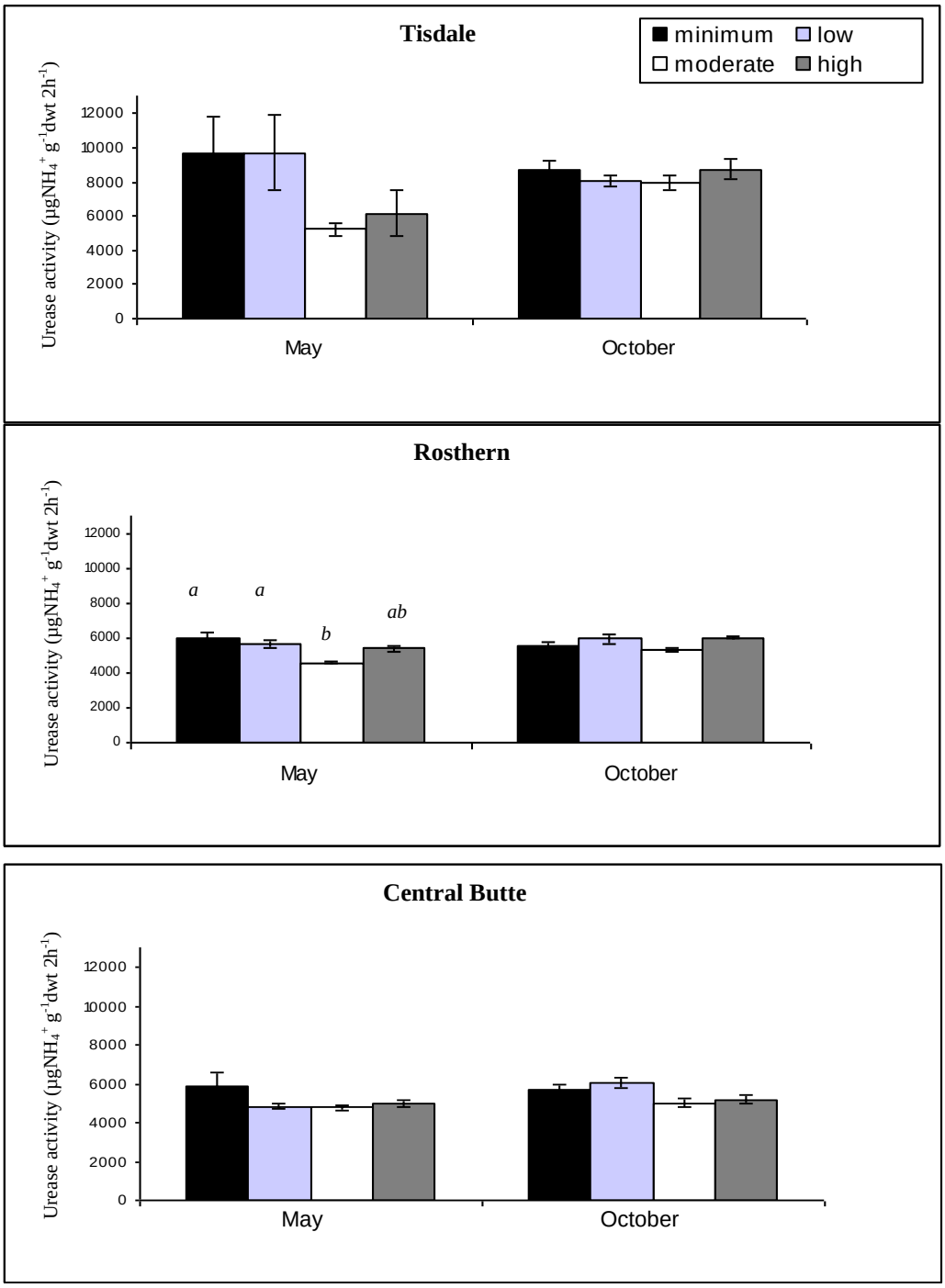


Figure 3.8 Urease activity measured by the conversion of urea to ammonium as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

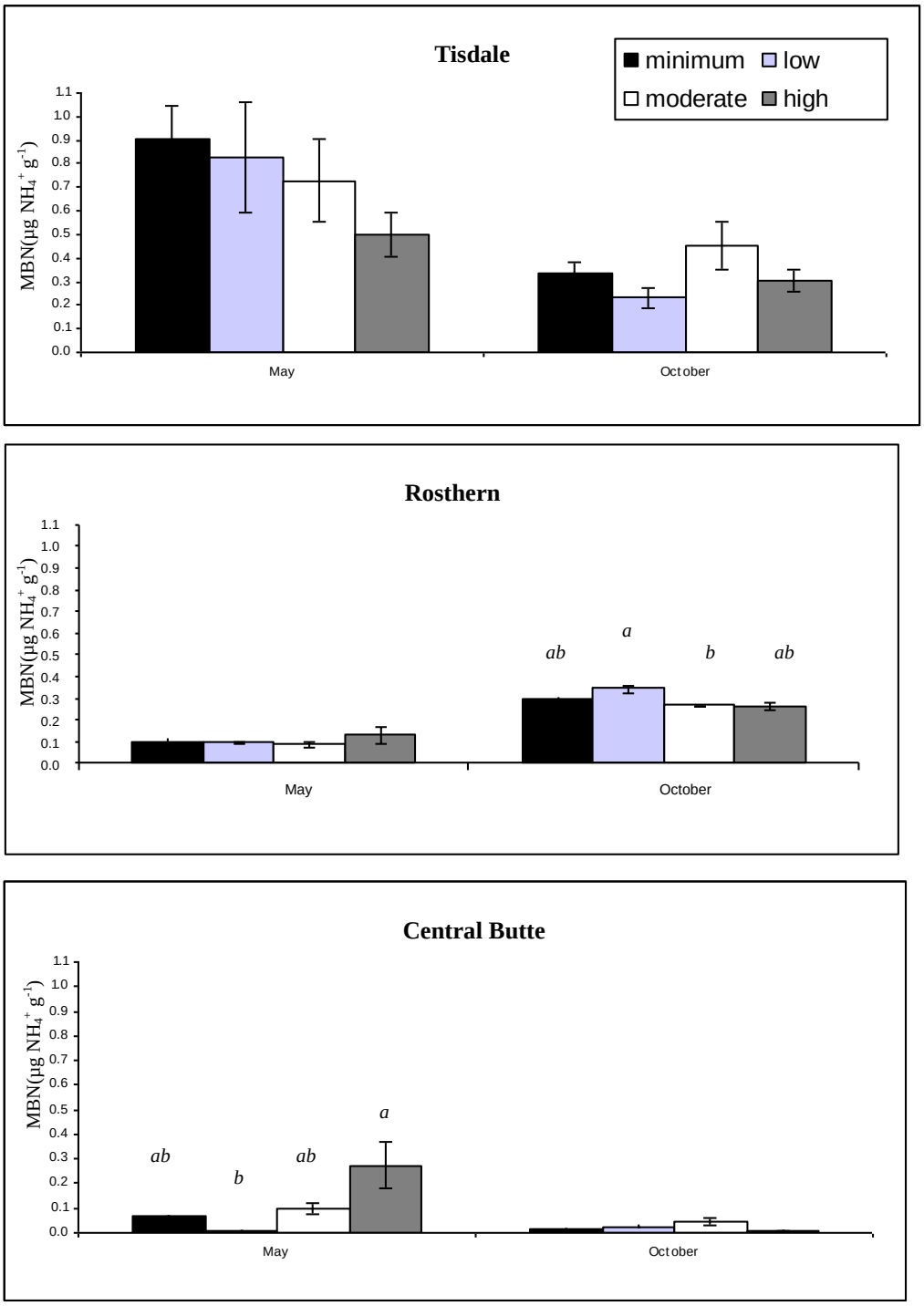


Figure 3.9. Microbial biomass nitrogen as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

Tillage intensity affected MBC in Tisdale and Central Butte (Fig. 3.10). In Tisdale MBC decreased in the low and moderate intensity treatment relative to the high intensity treatment in May. This effect did not continue into October although a trend was observed but the significance was lost due to the highly variable nature of the data. In Central Butte, in May, MBC increased in the high intensity treatment relative to the minimum intensity control, and in October it was increased in the moderate treatment relative to control. In Rosthern MBC did not change due to the tillage treatments. Microbial biomass C and N followed similar patterns at the Central Butte site in May but tended to diverge for the other sites and for the fall sampling. Microbial quotient N was affected by tillage intensity in Rosthern and Central Butte (Fig 3.11). In October the MQN in Rosthern decreased in the moderate and high intensity treatments relative to the low treatment. In Central Butte in May it increased in the high tillage intensity treatment relative to the low intensity tillage treatment, but the effect did not continue into October. At Tisdale, no significant differences between tillage treatments were detected.

3.4 Discussion

3.4.1 **Effects of tillage on litter distribution and incorporation.**

Under LD management, soil disturbance is minimal, allowing crop residues to accumulate on the soil surface. Soil disturbances and subsequent crop residue placement alters soil physical and chemical properties which may lead to significant changes in composition, distribution and activities of soil microbial communities and enzymes (Deng and Tabatabai, 1996). In this study, the effect of tillage intensity, both directly and indirectly, on soil enzyme activity was studied at all three sites, showing the sensitivity of microbial and enzyme activity to disturbance. The quality and redistribution of fresh and partially decomposed crop residues and the alteration of the soil structure by the tillage treatments were dominant factors effecting the biochemical reaction of the long-term LD soils studied at Central Butte, Rosthern and Tisdale, Saskatchewan. Understanding the effects of the tillage treatments on the physical characteristics of the soil and litter is necessary for a complete understanding of the soil's biological response and subsequent alterations of its biochemical functioning or health.

The variation in the implements used for each tillage treatment played a defining role in compromising the condition of the soil and litter. The minimum treatment plots were disturbed only during seeding. The Tisdale and Rosthern sites utilized LD implements, having minimal

