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Total organic carbon, total nitrogen, microbial respiration and enzyme activity (β-glucosidase) were measured on several horizons of a Dayton silt loam (fine, montmorillonitic, mesic, Typic Albaqualf) soil cropped to annual ryegrass under two straw residue management systems. The study evaluated the effects of annual burning of straw residues or annual incorporation of straw residues on the content, distribution and bioavailability of soil organic carbon.

Four fields were selected to represent the burn management system which have been annually burned for a minimum of 40 years. Four fields were selected to represent the straw incorportated system (mold board plow) which had been annually burned for approximately 30 years, followed by incorporation of straw residues into soil for a minimum of 10 years. One native site was selected to represent non-cultivation conditions.

Straw management system strongly influenced both the total organic C and N and microbial activity the surface soil horizon. Soil organic C and N content

were significantly greater ($p < 0.05$) in the Ap horizons of soils under the plowed management system than soils under the burned management system. The collective evidence suggests, however, that the significant differences observed between the two residue management systems are not due to greater losses of soil organic C and N as a result of burning but rather that organic C levels have increased as a result of a change in management. Soil C:N ratios are slightly higher in the Ap horizons of soils as a result of straw residue incorporation in comparison to burning of straw residues.

When expressed on a mass soil basis, both CO_2 evolution from microbial respiration, during a 32 day incubation period, and enzyme activity were significantly greater ($p < 0.10$) for the Ap horizon of soils where straw residue had been incorporated than in soils where residues had been annually burned. When expressed on a per gram C basis, nieither CO_2 evolution from microbial respiration or enzyme activity were significantly different between the two management systems. These results indicate that long-term annual burning of straw residues has not decreased the bioavailability of soil organic C.

Effects of Ryegrass Residue Management on Dayton Soil Organic Carbon Content, Distribution and Related Properties

by

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INTRODUCTION

The use of fire by humans is not a modern phenomenon in the settlement of the Willamette Valley. Fire was used by the Native Americans to alter the vegetation and landscape to fit their hunting and gathering strategies (Boyd, 1986). Documented journals from early European explorers indicate that the Kalyapuya people burned the Willamette Valley grasslands extensively and annually for thousands of years prior to European settlement. In the 1800's, as Europeans settled in the valley, Native American populations declined, the annual use of fire was suppressed, and land-use and vegetational patterns changed (Boyd, 1986).

Extensive annual use of fire in the Willamette Valley was reinstated in the 1940's by the grass seed industry with the discovery that open-field-burning of straw residues controled the disease "blind seed" that threatened it's development. Burning of grass straw residues was also found to be useful for straw residue removal, weed seed and pest control, stimulating seed yields, and decreasing fertilizer needs (Conklin et al., 1989). The discovery of field burning allowed the grass seed industry to thrive, and the amount of land open-burned increased rapidly. By the early 1960's more than 121,400 ha of grass seed and small grain fields were burned annually in the valley.

The Willamette Valley Seed Industry is presently the world's major producer of cool-season forage and turf grass seed. There are 133,500 hectares of various grass seed types harvested annually in the valley. This represents 42% of the total harvested cropland in the valley, and 53% of the total harvested cropland in the southern valley, where poorly drained soils limit other crop alternatives. Annual ryegrass accounts for one third of the total grass seed acreage in the south valley, the majority of which is open- field-burned annually.

The greatest problem with field burning is effects of the smoke and air quality. This has been a major public and political point of contention. In response to public and political pressures, legislation since the 1960's has gradually reduced the annual limit of land open-field-burned and has encouraged the development and use of alternative field sanitation methods. The 1992-93 limit is set at 56,660 ha for the year. However, by the year 1997 the limit will rest at a maximum of 16,190 ha (Capital Press, July 5, 1991).

The best alternative for open-field-burning for the production of annual ryegrass seed involves flail chopping of straw residue and its incorporation into the soil by conventional tillage practices (Conklin et al, 1989). Unfortunately, this practice requires larger capital inputs, more labor and machinery, greater quantities of fossil fuel and increased chemical fertilizer applications (Young *et al.*, 1984a, 1984b; Chilcote and Youngburg, 1975).

Recent concerns that annual burning of straw residues may influence soil tilth and long-term soil fertility prompted this study. The extended acreage of annual ryegrass cultivated in the south Willamette valley, on uniform soils with a similar climate, offered an opportunity to compare the effects of field burning straw residues on the organic matter distribution and C bioavailability in a soil profile with the effects of incorporation of the straw residues into the soil by conventional tillage. Understanding the soil organic matter dynamics under different straw residue management systems is essential for informed use of agricultural land.

The objectives of this study were

1) To characterize the distribution of soil organic carbon throughout the soil profile;
2) To determine the influence of two long-term straw residue management systems, burn and plow, on the distribution of soil organic carbon and related properties: total nitrogen, microbial respiration and enzyme activity;
3) To evaluate the effect of straw management system on the bioavailability of soil organic carbon.

LITERATURE REVIEW

Soil Organic Matter Dynamics in Undisturbed Soils

Soil Organic Matter

Soil organic matter (SOM) consists of plant and animal matter in partially decomposed stages, chemically and biologically resynthesized decay products, and living microbial and root biomass. The dynamics of SOM formation, accumulation and distribution depend on the interactions between the soil forming factors. Jenny (1941) arranged the soil-forming factors influencing SOM content in order of importance as climate > vegetation > topography = parent material > age. Schnitzer (1978) also added soil management system to the list. In general SOM content increases as precipitation and clay content increase, and decreases as temperature increases (Burke *et al.*, 1989).

Although the percent of SOM by weight is very small, generally ranging from less than one to ten percent (Bohn *et al.*, 1985), SOM contributes greatly to the chemical, physical and biological properties of the soil. SOM content and bioavailability control the natural fertility and the primary productivity of both agricultural and native grassland soils (Schoenau and Bettany, 1987; Burke *et al.*, 1989). Organic matter supplies a major source of nutrients and energy to microorganisms that are responsible for the mineralization and cycling of plant available nutrients, and the formation of polysaccharides essential for the development of soil structure. As a colloidal component of soil, SOM contributes to the cation exchange capacity and acts as a chelating agent holding nutrients in available form (Paul and Clark, 1989; Bohn *et al.*, 1985). SOM also plays a singnificant role in the control of soil acidity and the detoxification of hazardous compounds (Sposito, 1989).

The living components of SOM comprise only a few percent of the mass of total organic matter (Bohn *et al.*, 1985), thus most concern is given to the nonliving components, humic and nonhumic substances. The nonhumic materials are unaltered or slightly altered plant parts and microorganisms with identifiable physical and chemical characteristics. Nonhumic substances include bipolymers such as carbohydrates, polysaccharides, proteins, peptides, animo acids, alkanes and low molecular weight organic acids (Sposito, 1989). These compounds are readily degraded by microorganisms; thus they do not persist in the soil. Nonhumic substances comprise approximately 10 to 15% of the total SOM (Allison, 1973).

The major portion of the non-living SOM, approximately 65 to 75%, consists of humic substances. These are amorphous, dark-colored, generally hydrophillic, acidic, aromatic, chemically complex substances. Humic materials include humic acid, fulvic acid and humin (Schnitzer, 1982). Distinctions between the three humic fractions, in chemical composition and functional group content, are based on thier solubility in dilute acids and bases, molecular weights and degree of stability in the soil. Although the biochemical processes by which humus is formed are not clearly understood, it is generally accepted that these dark colored, microbial resistant, polymeric compounds are synthesized through microbial enzymatic and chemical reactions and alterations, and cycling and polymerization of C, H, N, and O (Sposito, 1989).