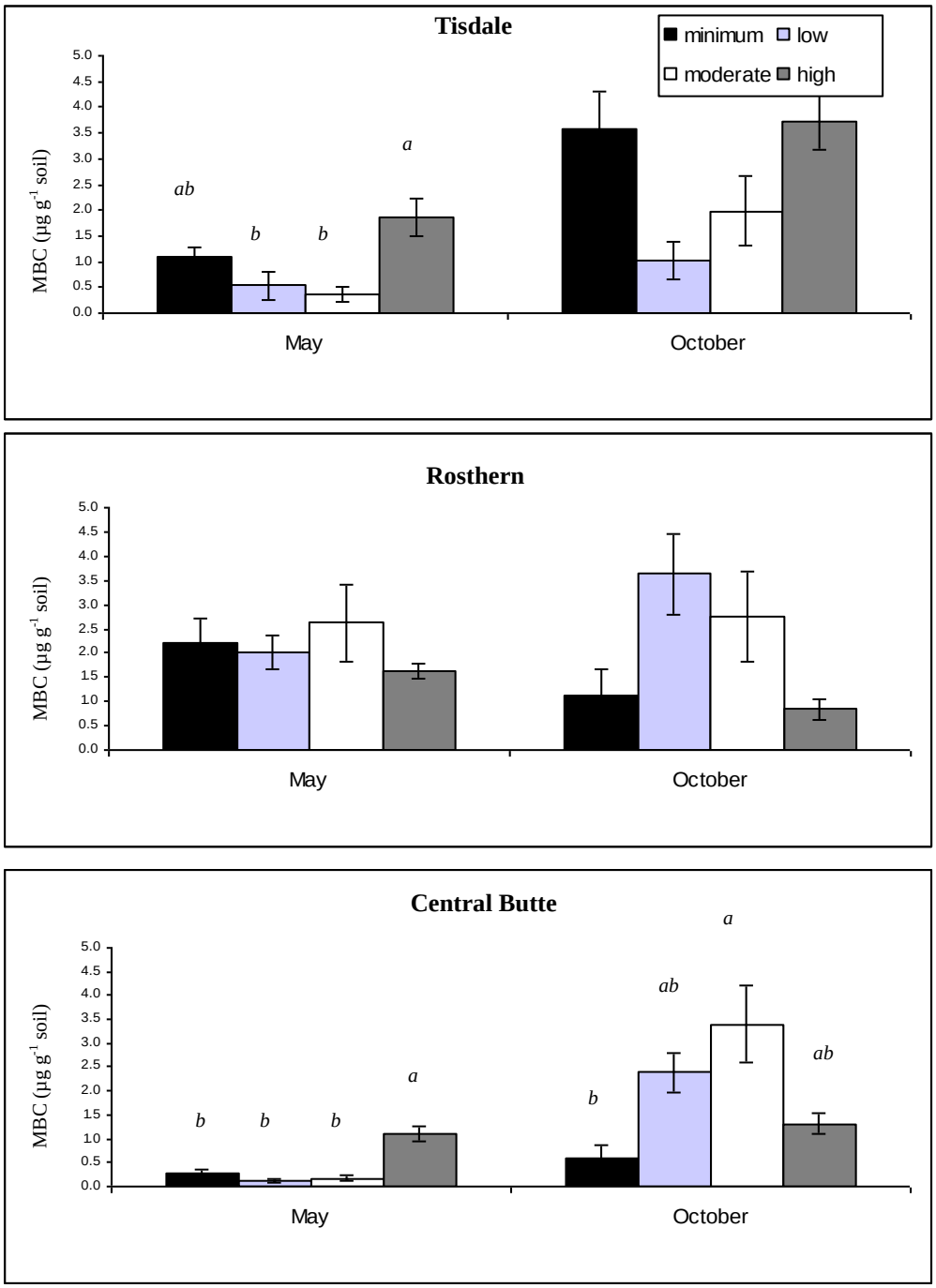


Figure 3.10. Microbial biomass carbon as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

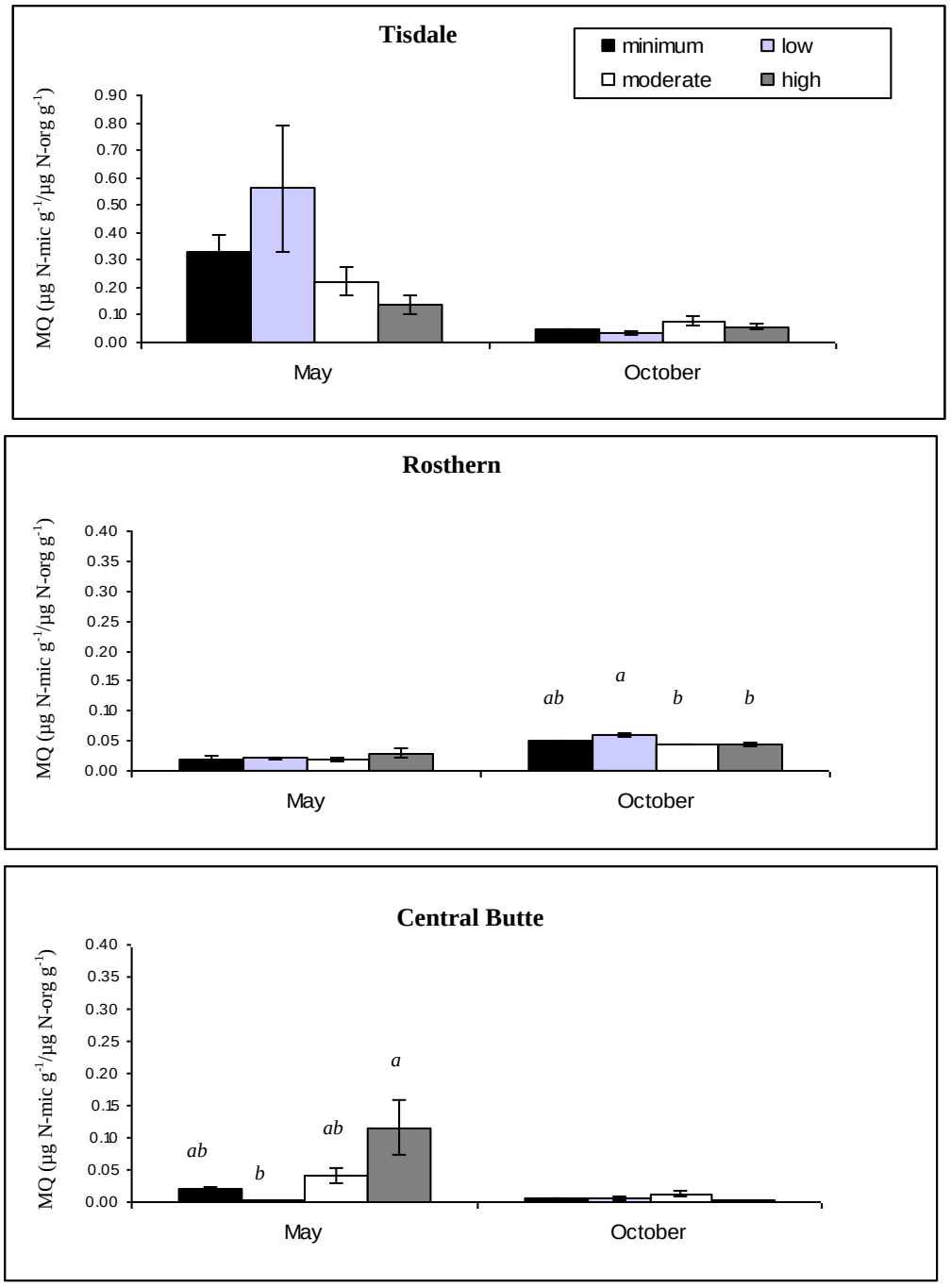


Figure 3.11. Microbial quotient as a ratio of total microbial N vs. total organic N as affected by tillage intensity in May and October 2005 at three sites in Saskatchewan. Minimum represents no tillage but only a minimal disturbance seeding pass, low is one conventional spring tillage pass, moderate is one fall and spring tillage pass, and high is a fall, and spring tillage with an added spring disc pass. Bars within a sampling time followed by the same letter indicates no difference ($p>0.10$) according to LSD. Error bars represent standard error.

soil disturbance, whereas in Central Butte, an air seeder with standard shovels was used, causing similar soil disturbance as the single tillage pass used for the treatments. The low and moderate treatments were imposed, at all sites, by a cultivator equipped with 30-cm sweep-type shovels. Sweep-type shovels move under the soil surface, mainly lifting and inverting only a small amount of soil from below. The crop residues are not entirely incorporated into the soil, leaving the largest proportion of residue on the surface with the physical structure maintained. In contrast, a tandem disc was used in the high intensity plots, inverting the plough layer, breaking up the crop residue and mixing it thoroughly through the whole plough layer.

Therefore, the increase in tillage intensity from moderate to high was greater in magnitude than the increase from low to moderate or even minimum to moderate. The high intensity tillage altered the soil to such an extent that the treatments cannot be compared as gradual successive increases in tillage intensity; rather, the high intensity treatment needs to be viewed as an extreme disturbance event, severely altering the soil's physical condition, crop residue distribution, and biological properties, and therefore should be considered separately. This effect can be seen in the response of MBC, dehydrogenase, protease and urease to the high intensity treatment (Fig 3.6, 3.7, 3.8, 3.10).

The incorporation of fresh organic residues into the soil, as seen in the high intensity treatment, can temporarily increase soil MB by offering new sites for microbial growth and releasing fresh substrates for microbial growth (Chotte et al., 1998). The tillage treatments incorporated the litter layer into the plough layer, to various degrees, increasing the exposure of the microbial communities to fresh organic materials. This exposure occurred at different scales relative to tillage intensity and the effect was site dependant due the condition and abundance of the litter at each of the sites. The large quantity of litter at Rosthern was mostly fresh barley residue from the previous season, while in Central Butte, little litter was present and what was present was in advanced stages of decomposition. The minimum tillage treatment left the litter layer unaltered, while the minimum and moderate treatments redistributed the litter layer but still left a large proportion of the litter on the surface. The high intensity treatment, on the other hand, incorporated all the surface materials into the entire plough layer, as well as altering the physical relationship of both the organic materials and soil aggregates. This created a more favorable environment for microbial growth resulting in an increase in MBC, MBN and MQN in

Central Butte as the degraded litter was metabolized (Fig. 3.9, 3.10, 3.11), while in Rosthern, the incorporation of the fresh residue had no effect on the same parameters.

Physical characteristics such as temperature and moisture are especially influential on microbial communities and enzymes within the soil plough layer (Deng and Tabatabai, 1996). Therefore obvious differences in the soil type, OM levels, temperature, and moisture between the sites naturally created comparative variability in the parameters assessed. The increased soil moisture lower down in the soil profile relative to the surface is probably the largest contributing factor leading to accelerated decomposition in tilled soils (Franzbluebbers and Arshad, 1996). The amount of crop litter on the soil surface, from abundant and fresh in Tisdale and Rosthern to the much less and weathered litter in Central Butte, experiences temperature fluctuations and wetting and drying that can limit microbial growth. Conversely, the crop litter mixed into the soil profile as OM is buffered against the climatic variability allowing it to support a larger and a more active MB (Franzluebbers and Arshad, 1996). Because the high intensity tillage treatment likely accelerated decomposition rate of incorporated surface litter, it becomes the most profound factor influencing the soil biochemical response to the tillage treatments.

3.4.2 **Soil enzymes**

Dehydrogenase is proven to be a reliable indicator of soil microbial activity, and is therefore the most widely studied as such (Dick, 1997). On all sites, the low and moderate tillage treatments had no significant effect on dehydrogenase activity in May, although a tendency toward decreased activity is seen. This is possibly due to soil drying. The high intensity treatment significantly increased activity in May in Rosthern over the low and moderate treatments, but the high intensity decreased dehydrogenase activity in Tisdale relative to the control. The response in Rosthern is likely due to the stimulation of microbes by the high intensity of the disc treatment and mixing of the soil aggregates and crop residue. Crop residue with high C:N ratios, such as cereal straw, are greater than 30:1 (>30:1), on the other hand residue with a low C:N ratio, such as heavily N-fertilized crops or legumes are less than 30:1 (<30:1)(Bremer and van Kessel, 1992; Ocio et al., 1991). The response in Tisdale again was likely limited by the N-limiting environment created by the incorporation of the high C:N ratio of the surface litter, causing immobilization of the inorganic fertilizer N pool. Upon incorporation of large amounts of N poor residue, such as the abundant wheat straw, can enhance

immobilization and reduce N availability (Schoenau and Campbell, 1996). The MBC:MBN ratio grew to nearly 4:1 in the high intensity treatment in May, meaning microbial cells were in need of N, thus making the competition for N critical and likely shrinking the total MB of the high intensity treatment relative to the other intensities and thus similarity decreasing dehydrogenase activity.