Soil Organic Matter Distribution and Related Properties in a Virgin Grassland

North American grassland soils are noted for their high levels of soil organic matter contents which contribute to their biological, productivity and structural stability. The majority of above-ground and root biomass produced by grassland vegetation accumulates in the surface few centimeters of the soil (Woods, 1989) and is responsible for the dynamics of soil organic matter development, composition, content and distribution throughout the soil profile (Lura *et al.*, 1986).

The processes affecting SOM content, distribution and composition in both the surface and the subsurface soil are not clearly understood and are commonly disputed among researchers (Woods, 1989; Catroux and Schnitzer, 1987; Shiel, 1986; Shoenau and Bettany, 1987; Dormaar, 1990). Surface SOM dynamics are highly dependent on a number of variables including soil pedogenic processes, degree and type of vegetation cover, and soil physical and chemical properties. Subsoil organic matter dynamics are strongly associated with soil particle size, root proliferation, and leaching of surface humic acids (Schoenau and Bettany, 1987).

The processes, including microbial activities and biomass decomposition, that are reponsible for SOM formation rates are greatest in the surface few centimeters of grassland soils and decline sharply with increasing depth (Shiel, 1986; Catroux and Schnitzer, 1987; Woods, 1989). In a study to measure surface soil organic matter dynamics in a high plains grassland soil (Aridic Argiustoll), Wyoming, Woods (1989) documented concentrations of total SOM, bioavailable

SOM and total N that were more than twice as great in the surface centimeter as in the 5 to 15 cm layer. The bioavailable SOM content was 7 times greater for the surface 15 cm of the soil than at any other depth in the soil profile below 15cm.

SOM in the subsoil is synthesized from root residues (Lura *et al.*, 1986) or translocated as water soluble humic acids (Shoenau and Bettany, 1987; Balesdent *et al.*, 1988. This SOM is biologically stable, and it is minimally affected by the development of soil organic matter in the surface horizon (Balesdent *et al.*, 1988; Shiel, 1986). The amount of organic C that can be readily oxidized remains relatively constant throughout the soil profile below approximately 20 cm depth. Differences in root growth, soil cracking and SOM leaching, however, can affect the SOM content below 20 cm (Dick, 1983).

Soil organic matter leaching not only is an important pedogenic process in the formation of genetic horizons but also may influence SOM composition and quality and the distribution of nutrients throughout the soil profile. Shoenau and Bettany (1987) found that low molecular weight fulvic acids produced in the biologically active surfaces of a forest soil (Typic Cryoboralf), a grassland soil (Aridic Haploboroll), and a gleyed soil (Argiaquoll) susceptible to leaching, are translocated to the subsoil by percolating water, resulting a decreased humic acid/fulvic acid ratios with increased soil depth.

Organic nitrogen comprises more than 99% of the total soil nitrogen (total N) and is highly correlated with the soil total organic carbon (TOC) content (Burke *et al.*, 1989). The major forms of organic nitrogen are proteins, amino sugars and nucleic acids (Paul and Clark, 1989).

Surface soil total N content depends on plant litter N content and C:N ratios, and the dynamics between microbial mineralization and immobilization (Gough and Marrs, 1990; Paul and Clark, 1989). The total mineralizable N is positively related to the total N content for the soil surface (Burke *et al.*, 1989).

Changes in total N throughout the soil profile parallel changes in TOC and SOM composition. As with soil TOC, total N content typically decreases with depth (Shiel, 1986), and there is a more rapid decrease in the mineralizable N content relative to the total N pool (Soudi *et al.*, 1990). A decrease in the bioavailability of soil N is often associated with a change in the SOM compostion. Typically the humic:fulvic acid ratios increase with depth. Humic acids are considered to be more microbe-resistant than the fulvic acid SOM fraction. In addition, the fulvic acid fraction of the SOM found in the subsurface horizons has an increased resistance to microbial degradation. However, the subsoil fulvic acids are enriched with nutrients N, P and S in comparison to the fulvic acids of the surface soils (Shoenau and Bettany, 1987), and a decrease in mineralizable N with depth is also associated with a decrease in the soil C:N, C:P and C:S ratios with depth (Soudi *et al.*, 1990). Although microbial-resistant, the subsurface fulvic acids are considered to be important for the maintenance of subsoil fertility, N availability and the long-term sustainablility of soil productivity (Schoenau and Betanny, 1987; Balesdent *et al.*, 1988).