In October, the effect of tillage on dehydrogenase activity in Tisdale no longer existed. However, the Rosthern and Central Butte sites responded differently than in May with activity increasing in the low and moderate treatments and then decreasing in high intensity plots seen in May. Dehydrogenase activity in the low and moderate intensity treatments was slower to respond than the dehydrogenase in the high intensity treatment plots, but by October, relative to the high intensity treatment, the low intensity treatment in Rosthern and the moderate intensity treatment in Central Butte gained significantly higher levels of dehydrogenase activity. This means that the tillage-induced biological acceleration seen in May had caused rapid consumption of the easily degradable substrate made available by the high intensity treatment and was thus unnoticeable by October. The more gradual response seen in the low and moderate treatments, unnoticeable in May, realized the full effect of the tillage treatment only in October. It is important to note that, in all cases, the minimum treatment remained relatively constant throughout the season.

Soil alkaline phosphatase is a good indicator of microbial activity, as it is believed to be totally derived from microorganisms (Juma and Tabatabai, 1977). In all three study sites the alkaline phosphatase was unresponsive to the tillage treatments. The Tisdale site in October showed a decreasing trend of activity, suggesting that phosphatase may be sensitive to tillage, but only in the long-term. The response of alkaline phosphatase to changes in soil management is detectable in the long-term (Gupta and Germida, 1988; Saviozzi et al., 2001). Also, the data had high variability making it difficult to assess significance. This high variability may be due to a naturally high variance of enzyme activity within the soil, perhaps indicating that phosphatase is dependant on micro-site activity. Nonetheless, the data suggests that short-term soil management changes do not affect phosphatase activity likely due to the ability of most soils to maintain a pH buffered labile pool of phosphorus that responds more slowly to management changes that other plant nutrients.

Inorganic PO_4 content increased in the high intensity treatment in Tisdale and Central Butte in May and October, relative to the control (Table 3.6), indicating increasing P mineralization with increasing tillage intensity. At Rosthern PO_4 was decreased in the low, moderate and high intensity treatments relative to the control. This effect may be due to the fresh residue that was not as readily decomposed as the Tisdale and Central Butte residues.

At the Rosthern site, urease activity decreased in the moderate treatment relative to the minimum intensity control. Protease and dehydrogenase responded similarly to urease, increasing in the high intensity treatment relative to the moderate intensity treatment. This may be attributable to a gradient of decreasing activity from the soil-litter interface to the bulk soil (Kandeler et al., 1999b). The litter layer was increasingly broken and partially incorporated into the soil by the cultivator treatments. The litter was not compromised in physical structure but spread disproportionately above and through the surface layer, disrupting the soil-litter interface. Enzyme activities, including protease and urease were depressed under intensive agricultural management relative to undisturbed grassland and forest (Saviozzi et al., 2001). The protease and urease activity observed in the minimum intensity treatment reflects the undisturbed soil-litter interface that exists there, with the most degraded materials at the soil surface supporting an active microbial pool. The disruption of the litter layer and interface area by the low and moderate treatments probably caused the lower enzyme activity. The high intensity treatment, on the other hand, by evenly disturbing the litter throughout the soil profile, accelerated microbial decomposition by having the litter inside the profile in a more favorable microbial environment. This allowed the microbial community to more easily colonize and metabolize the litter and resulted in net NO_3^- mineralization in the high intensity treatment in May (Table 3.6).

The initial response in Rosthern in May to the high intensity tillage treatment caused an increase in dehydrogenase activity in the high intensity treatment relative to the low and moderate treatments. The degree of tillage in the moderate and high intensity treatments caused net N mineralization to occur. By October, this effect was lost in the high intensity treatment, with dehydrogenase, urease and protease activities returning to values of the minimum intensity control and net N mineralization dropping (Table 3.6). The moderate intensity treatment, in October, on the other hand, had dehydrogenase activity values similar to the control, and MBC and MBN, however, NO_3^- levels are equal to that of the high intensity treatment, significantly higher than the minimum intensity control. This may indicate that a period of increased

microbial activity stimulated by the moderate tillage treatment, as captured in the high intensity treatment, was missed in the sampling for the moderate treatment.

Dehydrogenase activity in the low intensity tillage treatment in Rosthern in October increased relative to the minimum intensity control. The low intensity treatment also had increased MBN and MQ values relative to the moderate intensity treatment. This indicates that the low intensity tillage treatment stimulated the microbial activity in October. This means that in Rosthern the increasing tillage intensity increasingly stimulated microbial activity as the intensity of the tillage increased. The high intensity treatment stimulated the microbial community almost immediately after treatment. Incrementally lower tillage intensities were stimulated gradually and was carried out over the growing season, as in the moderate intensity treatment, and possibly into the following year as in the case in the low intensity treatment.

Central Butte experienced a similar effect to Rosthern except not as profound. The high intensity treatment in May increased MBC relative to the minimum intensity control treatment, while MBN and MQ were increased relative to the low intensity treatment. As well, there was possible N mineralization and nitrification with increased NO_3^- levels in the high intensity treatment, possibly due to accelerated microbial activity. Evidence of a long-term effect in October is indicated by an increase in dehydrogenase activity in the moderate intensity treatment over the minimum intensity control treatment. This is similar to the Rosthern site where there may be a delayed response to the tillage treatment under the moderate intensity treatment. Reasons for the possibility of Central Butte's delayed response or lack of enzyme response may be explained by the seeding method, which was done with a high disturbance air seeder with sweeps, which would have acted as an additional tillage treatment over the treatments used in Rosthern and Tisdale. As well, the Central Butte site had a relatively small amount of litter present due to the chemical fallow period the year before that left behind small amounts of partially degraded residue. Due to the easily metabolized litter and the added tillage intensity the MBC, MBN and MQ responded quickly to the tillage treatment.

Tisdale, being typical of a soil located in the Dark-Grey soil zone, has more OM than Rosthern and much more than Central Butte . The abundance of degradable substrate already present as OM may have buffered the effect of the tillage and litter redistribution. In addition, the inorganic N levels in the soil indicate that there was large-scale immobilization of fertilizer N, in the high intensity treatment. This is probably due to the incorporation of a litter layer to the

soil plough layer that likely had a high C:N ratio (>30:1) and/or N compounds resistant to microbial degradation, triggering microbial inorganic N assimilation from the fertilizer N pool. The N competitive environment created in the high intensity treatment and the magnitude of the disturbance caused a decrease in dehydrogenase activity relative to the minimum intensity control, as well as a trend of decreasing activity in the urease activity, MQ and MBN. This indicated that microbial activity was negatively affected by the high intensity tillage treatment, although MBC increased in the high intensity treatment relative to the low and moderate intensity treatments. This may indicate a high turnover of the MB, and the MBC being an unexpected or and inaccurate measurement.

3.4.3 **Microbial biomass (MB)**

Microbial biomass carbon and MBN both responded to the treatments, but differently. Microbial biomass N appears to be more sensitive to seasonal soil perturbations and treatment effects than MBC (Campbell et al., 1992b) and was the case for the Rosthern site where MBC was not affected by tillage treatment, and MBN was higher in the low intensity treatment than the moderate and high intensity treatments. This may have been due to the accelerated MB turnover associated with the high tillage intensity.

Microbial biomass C was more sensitive to the tillage treatments in both Central Butte and Tisdale than MBN. In May in Central Butte the high intensity treatment had much larger MBC and MBN, likely due to the stimulation of the microbial community by the perturbation of the high intensity treatment. In Tisdale and Central Butte in October the MBC remained nearly the same as May in the high intensity treatment, however in Central Butte the low and moderate treatments increased as they were affected by the impact of the tillage over a longer period of time, receiving the microbial stimulation throughout the season. However, all the MBN was depressed in October relative to its May values, especially the high intensity treatment. This could be due to the poorer moisture conditions and the fact that crop uptake immobilized most of the available N through the growing season, decreasing the amount of N available for microbial assimilation.

3.4.4 **Microbial quotient (MQ)**

In this study MQ was calculated to compare MBN to total soil organic N (Nmic:Norg). Traditionally a ratio of MBC to total soil organic C is calculated. However, given the short-term

of this study it was thought that changes in the C ratio in the microbial biomass would be difficult to detect. Nitrogen might be a more sensitive indicator of the short-term impact of tillage treatments over a single growing season. Microbial biomass nitrogen was more sensitive in the short-term than other indicators in both the Dark Brown and Black soil zones of Saskatchewan (Campbell et al., 1992a; Campbell et al., 1992b).

There was no significant difference in MQN in Tisdale, demonstrating the effect of the OM and, specifically, the resiliency which high levels of OM provide to a soil. Central Butte in May showed a significant increase in MQ in the high intensity tillage treatment; by October, however, this had fallen to an insignificant level. This shows that high intensity tillage had a temporary, short-term impact on the soil in Central Butte, stimulating the microbial community and increasing nutrient cycling as demonstrated in increased nutrient levels (Table 3.6). In Rosthern the treatment response did not occur until October, but in this site the low intensity treatment featured significantly higher MQ, indicating that low intensity treatment may have had more impact than the more intensive moderate and high treatments. This is a similar trend to the dehydrogenase, and MBN (Figure 3.5, 3.9). Increasing tillage intensity had a negative effect on the soil microbial population. As tillage intensity increased, the MQ ratio began to decrease indicating a more N-limiting environment and lower nutrient cycling.

3.5 Conclusion

This assessment of the impact of variable intensities of intermittent tillage on long-term LD cropping systems has shown that there is an effect on the biochemical status of the soil. The significance of the impact of intermittent tillage in these systems must be viewed with consideration of the tillage technique, the unique characteristics of the soil and especially undecomposed residue and OM. How each tillage treatment is conducted plays a significant role in the effect observed, with more severe tillage operations causing greater incorporation of residue. Soils with high OM levels may not be affected even at high intensities due to their inherent resiliency. In contrast, a soil with low OM may show longer term effects. Lastly, the characteristics of the soil litter, such as its stage of degradation, the C:N ratio, the amount present and its layering will all have different effects. All these physical factors need to be considered when conducting intermittent tillage.

High OM soils tend not to have a lasting significant response to tillage treatments, even at the highest intensity of tillage. The reduced substrate availability in low OM soils makes them more responsive to tillage that incorporates litter and breaks soil aggregates. Incorporation of surface residue can cause changes in microbial activity that can last for an entire season. These changes are likely not detrimental to LD soils, but they are worth consideration in low OM soils.

The tillage technique also may need to be considered. Highly aggressive techniques that reduce aggregation and incorporate large amounts of residue need to be considered in terms of the resulting loss of soil structure. As well, the introduction of litter material into the soil profile can alter the biochemistry quite easily. In contrast, lower intensity tillage treatments that do not incorporate as much residue and do not impact structure as significantly have a decreased impact on biochemical parameters. However, the disruption of the soil litter may interfere with the ongoing decomposition processes occurring in the litter layers of these soils. Nonetheless, these techniques when used intermittently in a long-term LD system likely will not have an influence that will contribute to the overall degradation of the soil.

Lastly, the characteristics of the litter need to be known before tillage occurs. In soils with large amounts of litter on the soil surface, knowing the C:N ratio is very important when planning fertilizer rates for a subsequent crop. Incorporation of high C:N residues (>30:1) into the soil will require the microbial pool to assimilate and immobilize N in order to successfully consume the new material. This will increase competition for N with the crop and in cases where large amounts of high C:N litter or litter with resistant N compounds is added, the microbial demand may immobilize a large amount of N that otherwise would be available for crop uptake. However, litter with high C:N may benefit from periodic incorporation of N rich residues, allowing for net mineralization and other agronomic benefits.

All these factors play a large role in the biochemical response to tillage, but in terms of a long-term LD cropping system, tillage events, even at the highest intensities, are not likely to be detrimental to the soil health or quality. Even after the highest intensity, the effect of tillage showed signs of diminishing quickly, and in most cases caused no responses that were alarming in terms of the soils' long-term health. On the other hand, in long-term LD cropping systems, consideration of these factors is necessary to ensure that the soil performs to its agronomic potential. This demands that we know the physical and chemical conditions of the soil and litter

as well as the impact of different tillage techniques on them in order to ensure sustained agricultural productivity.

4.0 EFFECT OF HILLSLOPE VEGETATIVE TERRACES ON SOIL BIOCHEMICAL PARAMETERS IN SOUTHERN ETHIOPIA

4.1 Introduction

Ethiopia, typical of East Africa, has such a large population that it has far outstripped the productivity of its agricultural land base, forcing farming out of more sustainable and productive areas (the fertile Rift Valley) and higher into mountainous highlands. The national economy of Ethiopia is highly dependant on agriculture, which comprises 42% of the GDP (2003/2004) and accounts for 80% of the total Ethiopian employment (MoFED, 2004). The highlands, where the abundance of the population pressure has been exerted, comprise 44% of Ethiopia's land area, 95% of its cultivated area and 88% of its population (Kruger et al., 1996). Highland agriculture has existed for centuries in parts of Ethiopia. The recent push into marginal land with steeper slopes, more erodible soils, and poorer fertility is causing landscape degradation on a scale previously not seen.

It is not surprising that soils in tropical regions are physically different from soils in temperate regions. The combination of climate, mineralogy and ecology makes tropical highland soils susceptible to large-scale erosion after cultivation. Rainfall events are often more intense in tropical regions, contributing to ecologically devastating erosion. The high humidity and temperature accelerate microbial decomposition, reducing the half-life of SOM and thereby the protection it provides. The removal of the tropical vegetative cover allows rainfall to impact directly on the soil surface, destroying its structure and promoting surface runoff. The steepness of the slopes worsens the situation, especially since expansion into marginal areas means farming steeper and more inaccessible mountain sides. Many highland soils have a fine textured mineralogy originating from volcanic ash which is easily erodible by intensive rainfall events. These factors, manageable in areas considered suitable for agriculture, combine and compound with one another in marginal areas to create a scenario that is very difficult to manage even with abundant technological, financial and strategic resources, and disastrous where these resources are limited.

The amount of rainfall received in Ethiopia between 1960 and 2002 ranged from 615 mm to 1742 mm annually, and is highly dependant on elevation. The southern highland areas near Sodo and Awassa have mean annual values between 1000 mm and 1250 mm over the 40 year

period (Cheung et al., 2008). Most rain falls during the two rainy seasons: the Belg, from March to May and the Kiremt, from June to September. It is not the high annual rainfall which necessarily causes landscape-scale erosion, but the intensity of the rainfall events. Under natural tropical conditions much of the energy of rainfall is absorbed by vegetation in the canopy or litter on the soil surface. Depending upon amount of precipitation, the canopy can retain 20% to 80% of rainfall (Mohr et al., 1972). When forests and other vegetation are removed and ploughed for agriculture the soil is left exposed. The full velocity of the raindrops impacts the bare soil surface destroying aggregation, forming a fine, compacted crust which impedes infiltration and promotes surface runoff (Ross, 1993). In this way, short but intense rainfalls can cause devastating erosion events in agricultural areas where soil is conventionally tilled and void of vegetation and litter.

Climates in tropical areas also tend to increase SOM turnover. Warm, humid atmospheric conditions combined with abundant precipitation create a favorable environment for microbial decomposition (Ross, 1993). While temperate soils experience seasonal periods where microbial function is severely limited by temperature and moisture, in tropical areas the temperature is almost constantly above 10ºC, providing no constraint to microbial activity. However, this is not always the case, because many tropical soils will experience seasonality in moisture. Prolonged periods of excessive drought can reduce SOM turnover to rates similar to those found in more temperate regions. The labile SOM pool is usually smaller than that of temperate soils due to the warmer and wetter soil conditions and faster turnover of SOM (Duxbury et al., 1989; Ross, 1993). In situations where tropical soils are deforested and then tilled intensively they lose SOM rapidly (Piccolo et al., 2008). In either case the smaller and more fragile SOM pool of tropical soils provides less aggregation and structure, creating a soil highly susceptible to water erosion.

Along with vegetative cover, slope is the most significant factor in soil erosion. The erosion rates of nutrients and SOM in fallow and corn fields increase with slope angle (Lal, 1976). Upper slope positions suffer OC loss while level depressions accumulate it (Gregorich et al., 1998). In Ethiopia upslope areas generally have lower nutrient levels than lower slope positions due to the erosional processes on hillslopes (Alemayehu, 2007; Wolde et al., 2007). In highland agricultural soils that have low SOM levels, lack of vegetative canopy, and surface

litter and increased slope, it is difficult to manage soil erosion and maintain a sustainable production system.

Land degradation caused by large-scale erosion depletes the agricultural productivity of land through plant nutrient pools and SOM losses. The most common soils in the humid tropics are Oxisols, which are high in iron and are typically highly weathered and acidic with very low nutrient retention ability. Because of their nature, these soils will have low amounts of SOM and small nutrient reserves making them fragile and not very resilient. In tropical marginal agricultural land any loss of plant nutrients or SOM is devastating for both soil quality and agricultural productivity, given that the farmland is already limited in terms of agricultural production.

To truly understand the full spectrum of a soil's quality it is necessary to examine its microbial functioning, especially as this relates to nutrient transformations and availability (Pankhurst et al., 1997). Soil enzymes are mostly secreted by microorganisms that mediate and catalyze many ongoing soil biochemical transformations including nutrient cycling, and the degradation, mineralization and formation of SOM (Acosta-Martinez et al., 2007). Therefore, any compromise in the soil's ability to conduct these essential transformations can be reflected by the activity and abundance of the microorganisms and the enzymes responsible for them (Dinesh et al., 2004).

Most studies of soil enzymes have been conducted in temperate zones, and little information is available on enzyme activities in tropical soils (Chander et al., 1997; Cleveland et al., 2003). What information exists on the effect of deforestation and subsequent cultivation indicates that the activity of key enzymes is suppressed under cultivation. In the conversion of Indian wet tropical forest to cultivation, microbial activity is suppressed in addition to the activity of the enzymes involved in the cycling of C, N, P and S (Pankhurst, 1997). Oxisols, Utisols and Inceptisols in a tropical watershed in Puerto Rico featured the same suppressed enzyme activities under cultivation compared to pastured and forested areas (Acosta-Martinez et al., 2007). In Bangladesh total and active microbial biomass and total organic C and N were all reduced in cultivated soils versus reforestation and grass (Islam and Weil, 2000). It is known that P is deficient in tropical soils, especially acidic Oxisols. Not surprisingly the activity of phosphatases is significantly reduced by the low soil pH of acidic oxisols (Acosta-Martinez et al., 2007). Assessment of key soil enzymes provides valuable information about the status of

the biochemical functioning of the soil. The true benefit of soil enzymes, compared to traditional physical parameters, is often in detecting changes in soil management and land use and in detecting these changes earlier and more efficiently than traditional physical analysis (Ndiaye et al., 2000).

4.2 Materials and methods

Site selection A watershed in southern Ethiopia in Damot Woyde Woreda, in the Wolayita Zone was selected. The area selected demonstrates the effects of long-term hillslope cultivation by traditional methods directly adjacent to a hillslope under conservation management in the form of a hillslope terrace. The site has been terraced since 1977. The site was separated into two plots, one above the terrace called Terrace Upper (*Tu)* and the other below the terrace called Terrace Lower (*Tl*). An adjacent unterraced area was also terraced in 1977 but was abandoned 20 years ago to be farmed as an entire hillslope. This plot also was separated into two plots, the plot above the destructed terrace was called Unterraced upper (*Uu*) and the plot below the terrace on the steep hill-slope was called Unterraced lower (*Ul*) (Fig. 4.1). The GPS coordinates are N 6° 53.185 and E 37° 52.136 with an elevation of 2002 meters above sea level (m.a.s.l.) and with an average overall east-facing slope of 20%. The unterraced lower slope (*Ul*), features a steeper slope of 25%. The site was planted with an intercrop of beans (*Phaseolus vulgaris*) and corn *(Zea mays)*. A second west facing field site (1993 m.a.s.l.) was selected across the valley to serve as a comparison to the first. This site (Site 2) was an old terrace that was highly eroded without an adjacent terrace for comparison. Nonetheless, it serves as a second contrast to the main study site. This plot was intercropped with sweet potato *(Ipomoea batatas)* and corn *(Zea mays)*.

4.2.1 Sampling design

Samples, 7 cm in diameter, were taken from the tilled layer to a depth of 10 cm using a five sample grid pattern to ensure equal representation of the soil condition from each plot. The samples were stored individually at room temperature and kept and maintained at field moisture and shipped to Saskatoon for analysis, which unfortunately took 3 months due to delays in getting the required permits from the Ethiopian government.

4.2.2 **Analysis**

Dehydrogenase activity was measured by the TTC method which uses 2,3,5-triphenyltetrazolium chloride (TTC) as an NAD^+ inhibitor. The exclusion of oxygen favours the transfer of electrons to the TTC reducing it to the red triphenyl formazan (TPF) (Pepper and Gerba, 2004). The method was according to Casida (1977) with modifications (Sec. 3.2.3.2).

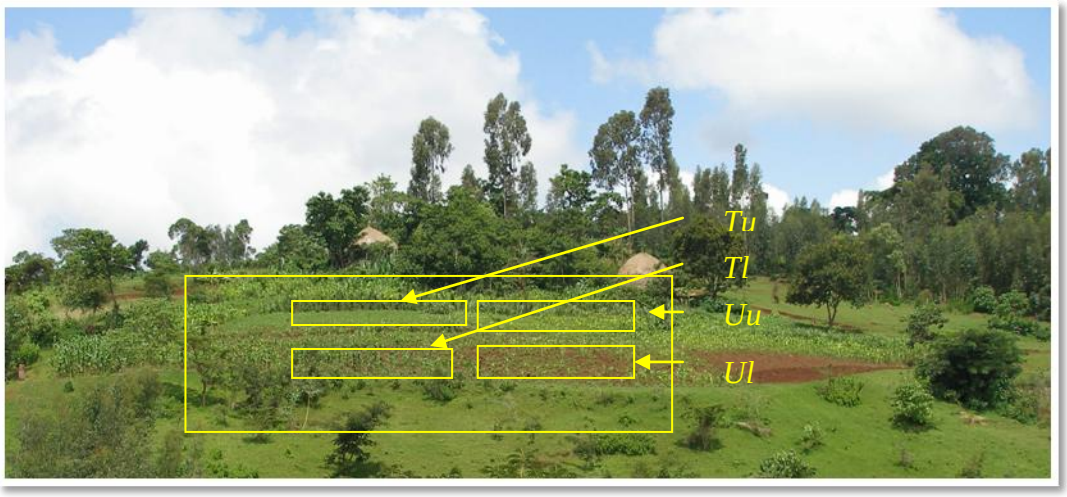


Figure 4.1 Research Site 1 in southern Ethiopia in Damot Woyde Woreda, in the Wolayita Zone. The site features two adjacent field plots one terraced with a vegetative hedgerow (upper left) and the other farmed as a complete hillslope (right).