Soil Organic Matter Association with Soil Texture

Soil texture is highly correlated with the SOM content, total N content, the decomposition rates and stability of SOM (Catroux and Snchitzer, 1987). SOM content tends to increase with an increase in the clay or the fine silt fraction (Aguilar and Heil, 1988; Burke *et al.*, 1989; Catroux and Snchitzer, 1987; Shiel, 1986). However, several authors (Burke *et al.*, 1989; Shiel, 1986; Catroux and Schnitzer, 1987) have shown, through particle size fraction analyses, that the greatest portion of SOM in the soil surface is associated with the sand and coarse silt fractions.

SOM content decreases with depth in all particle size fractions. However, the SOM associated with the clay mineral size fractions decreases at a lower rate than the SOM associated with the other particle size fractions in subsoil horizons (Shiel, 1986; Catroux and Schnitzer, 1987; Burke *et al.*, 1989). This is because clay minerals are able to physically or chemically protect the protein, nitrogen, polysaccharides and humic SOM from decomposition through the formation of organomineral complexes (Greenland, 1971). Montmorillonitic soils have an exceptionally high adsorptive capacity for organic molecules and nitrogenous constituents (Balesdent *et al.*, 1988). The SOM associated with the coarser soil particles is less humified, less physically protected and more readily decomposed than the humic organic material associated with the clay sized fraction.

Soil Microbiology

Soil microorganisms and their decay products account for only a small percentage (1 to 2%) of TOC, but they play a fundamental role in soil formation, soil fertility and nutrient cycling. Microorganisms participate in soil biological processes necessary for SOM decomposition, humus formation, mineralization and immobilization of nutrients (carbon, nitrogen, phosphorus, sulfur) (Brady 1990; Paul and Clark 1989).

Microbial population densities, distributions and metabolic activities are correlated with soil organic matter content and composition. Soil microorganism populations and activities typically decrease with an increase in soil depth (Reganold *et al.*, 1987; Alexander, 1977; Dick, 1984). Near the soil surface, microbial populations and rates of activity are high because of the relative abundance of readily decomposable organic materials (fresh plant residues and partially decomposed plant and animal debris). In the subsoil, low microbial populations and rates of activity are correlated with highly humified materials (Ramsay *et al.*, 1986; Woods, 1989). Within a horizon at a constant depth however, populations can vary due to discontinuities, on a micro-scale, in soil physical and chemical properties such as soil texture, particle size distribution, SOM content, nutrient availability and pH (Dalal and Mayer 1986a; Alexander, 1977).

Particle and aggregate size distribution are important factors correlated with population distributions, microbial activity, and organic C mineralization in the soil profile (Paul and Clark 1989; Alexander 1977; Dalal and Mayer 1986d). Large microbial populations are often associated with the clay sized fraction due to the formation of stable clay-organic complexes (Alexander, 1977; Paul and Clark, 1989). In contrast, however, Dalal and Mayer (1986d) found microbial activity levels associated with the clay sized fraction to be low because of the recalcitrant nature of the SOM and the clay's strong capacity to adsorb both enzymes and SOM.