Alkaline phosphatase activity was measured according to the method described by Tabatabai and Bremmer (1969). This method uses an artificial phosphorus (p-nitrophenyl phosphate) substrate that is mixed with the soil to promote hydrolysis and the release of orthophosphate (Sec. 3.2.3.2).

The activity of urease was measured using methods described by Kandeler and Gerber (1988) where urease activity was determined by the amount of NH_4^+ released when soil is incubated at 37°C for 2 h with an urea solution (Sec. 3.2.3.2).

Soil pH was determined using air-dried, ground soil passed through a 2 mm sieve. A 2:1 suspension of distilled water and soil was then made, using 20mL of distilled water and 10 g of soil. Soil pH was determined using an ACCUMET model 50 pH/ion/conductivity meter (Fisher Scientific Company, Ottawa, ON).

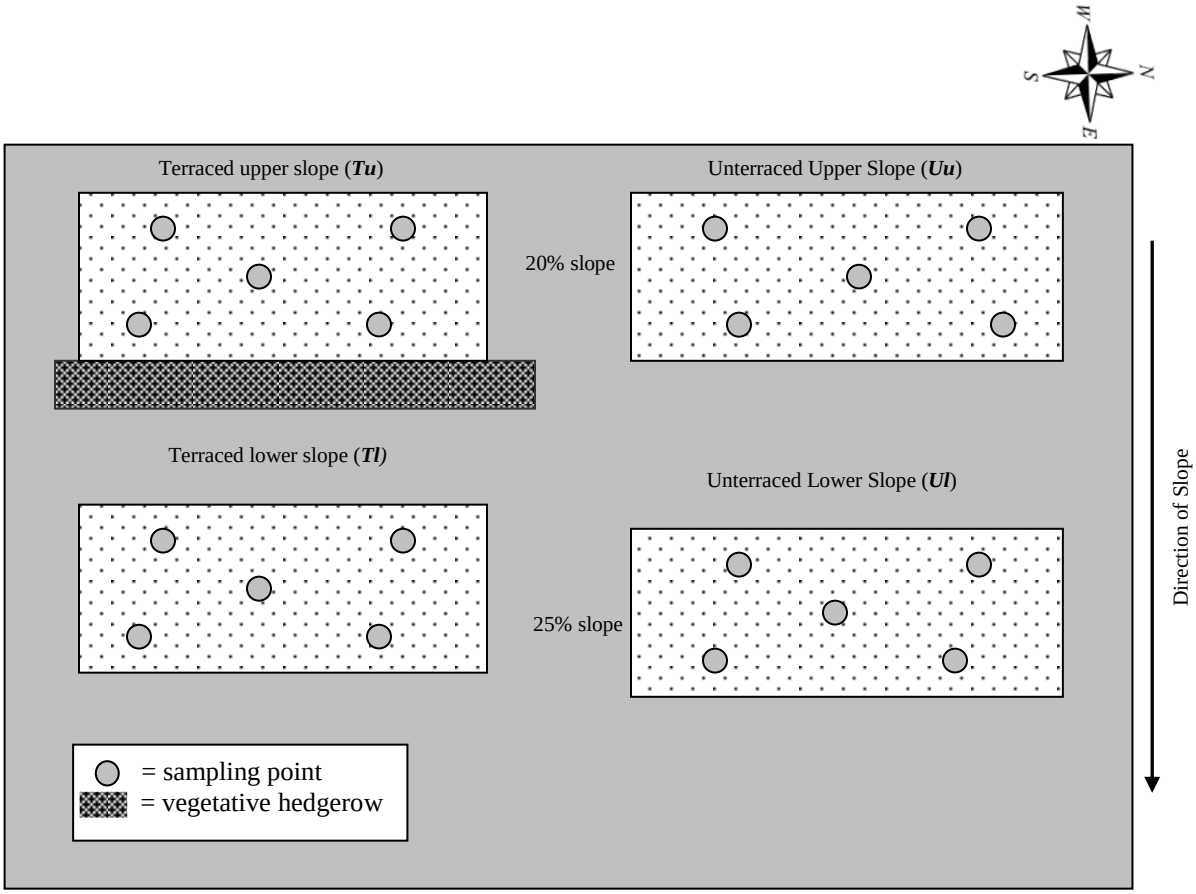


Figure 4.2 Layout of the research plot Site 1 in southern Ethiopia in Damot Woyde Woreda, in the Wolayita Zone. The site features two adjacent field plots one terraced with a vegetative hedgerow and the other farmed as a complete hillslope.

4.3 Results

4.3.1 pH, total C and N

Although no statistically significant differences were detected, soils at Site 1 tended to have higher pH values in the unterraced plots (*Uu* and *Ul*), with mean pH values of 5.49 and 5.36, than in the terraced plots (*Tu* and *Tl*) with mean pH values of 5.31 and 5.24 in the terraced upper and lower plots respectively (Table 4.1). As well, there was a tendency toward higher pH in the upper plots (*Tu, Uu*) than in the lower plots. Site 2 had lower pH than Site 1 having mean values of 4.42 and 4.79.

Total C tended to be higher in the terraced plots than the unterraced plots although no statistical significance was detected (Table 4.1). Of the terraced plots, a higher mean total C

(1.25 Mg ha^{-1}) was found in the lower plot (*Tl*), while the adjacent unterraced plots had total C mean values of 1.12 Mg ha^{-1} (*Uu*) and 1.05 Mg ha^{-1} (*Ul*). Similarly, Site 2 featured a higher total C value (1.13 Mg ha^{-1}) in the upper plot than in the lower plot (1.11 Mg ha^{-1}).

Total N values ranged from 0.16 Mg ha^{-1} to 0.18 Mg ha^{-1} (Table 4.1). The terraced plots tended to have slightly higher means than the unterraced plots.

Table 4.1 Soil pH, total C and N Mg ha^{-1} on adjacent terraced and unterraced hillslope (Site 1) and an unterraced hillslope (Site 2).

Treatment†	pH	Carbon	Nitrogen	C:N ratio
		----- (Mg ha^{-1})-----		
Site 1				
Tu	5.31	1.21	0.17	7.1
Tl	5.24	1.25	0.18	6.9
Uu	5.49	1.12	0.17	6.5
Ul	5.36	1.05	0.16	6.6
LSD$_{(0.10)}$ ‡	**NS§**	**NS**	**NS**	
Site 2				
2u	4.42	1.13	0.16	7.1
2l	4.79	1.11	0.17	6.5
LSD$_{(0.10)}$	**NS**	**NS**	**NS**	

† Tu: site 1; terraced; upper slope; Tl: site 1; terraced; lower slope; Uu: site 1; unterraced: upper slope; Ul: site1; unterraced; lower slope; 2l: site 2; eroded terrace; lower slope; 2u: site 2; eroded terrace; upper slope.
‡LSD, least significant difference assessed at $\alpha = 0.10$
§NS, not significant at $\alpha = 0.10$

4.3.2 **Soil quality parameters**

At Site 1 the upper slope (*Tu* and *Uu*) had higher urease and dehydrogenase activity than the lower slope plots beneath the terrace (*Tl* and *Ul*) (Fig. 4.3). The unterraced hillslope (*Uu* and *Ul*) had significantly higher urease and alkaline phosphatase activity in the *Uu* than in *Ul*.

The unterraced upper slope (*Uu*) had significantly higher alkaline phosphatase activity than all of the other plots. Alkaline phosphatase activity was higher in the terraced slopes (*Tu* and *Tl*) than the unterraced lower slope plot (*Ul*).

There were no differences within the Site 2 plots (*2u* and *2l*). Site 2 had significantly lower activities of all three enzymes than the unterraced plots at Site 1. Dehydrogenase and urease activities were the same between Site 2 plots and the plots in Site 1 below the terrace (*Tl*). Furthermore, urease activity in the unterraced lower plots (*Ul*) was not different from Site 2.

4.4 Discussion

Few assessments of soil quality in eroded tropical soils have been performed. What research has been conducted focuses largely on strategies to control or reduce soil erosion in areas at high risk for large-scale erosion events. The most effective of these uses a complex approach and is usually completely impractical for developing nations with limited available resources (Welle et al., 2006). The most significant factor causing sheet and rill erosion in highland areas is the slope. Slope forces the transportation of soil particles in a thin film of water or in more severe situations forms an abundance of parallel channels (5mm- 20000mm in width) that transport soil off of steep slopes. If rills are left uncontrolled through continued water erosion they may deepen to form gullies. Contour vegetative terraces or barriers that reduce slope and runoff velocity are likely the single most effective means of reducing soil loss and far more practical for farmers to adopt and maintain. Vegetative terraces have been proven, in comparison to conventional methods, to mediate soil loss. Unfortunately, the effect of the reduction of soil loss on soil health and quality in these circumstances has not been well documented. This comparison of adjacent terraced and unterraced field plots in Ethiopia have revealed that the terraces, through reducing massive soil loss, have maintained a higher state of soil functionally and biochemical cycling relative to the adjacent slopes managed without any erosion prevention measures.

This study assessed the effects of soil erosion prevention and its corresponding effects on selected enzyme activities vital to soil nutrient cycling. The most visibly eroded plot in Site 1 was the unterraced lower slope (*Ul*), which had numerous rills and gullies that ran downslope between the crop rows. *Ul* was located below an old terrace that was previously destroyed, had a slope of 25% or more, and had not historically had any erosion management. The upper slope area (*Uu*) had a shallower slope of 20%; it was located above the old terrace, and had minimal visible signs of erosion. The *Ul* plot had significantly lower alkaline phosphatase and urease activities than both the *Uu* and *Tu*, along with the lowest %N and %C of all the plots. In this adjacent comparison, the plots that were protected by a vegetative terrace at one point (*Tu and Uu*) had increased urease, phosphatase and dehydrogenase activity than the positions on untterraceed slopes or below an existing terrace (*Tl and Ul*). As well, the terraces may have