Greater microorganism populations and higher metabolic activities are generally associated with soil macroaggregates (>2000um diameter) than with smaller soil aggregates. Chemical analysis of macroaggregates reveals greater amounts of decomposable organic materials, nutrients and microbial synthesized sugars in macroaggregates than in the rest of the soil. Larger pores inherent in macroaggregates allow for higher rates of gas exchange, diffusion of solutes and nutrients, and seasonal fluctuation of soil moisture and temperature. Larger pores also allow direct entry of microorganisms and roots into the aggregate interior (Paul and Clark, 1989).

Soil Enzymes

Biochemical activities involved in organic matter decomposition, humus production, nutrient cycling (C,N,P and S), and pesticide and organic waste degradation proceed through enzymatic processes. Enzymes are proteinaceous catalysts produced by live microbial cells. Enzymes are specific to the individual substrate or types of chemical reactions they catalyze (Alexander, 1977; Tabatabai, 1982; Brock, 1979).

Enzymes accumulate in the soil as 1) free enzymes, consisting of both intracellular enzymes released from disintegrating cells and extracellular enzymes released from the organism and 2) bound enzymes, consisting of both extracellular enzymes adsorbed to disintegrating cell fragments, organic and inorganic soil colloids and intracellular enzymes in nonproliferating cells. Extracellular enzymes are essential for the decomposition of polysaccharides such as cellulose and hemicellulose because the microbial cell is impermeable to the molecule (Tabatabai, 1982). The enzymes involved in polysaccharide decomposition, such as the glycosidase enzymes, are inducible enzymes, which means that they are excreted by the microbe only when a polysaccharide or related compound is available. By contrast, the constitutive enzymes are constantly produced regardless of substrate availability (Alexander, 1977).

Enzyme accumulation and activity are affected by soil chemical and physical properties, environmental conditions and substrate availability. Enzyme activities are strongly correlated with TOC and total N content. Soil organic C stimulates microbial activity, and thus enzyme activity, which allows for increased C turnover and nutrient cycling. Both enzyme activity and enzyme accumulation generally decline with soil depth. This decrease is correlated with the soil organic C content (Dick, 1984; Dick *et al.*, 1988b; Reganold *et al.*, 1987; Eivazi and Tabatabai 1990).

Each enzyme has a pH and temperature associated with optimum activity. Enzymes are denatured by elevated temperatures, and their activity is often affected by extremes in pH and soil moisture content. Soil pH can affect enzyme activity by altering the ionization and solubility of substrates and cofactors (a substance that activates an enzyme) (Kiss *et al.*, 1975; Alexander, 1977; Tabatabai, 1982; Dick, 1984; Pulford and Tabatabai, 1988).

Although most enzymes released into the soil are degradable by soil proteases, enzymes tend to persist in the soil for long periods of time (Tabatabai, 1982). Enzymes are protected from decomposition by being bound and stabilized by colloidal clay minerals and humus constituents. This enzyme sorption may increase or decrease enzyme activity (Alexander, 1977; Dick *et al.*, 1988b).

β-Glucosidase

The enzymes most commonly associated with the carbon cycle are invertase, amylase, cellulase and a group of glycosidase enzymes. The glycosidase enzymes are important for the degradation of carbohydrates in soils. They consist of a group of enzymes that catalyze the hydrolysis of glycosides to liberate one or several monosaccharides and an aglycon (non-carbohydrate group). Among the four glycosidase enzymes (α-glucosidase, β-glucosidase, α-galactosidase and β-galactosidase) β-glucosidase (obsolete name gentiobiase or cellobiase) activity is dominant.

β-glucosidase is essential for the final stage of cellulose degradation. β-glucosidase is an extracellular enzyme that catalyzes the hydrolysis of cellobiose (Alexander, 1977; Eivazi and Tabatabai, 1988; Eivazi and Tabatabai, 1990). Cellobiose is a common disaccharide obtained by the partial hydrolysis of cellulose. Cellobiose contains two D-glucose units with a β(1-4) glycosidic linkage (Hart and Schuetz, 1978) and is nonpermeable to microbial cell walls. β-glucosidase is important because its hydrolysis product, glucose, is an important energy source for soil microorganisms.