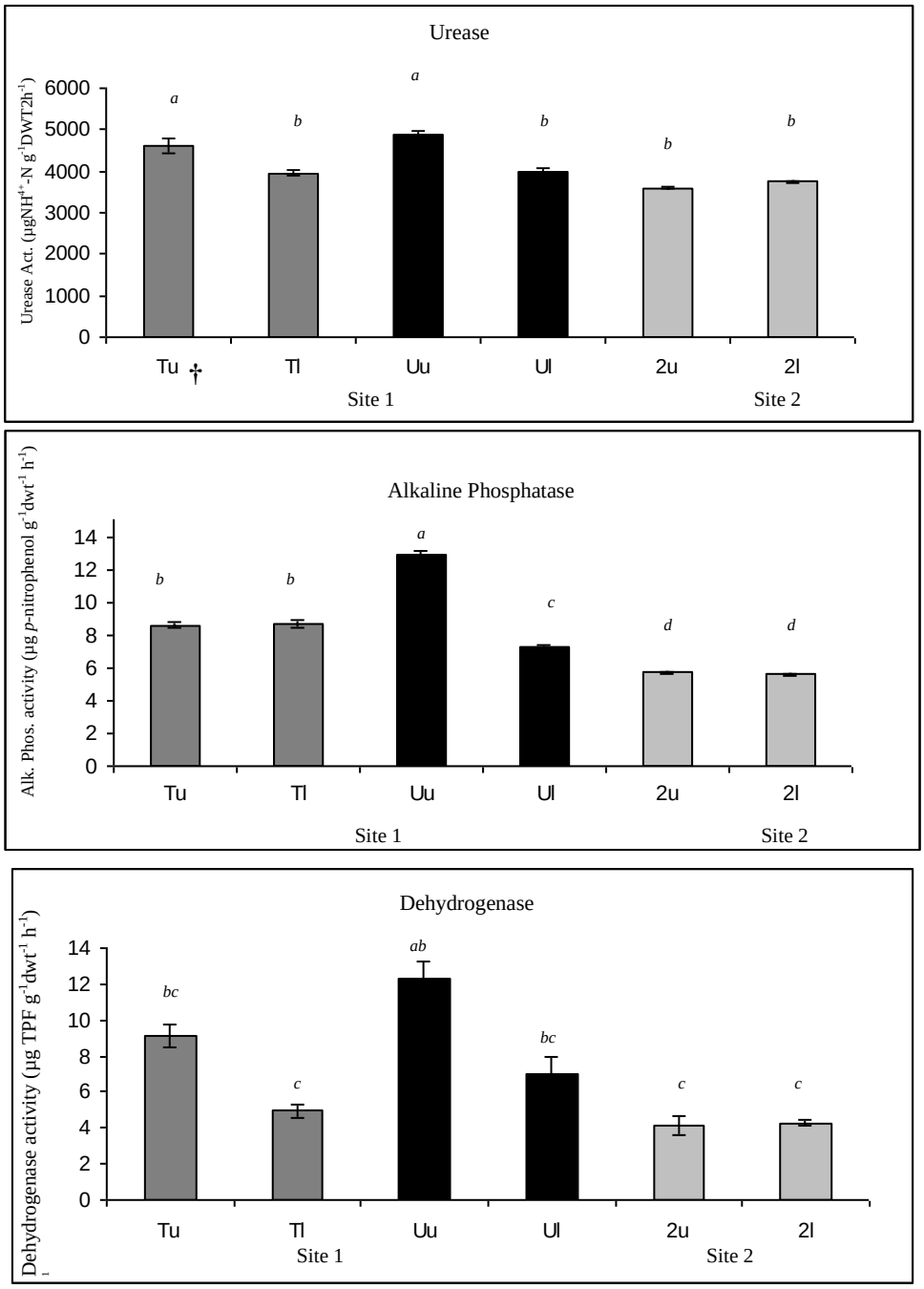


Figure 4.3. Enzyme activities measured as affected by use of contour hill-slope vegetative barriers Wolayita Zone Ethiopia. Dehydrogenase activity measured by the conversion of 2,3,5-triphenyltetrazolium chloride to triphenylformazan; Urease activity measured by the conversion of urea to ammonium; Alkaline phosphatase activity measured release of p-nitrophenol from sodium p-nitrophenol phosphate. † Tu: site 1; terraced; upper slope; Tl: site 1; terraced; lower slope; Uu: site 1; unterraced: upper slope; Ul: site1; unterraced; lower slope; 2l: site 2; eroded terrace; lower slope; 2u: site 2; eroded terrace; upper slope; Bars followed by the same letter indicates no difference ($p>0.10$). Error bars represent standard error.

preserved minor amounts of N and C in the form of retained SOM, that otherwise may have been lost through erosion had the terraces been absent.

Comparison of soil quality within Site 1 offered the opportunity of comparing soils above and below the terrace to one another, thereby highlighting the effects of terracing under similar slope, management and soil physical properties. This identified that urease was the most affected of the three enzymes, being significantly higher in *Tu* and *Uu*, possibly benefiting from the terracing. Alkaline phosphatase had significantly lower activity in *Ul* than *Uu*, *Tu* and *Tl*, where erosion was the greatest, while *Uu* had higher activity than *Ul*, *Tl* and *Tu*. This demonstrates that the old terrace, even after being worked down still retained a persistent effect that is still seen in microbial parameters, possibly due to the terracing effect on the hillslope.

The unterraced plots on Site 1 (*Uu* and *Ul*) show a larger differentiation in dehydrogenase and alkaline phosphatase than the terraced plots (*Tu* and *Tl*). Dehydrogenase and alkaline phosphatase are directly related to microbial activity. The slope of *Uu* is less than all the others, indicating that it had probably experienced the least erosion historically, while *Ul* had the steepest slope without prevention measures, indicating that it had probably suffered the most erosion. This created a large gradient between *Uu* and *Ul*. *Uu* is still possibly benefiting from the prior terracing, which left an embankment that remains visible, in terms of slope and vegetative productivity. In general, the effect of vegetative barriers is greatest at the beginning of field establishment, reducing runoff and increasing infiltration and thereby limiting soil erosion (Pansak et al., 2008). However, the competition of the vegetative row for nutrients and moisture limits the productivity of the nearby soil (Pansak et al., 2008). This may be the reason lower alkaline phosphatase and dehydrogenase activities were found in *Tu* and *Uu*.

The plots of Site 2 (*2u* and *2l*) were also visibly undergoing substantial erosion and had lower values across all soil parameters including pH and enzyme activity. Although the comparison with Site 1 is not as strong as the adjacent comparison within Site 1, Site 2 and Site 1 did have similar soil type, slope and management. The comparison to Site 1 does, to some extent, demonstrate the effect of uncontrolled erosion on these parameters. The fact that the soils of Site 2 had both suppressed enzyme activities and physical parameters while suffering the same long-term erosional conditions reinforces the concept that prolonged uncontrolled soil erosion depletes soil quality.

Site 2 highlights the degradation seen in Site 1 in *Ul* and *Tl.* Site 2, historically, had been conventionally managed providing contrast to the plots in Site 1 which had all had terraces at some point. This is shown by the suppression of nearly all physical and biological parameters. This comparison highlights the effect of historically uncontrolled erosion, decreasing of soil quality and agricultural productivity, as well as reiterating the positive effect that minor soil erosion prevention measures have on soil quality, even in the relatively short-term.

The seasonal erosion events, which caused the rills seen in May 2005, eliminate a great proportion of the biologically active topsoil. This occurrence every rainy season (biannually in Ethiopia) removes soil particles, SOM and associated nutrients. A huge proportion of active microbial biomass is lost, eliminating much of the microbial community of the plot. Frequent plowing further dilutes the remaining community with relatively biologically inactive subsoil, forming a new plough layer with a fraction of the original microbial community. This process forces the microbial community to be in a constant state of rebuilding and never reaching full functional potential.

The nutrient and SOM levels poorly reflect the constant erosion processes poorly, due to nature of the Oxisols having low nutrient retention, high leaching and low SOM levels. Oxisols typically have soil nutrients leached deeply into the soil profile (Wilcke and Lilienfein, 2005). The nature of tropical Oxisols and their naturally low levels of SOM cause percent C to be relatively unaffected by erosion loss. Any SOM near the soil surface is involved in an accelerated decomposition process, due to the high moisture levels and temperature of the tropical soil climate, and intensified by the frequent tillage events. The microbial community is more affected by sheet and rill erosion in tropical highland Oxisols than leachable plant nutrients such as N or even SOM. Therefore, the greatest loss during the erosion of Oxisols is the loss of their microbial pool (which unfortunately has the same devastating short-term impacts as a loss of nutrients) due to the lack of the soil's ability to transform and carry out vital biochemical processes.

Assessment of traditional soil parameters, such as plant available nutrient levels, pH, total N and C (even SOM), may provide a false perception of soils in tropical highlands which experience continual soil erosion loss. Dynamic measures are need rather than static ones (i.e., fluxes rather than snapshots of concentrations). The agricultural production capability of these soils is limited even in a state of optimal health. Therefore, loss of topsoil here, with its low

nutrient levels and SOM, is not comparable to a similar loss in soils of high intrinsic fertility and SOM levels. The marginal state of these soils provides them with a certain resiliency in that they can endure these losses if they are already in a marginal state. Given that the continual loss of the soil microbial community through erosion limits its ability to function effectively, and may be more limiting to these soils than the loss of scarce nutrients which can be replenished from the subsoil, or the loss of its inherently low SOM levels. The productivity of these soils is instantly and continually compromised by erosion, because of its decreasing ability to successfully perform its necessary transformations and the processes that are vital to the quality, health and productivity of any soil.

4.5 Conclusion

The study of the highland soils of Ethiopia provides a unique opportunity to understand the effect of large-scale erosion on marginal soils. The soil properties, management strategies and climate combine to make an agricultural landscape that is unique in its challenges to productivity and sustainability. This study demonstrates that continual and historical losses of soil may not be as devastating as the repeated loss of the soil's microbial community and subsequent reduction of its functionality. The simplest erosion prevention methods have a significant positive effect that can be long lasting and can increase the productivity of the soil. Without repeated massive erosion, the soil is able to maintain its microbial status and functionality, allowing it to reach a point of improved health and quality, which ultimately is reflected in the visible increase in agricultural productivity seen at this site, where the plots above the terraced slopes had visually higher yielding and healthier crops than those below the terraces or without terraces. This is not to say that simply curbing the massive loss of soil solves the problem of land degradation in tropical highlands. Rather, it means that even simple measures, affordable and practical, can have a positive effect. There is no doubt that the intensive cultivation of these soils is degrading. Therefore, they may never regain a state in which they are considered healthy, but erosion prevention is one step on the way to sustainability. In the short-term, the first step is to control massive land erosion, and to promote the understanding of its benefits. A complex management strategy may be needed in order to optimize their agricultural sustainability and productivity.

5.0 GENERAL DISCUSSION AND CONCLUSION

The soil is a valuable resource, incredibly complex but poorly understood. The success of civilization is tied closely to the productivity and management of agricultural soils. This is increasingly the case in a world where international trade is common and many nations are dependant on food imports to sustain their growing economies and populations. In this context developing agricultural management strategies that maintain a high level of productivity are essential in order to ensure the soil resource is preserved.

This study firstly analyzed what is deemed a highly productive and sustainable management system in Saskatchewan. These soils were under long-term LD management with high reliance on costly inputs. Variable intensities of a one time intermittent tillage treatment were analyzed for their effects on soil health. The purpose was to determine the effect of intermittent tillage and its intensity on the soil health through analysis of the biochemical properties and the agronomics of such a tillage treatment.

Analysis of the soils near Tisdale, Rosthern, and Central Butte revealed that the soil was affected by the tillage and by tillage intensity. The magnitude of effect depended on many factors, foremost being the quantity and quality of SOM and litter, as well as soil physical characteristics. The three soils responded uniquely making it difficult to make any broad conclusions for Saskatchewan long-term LD soils. Thus, this study did not indicate that long-term soil health was compromised by intermittent tillage intensity in any of the soil zones. The effect was short-term and even at the highest tillage intensity was unlikely to have a lasting effect that would be to the soil's detriment.

Soils with an abundance of surface litter high C:N content may cause short-term immobilization of soil and fertilizer N. On the other hand, with periodic high intensity tillage incorporation, land that has been rotated with crops with litter high in N may mineralize N. Therefore, the agronomic impact is dependant on the local soil and litter condition, and to determine if intermittent tillage would be beneficial to a long-term LD system, knowledge of the soil and litter condition is necessary.

Lastly, the effect of erosion prevention measures on soil health were evaluated on tropical highland soils in southern Ethiopia. Vegetative contour strips were evaluated for their role in

preventing large-scale erosion by evaluating the biochemical effect erosion prevention had on soils on adjacent terraced and unterraced hillslopes. This study indicated a possible benefit of erosion prevention on the soil's biochemical parameters.

The prevention of large-scale erosion allowed the soil to retain a functional microbial community that otherwise would have been regularly compromised during seasonal rain events. The continual loss of the soil microbial community due to erosion events, may have been of more of a detriment to the soil's productivity than the loss of soil and subsequent nutrients. This is due entirely to the nature of the soils studied which were eroded Oxisols, where nutrient retention is severely limited. In Oxisolic soils leaching of soil nutrients into the profile can be extensive; therefore loss of the soil nutrients in the topsoil may not be as detrimental to agricultural productivity as the loss of the microbial community responsible for the plant availability of the few nutrients there are.

This indicates that even simple, inexpensive measures of preventing soil erosion are effective in limiting land degradation, and are a key first step in returning marginal agricultural lands in developing nations to the sustainable level of production, which must be pursued in order to ensure long-term sustainability. However, given the difficulties in conducting biochemical research with such distance between study sites and necessary laboratory facilities, limitations on the research are obvious. Therefore, the results have to interpreted with consideration of the data presented without the corresponding microbial parameters that would usually accompany such a study.

6.0 LITERATURE CITED

Acosta-Martinez, V., L. Cruz, D. Sotomayor-Ramirez, and L. Perez-Algeria. 2007. Enzyme activities as affected by soil properties and land use in a tropical watershed. Appl. Soil Ecology 35:35-45.

Acton, D.F., and G.A. Padbury. 1993. A conceptual framework for soil quality assessment and monitoring. Centre for Land and Biological Resources Research Contribution No. 93-49, Research Branch, Agriculture Canada, Ottawa.

Alemayehu, K. 2007. Effects of different land use systems and topography on selected soil properties at Delbo Watershed, Wolayita Zone, southern Ethiopia. M.Sc. Thesis, Hawassa University, Hawassa, Ethiopia.

Asmar, F., F. Eiland, and N.E. Nielsen. 1992. Interrelationship between extracellular enzyme-activity, ATP content, total counts of bacteria and CO_2 evolution. Biol. and Fert. Soils 14:288-292.

Baan, C.D. 2007. The effects of imposing tillage on long term no-till soils. M.Sc. diss. University of Saskatchewan, Saskatoon, Saskatchewan

Bergstrom, D.W., C.M. Monreal, D.J., King. 1998. Sensitivity of soil enzyme activities to conservation practices. Soil Sci. Soc. Am. J. 62:1286-1295.

Bergstrom, D.W., C.M. Monreal, A.D., Tomlin, J.J., Miller. 2000. Interpretation of soil enzyme activities in a comparison of tillage practices along a topographic and textural gradient. Can. J. Soil Sci. 80:71-79.

Bremer, E., and C. van Kessel. 1992. Plant-available nitrogen from lentil and wheat residues during a subsequent growing season. Soil Sci. Soc. Am. J. 56:1155-1160.

Bremmer, J.M., and M.A. Tabatabai. 1973. Effect of some inorganic substances on TTC assay of dehydrogenase activity in soils. Soil Biol. Biochem. 5:385-386.

Brown, P.L., and D.D. Dickey. 1970. Losses of wheat straw residue under simulated field conditions. Soil Sci. Soc. Am. J. 34:118-121.

Campbell, C.A., S.A. Brandt, V.O. Biederbeck, R.P. Zenter, and M. Schnitzer. 1992a. Effect of crop rotations and rotation phase characteristics of soil organic matter in a Dark Brown Chernozemic soil. Can. J. Soil Sci. 72:403-416.

Campbell, C.A., A.P. Moulin, K.E. Bowren, H.H. Janzen, L. Townley-Smith, and V.O. Biederbeck. 1992b. Effects of crop rotations on microbial biomass, specific respiratory activity and mineralizable nitrogen on a Black Chernozemic soil. Can. J. Soil Sci.:417-427.

Campbell, C.A., G.P.Lafond, V.O., Biederbeck,G., Wen, J., Shoenau, D., and D. Hahn. 1999. Seasonal trends in soil biochemical attributes: Effects of crop management on a Black Chernozem. Can. J. Soil Sci. 79:85-97.

Carpenter-Boggs, L., P.D. Stahl, M.J. Lindstrom, and T.E. Schumacher. 2003. Soil microbial properties under permanent grass, conventional tillage, and no-till management in South Dakota. Soil Tillage Res. 71:15-23.

Casida, L.E. 1977. Microbial metabolic activity in soil as measured by dehydrogenase determinations. Appl. Environ. Microbiol.34:630-636.

Chander, K., S. Goyal, M.C. Mundra, and K.K. Kapoor. 1997. Organic matter, microbial biomass and enzyme activity of soil sunder different crop rotations in the tropics. Biol. and Fert. Soils 24:306-310.

Cheung, W.H., B.G. Senay, and A. Singh. 2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. Int. J. Climatology. DOI: 10.1002/joc.1623.

Cleveland, C.C., A.R. Townsend, S.K. Schmidt, and B.C. Constance. 2003. Soil microbial dynamics and biogeochemistry in tropical forests and pastures, southwestern Costa Rica. Ecol. Appl. 13:314-326.

Chotte, J.L., J.N. Ladd and M. Amato. 1998. Sites of microbial assimilation and turnover of ^{14}C soluble and particulate substrates decomposing in a clay soil. Soil Biol. Biochem. 30:205–218.

Cooper, T.H. 2005. Soil organisms and the nitrogen cycle: The nitrogen cycle [Online]. Available by University of Minnesota http://www.soils.agri.umn.edu/academics/classes/soil2125/doc/s9chap2.htm (verified March 03).

Davis, A., 2000. Soil quality in east Tennessee: case study at the Milan experiment station. TRACE: Tennessee research and creative exchange, Senior thesis projects: 1993-2002. University of Tennessee, Knoxville.

Deng, S.P., and M.A. Tabatabai. 1995. Cellulase activity of soils: effect of trace elements. Soil Biol. Biochem. 27:977-979.

Deng, S.P., and M.A. Tabatabai. 1996. Effect of tillage and residue management on enzyme activities in soils-I: amidohydrolases. Biol. Fertil. Soils 22:202-207.

Dick, R.P. 1997. Soil enzyme activities as integrative indicators of soil health. p. 121-156. *In* C. E. Pankhurst et al (ed.) Biological indicators of soil health. CAB International, Inc, New York.

Dick, W.A. 1984. Influence of long term tillage and crop rotation combinations on soil enzyme activities. Soil Sci. Soc. Am. J. 48:569-574.

Dinesh, R., S.G. Chaudhuri, and T.E. Sheeja. 2004. Soil biochemical and microbial indices in wet tropical forests: Effects of deforestation and cultivation. J. Plant Nutr. 167:24-32.

Duxbury, J.M., M.S. Smith, J.W. Doran, C. Jordan, L. Scott, and E. Vance. 1989. Soil organic matter as a source and sink of plant nutrients, *In* D. C. Coleman et al. (eds.) Dynamics of soil organic matter in tropical ecosystems, NifTAL Project. Department of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources, University of Hawaii, USA.

Frankenberger, W.T., Jr and Dick, W.A. 1983. Relationships between enzyme activity and microbial growth and activity indices in the soil. Soil Sci. Soc. Am. J. 47:1120-1124.

Franzbluebbers, A.J., and M.A. Arshad. 1996. Soil organic matter pools during early adoption of conservation tillage in northwestern Canada. Soil Sci. Soc. Am. J. 60:1422-1472.

Franzluebbers, A.J., and M.A. Arshad. 1996. Soil organic matter pools during early adoption of conservation tillage in northwestern Canada. Soil Sci. Soc. Am. J. 60:1422-1472.

Franzluebbers, K., R.W. Weaver, A.S.R. Juo, and A.J. Franzbluebbers. 1994. Carbon and nitrogen mineralization from cowpea plant parts decomposing in moist and in repeatedly dried and wetted soil. Soil Biol. Biochem. 26:1379-1387.

Gregorich, E.G., K.J. Greer, D.W. Anderson, and B.C. Liang. 1998. Carbon distribution and losses: erosion and deposition effects. Soil Tillage Res. 47:291-302.

Gupta, V.V.S.R., and J.J. Germida. 1988. Distribution of microbial biomass and its activity in different soil aggregate size classes as effected by cultivation. Soil Biol. Biochem. 20:777-786.

Hart, P.B.S., G.P. Sparling, and J. A. Kings. 1986. Relationship between mineralisable nitrogen and microbial biomass in a range of plant litters, peats, and soils of moderate to low pH. N. Z. J. Agric. Res. 25, 461-472.

Havlin, J.L., J.B. Beaton, S.L., Tisdale, W.L., and Nelson. 1999. Soil fertility and fertilizers: an introduction to nutrient management. 6th ed. Macmillan Publishing Company, New York.

Haynes, R.J., and R. Tregurtha. 1999. Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. Biol. and Fert. Soils 28:259-266.

Howard, P.J.A. 1972. Problems in estimating the biological activity in soil. Oikos 23:235-240.

Insam, H., C.C. Michell, and J.F. Dormaar. 1991. Relationship of soil microbial biomass and activity with fertilization and crop yeild of three Uitisols. Soil Biol. Biochem. 23: 459-464.

Insam, H., and K. Haselwandter. 1989. Metabolic quotient of the soil microflora in relation to plant succession. Oecologia 79:174-178.

Islam, K.R., and R.R. Weil. 1998. Microwave irradiation of soil for routine measurement of microbial biomass carbon. Biol. and Fert. Soils 27:408-416.

Islam, K.R., and R.R. Weil. 2000. Land use effects on soil quality in a tropical forest ecosystem on Bangladesh. Agric. Ecosyst. Environ. 79:9-16.

Jenkinson, D.S., and J.N. Ladd. 1981. Microbial biomass in soil: measurement and turnover, p. 415-471, *In* E. A. Paul and J.N. Ladd. (eds.) Soil Biochemistry, vol. 5. Marcel Dekker, Inc, New York and Basel.

Jimenez, M.D., A.M. de la Horra, L. Pruzzo, and R.M. Palma. 2002. Soil quality: a new index based on microbiological and biochemical parameters. Biol. Fert. Soils 35:302-306.

Jordan, D., R.J. Kremer, W.A. Bergfeild, K.Y. Kim, and V.N. Cacnio. 1995. Evaluation of microbial methods as potential indicators of soil quality in historical agricultural fields. Biol. Fert. Soils 19:297-302.

Juma, N.G., and M.A. Tabatabai. 1977. Effects of trace elements on phosphatase activity in soils. Soil Sci. Soc. Am. J. 41:343-346.

Kandeler, E., and H. Gerber. 1988. Short-term assay if soil urease activity using colorimetric determination of ammonium. Biol. Fert. Soils 6:68-72.

Kandeler, E. and G. Elder, 1993. Effect of cattle slurry in grassland on microbial biomass and on activities of various enzymes. Biol. Fert. Soils, 5:249-254

Kandeler, E., S. Palli, M. Stemmer, and M.H. Gerzabek. 1999a. Tillage changes microbial biomass and enzyme activities in particle-size fractions of a Haplic Chernozem. Soil Biol. Biochem. 31:1253-1264.

Kandeler, E., J. Luxhhoi, D. Tsherko, and J. Magid. 1999b. Xylanase, invertase and protease at the soil-litter interface of a loamy sand. Soil Biol. Bioch. 31:1171-1179.

Kenney, D.R., and D.W. Nelson. 1982. Nitrogen - inorganic forms. p. 643-698, *In* A.L. Page et. al. (eds.) Methods of soil analysis. part 2. Chemical and Microbiological Properties. ASA and SSSA Inc., Madison WI.

Kruger, H., F. Berhanu, G.M. Yohannes, and K. Kefene. 1996. Creating an inventory of indigenous SWC measures in Ethiopia, p. 163-169, *In* C. Reij, et. al. (eds.) Sustaining the soil: indigenous soil and water conservation in Africa. Earthscan Ltd., London.

Ladd, J.N., and J.H.A. Butler. 1972. Short-term assays of soil proteolytic enzyme activities using proteins and dipeptide derivatives as substrates. Soil Biol. Biochem. 4:19-30.

Lal, R. 1976. Soil erosion on alfisols in Western Nigeria. VI. Nutirent element loss on runoff and eroded sediments. Geoderma 16:403-17.

Larson, W.E., and F.J. Pierce (eds.) 1991. Conservation and enhancement of soil quality Evaluation for sustainable land management in the developing world. Proc. International Board for Soil Research and Management., Bangkok, Thailand.

Laugesen, K. and J.P. Mickelson. 1972. Urease activity in Danish soils. Danish J. Plant Soil Sci. 77:221-229.

Laugesen, K. and J.P. Mickelson. 1973. Phosphatase activity in Danish soils. Danish J. Plant Soil Sci. 77:252-257.

Madejon, E., F. Moreno, J.M. Murillo, and F. Pelegrin. 2007. Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. Soil Tillage Res. 94:346-352.

Miller, M., and Dick, R.P. 1995. Dynamics of soil C and microbial biomass on whole soil aggregates in two cropping systems. App. Soil Ecol. 2:253-261.

MoFED. 2004. Annual Report on Macroeconomic Development in Ethiopia, Ministry of Finance and Economic Development. Addis Ababa, Ethiopia.

Mohr, E.C.J., F.A.van Baren, and J. van Schuylenborgh. 1972. Tropical Soils: a comprehensive study of their genesis. 3rd Edition. Mouton, The Hague.

Myrold, D. D. (1987). Relationship between microbial biomass nitrogen and a nitrogen availability index. Soil Science Society of America Journal 51, 1047–1049.

Nannipieri, P., L. Muccini, and C. Ciardi. 1983. Microbial biomass and enzyme activities: production and persistence. Soil Biol. Biochem. 15:679-685.

Nannipieri, P., R.L. Johnson and E.A. Paul. 1978. Criteria for measurement of microbial growth and activity in soil. Soil Biol. Biochem. 10:223-227.

Ndiaye, E.L., J.M. Sandeno, D. McGrath, and R.P. Dick. 2000. Integrative biological indicators for detecting change in soil quality. Am. J. Altern. Agric. 15:26-36.

Neas, E.D., and M.J. Collins. 1988. Microwave heating: theoretical concepts and equipment design, p. 7-32, *In* H. M. Kingston et al. (eds.) Introduction to microwave sample preparation: theory and practice. American Chemical Society, Washington, D.C.

Ocio, J.A., J. Martinez, and P.C. Brookes. 1991. Contribution of straw-derived N to total microbial biomass N following incorporation of cereal straw to soil. Soil Biol. Biochem. 23:655-659.

Olson, R.A. and L.T. Kurtz. 1982. Crop nitrogen requirements, utilization, and fertilization. p. 567-604, *In* F. J. Stevenson, (ed.) Nitrogen in agricultural soils. American Society of Agronomy, Inc., Madison, Wisconsin.

Pankhurst, C.E., B.M. Doube, and V.V.S.R. Gupta. 1997. Biological indicators of soil health CAB International, New York, NY, USA.

Pankhurst, C.E., C.A. Kirkby, B.G. Hawke, B.D. Harch. 2002. Impact of a change in tillage and crop residue management practice on soil chemical and microbiological properties in a cereal-producing red duplex soil in NSW, Australia. Biol. Fert. Soils 35:189-196.

Pansak, W., T.H. Hilger, G. Dercon, T. Kongkaew, and G. Cadisch. 2008. Changes in the relationship between soil erosion and N loss pathways after establishing soil conservation system in uplands of Northeast Thailand. Agric. Ecosyst. Environ. 128:167-176.

Paul, E.A. 1984. Dynamics of organic matter in soils. Plant Soil 76:275-285.

Pepper, I.L., and C.P. Gerba. 2004. Environmental Microbiology: A Laboratory Manual. Elsevier Academic Press, New York.

PFRA. 2003. Economics of Zero Tillage, *In* Agriculture and Agrifood Canada, (ed.). Prairie Farm Rehabilitation Administration.

Piccolo, G.A., A.E. Andriulo, and B. Mary. 2008. Changes in soil organic matter under different land management in Misiones province (Argentina). Scientia Agricola 65:290-297.

Powlson, D.S., and D.S. Jenkison. 1981. A comparison of the organic matter, biomass, adenosine triphosphate and mineralizable nitrogen contents of ploughed and direct drilled soils. J. Agric. Sci. 97:713-721.

Powlson, D.S., P.C. Brookes, and B.T Christensen. 1987. Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter due to straw incorporation. Soil Biol. Biochem. 19:159-164.

Qian, P., J.J. Schoenau, and R.E. Karamanos. 1994. Simultaneous extraction of available phosphorus and potassium with a new soil test - a modification of kelowna extraction. Commun. Soil Sci. Plant Anal. 25:627-635.

Ramirez-Martinez, J.R. and A.D. MacLaren. 1966. Some factors influencing the determination of phosphatase activity in native soils and in soils sterilized by irradiation. Enzymologia 31:23-28.

Rice, C. 2004. Phosphatase activity of soils. Kansas State University: Department of Agronomy Manhattan Kansas.

Roldan, A., J.R. Salinas-Garcia, M.M. Alguacil, E. Diaz, and F. Caravaca. 2005. Soil enzyme activities suggest advantages of conservation tillage practices in sorghum cultivation under subtropical conditions. Geoderma 129:178-185.

Ross, S.M. 1993. Organic matter in tropical soils: current conditions, concerns and prospects for conservation. Progress in Physical Geography 17:265-305.

Saskatchewan Institute of Pedology. 1985. Soils of the Swift Current Map Area, 72J, Publication S6, Saskatoon, Saskatchewan.

Saskatchewan Insitute of Pedology. 1978. Soils of the Saskatoon Map Area, 73B, Publication S4, Saskatoon, Saskatchewan.

Saviozzi, A., R. Levi-Minzi, R. Cardelli, and R. Riffaldi. 2001. A comparison of soil quality in adjacent cultivated, forest and native grassland soils. Plant Soil 233:251-259.

SCCC. 2001. Reduced tillage helps reduce carbon dioxide levels. [Online] http://www.soilcc.ca/ggmp_feature_articles/2004/2004-02.php.verified December 02, 2010

Schloter, M., O. Dilly, and J.C. Munch. 2003. Indicators for evaluating soil quality. Agric. Ecosyst. Environ. 98:255-262.

Schoenau, J.J., and C.A. Campbell. 1996. Impact of crop residues on nutrient availability in conservation tillage systems. Can. J. Soil Sci. 76:621-626.

Six, J., E.T. Elliot, and K. Paustian. 1999. Aggregate and soil organic matter dynamics under conventional and no-tillage systems. Soil Sci. Soc. Am. J. 63:1350-1358.

Skujins, J. 1978. History of abiotic soil enzyme research, p. 371-414, *In* R. G. Burns, ed. Soil Biochemistry. Marcel Dekker, New York.

Sorn-srivichai, P., J.K. Syers, R.W. Tillman, and I.S. Cornforth. 1988. An evaluation of water extraction as a soil-testing procedure for phosphorus II. Factors affecting the amounts of water-extractable phosphorus in field soils. Fertilizer Research 15:225-236.

Sparling, G.P. 1992. Ratio of microbial biomass carbon to soil organic carbon as a sensitive indicator of changes in soil organic matter. Aust. J. Soil Res. 30:195-207.

Sparling, G.P. 1997. Soil Microbial Biomass, Activity and Nutrient Cycling as Indicators of Soil Health, p. 97-120, *In* C. E. Pankhurst, Doube, B.M. and Gupta, V.V.S.R., ed. Biological Indicators of Soil Health. CAB International, Inc., New York, NY. USA.

SSCA. 2005. Economics of Direct Seeding [Online] www.ssca.ca (verified December 20).

Tabatabai, M.A. 1994. Soil enzymes, p. 775-833, *In* R. W. Weaver, et al. (eds.) Methods of soil analysis. Part 2 - Microbiological and biochemical properties. Soil Sci. Soc. Am. Madison Wisconsin.

Tabatabai, M.A., and J.M. Bremmer. 1969. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. Soil Biol. Biochem. 1:301-307.

Tadano, T., K. Ozawa, H. Sakai, M. Osaki, and H. Matsui. 1993. Secretion of phosphatase by the roots of crop plants under phosphorus-deficient conditions and some properties of the enzyme secreted by lupin roots. Plant Roots 155/156:95-98.

Tisdale, S.L. and W.L. Nelson. 1966. Soil Fertility and Fertilizers. 2nd ed. MacMillan Publishing Company, New York.

UN. 2005. World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision [Online] http://esa.un.org/unpp (verified January 22, 2009).

University of Minnesota. 2002. Organic Matter Management [Online] http://www.extension.umn.edu/distribution/cropsystems/components/7402_02.html (verified February 23).

Vigil, M.F., and D.E. Kissel. 1991. Equations for estimating the amount of nitrogen mineralized from crop residues Soil Sci. Soc. Am. J. 48:152-156.

Ward, G. 2002. Sharp decline in number of farms in Saskatchewan, *In* S. Canada, (ed.), Vol. 2001 Census of Agriculture. Government of Canada.

Watanabe, K., J. Sakai, and K. Hayano. 2003. Bacterial extracellular protease activities in field soils under different fertilizer managements. Can. J. Microbiol. 49:305-312.

Weil, R.R., and F. Magdoff. 2004. Significance of Soil Organic Matter to Soil Quality and Health, p. 1-44, *In* F. Magdoff, and Weil, R.R., ed. Soil Organic Matter in Sustainable Agriculture. CRC Press, New York.

Welle, S., K. Chantawarangul, S. Nontananandh, and S. Janatawat. 2006. Effectiveness of grass strips as barrier against runoff and soil loss in Jijiga area, northern part of Somalia region, Ethiopia. Kasetsart J. 40:549-558.

Wilcke, W., and J. Lilienfein. 2005. Nutrient leaching in Oxisols under native and managed vegetation in Brazil. Soil Sci. Soc. Am. J. 69:1152-1161.

Wolde, M., E. Veldkamp, M. Haile, J. Nyssen, B. Muys, and K. Gebrehiwot. 2007. Effectiveness of enclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. Journal of Arid Environments 69:270-284.

Zentner, R.P., D.D. Wall, C.N. Nagy, E.G. Smith, D.L. Young, P.R. Miller, C.A. Campbell, B.G. McConkey, S.A. Brandt, G.P. Lafond, A.M. Johnston, and D.A. Derksen. 2002. Economics of crop diversification and soil tillage opportunities in the Canadian prairies. Agronomy Journal 94:216-230.