β-glucosidase is an inducible enzyme, thus its activity is partially regulated by microorganisms and is produced only in the presence of the appropriate substrate. Microorganisms repress the synthesis of the enzyme if the rate of product formation exceeds rate of assimilation by the cell. This limits stimulation of neighboring heterotrophic organisms, or adsorption of their products or the enzyme itself by clay minerals (Alexander, 1977).

Effect of Cultivation on Distribuiton of Soil Organic Carbon, Content and Related Properties

Cultivation and cropping of a soil previously supporting native vegetation or pasture results in a marked change in soil chemical, physical, and biological properties. Cultivation of a virgin, undisturbed soil decreases the total SOM and total N contents (Rasmussen *et al.*, 1980; Dick, 1983; Dalal and Mayer, 1986a; Dalal and Mayer, 1986b; Shiel, 1986; Aguilar *et al.*, 1988; Woods, 1989), other SOM related nutrients (Gotoh *et al.*, 1984; Burke *et al.*, 1989; Soudi *et al.*, 1990; Elliot and Lynch, 1984), and the soil biological activity (Woods, 1989; Ramsay *et al.*, 1986).

Soil Organic Matter Loss

Numerous studies on the dynamics of SOM loss (Balesdent *et al.*, 1988), change in composition (Catroux and Schnitzer, 1987), and redistribution within the soil profile (Sheil, 1986) as affected by cultivation have been conducted for both virgin and grazed grassland soils. Researchers have sought to understand pedologic processes involved in virgin SOM turnover, new SOM formation, and SOM equilibrium levels, and they have tried to establish baseline SOM values throughout the U.S to assess total SOM losses.

Most research on the effects of cultivation on SOM and related properties has been conducted on paired plots of cultivated and virgin sites or with long-term experimental plots with annotated history. Total SOM losses are variable throughout the United States and Canada. Total losses of SOM reported for the central plains of Canada and the United States range between 40 and 60% for soils cultivated from 40 to 100 years (Rasmussen *et al.*, 1980; Tisdall and Oades, 1982; Mann, 1985). Reported losses for the Pacific northwest ranged from 20 to 40% (Pauson *et al.*, 1953; Rodman, 1988). Mann (1986) compared 625 paired soils in the central United States and documented changes in SOM after cultivation that ranged from 70% loss to 200% gain. He attributed these variations to differences in soil type, depth of sampling, management history and initial SOM level.

Most changes in soil organic matter and total N are confined to the surface 2 to 20 centimeters (Rasmussen *et al.*, 1980; Dick, 1983; Shiel, 1986; Woods, 1989; Balesdent *et al.*, 1988). Balesdent *et al* (1988) concluded from a study involving a soil continuously cropped to wheat, that subsoil organic matter was biologically stable, essentially of native prairie origin, and unaffected by SOM changes in the surface horizon.

The net primary productivity is higher, and root and crown tissue production are generally greater for native grasses than for cultivated crops, and erosional and oxidation losses are minimal from virgin sites (Rasmussen and Collins, 1992-in press). Therefore, much of the SOM loss is associated with changes in the soil physical properties due to cultivation, including the degradation of soil structure, a decrease in aggregate stability, a decrease in the number macroaggregates and a relative increase in the proportion of microaggregates (Elliott, 1986; Ramsay *et al.*, 1986), and an increase in soil erodibility (Ekwue, 1990; Hadas, 1987). Soil organic matter oxidation and decomposition are stimulated because of the physical disruption of soil aggregates and the exposure of the bioavailable organic materials to oxygen and microbial populations.

Upon cultivation of a virgin soil, the greatest losses in SOM occur in the bioavailable fraction (e.g. the readily decomposable fresh plant residues, live roots, microbial C, water soluble C, and the fulvic acid fraction of the native SOM) (Dalal and Mayer, 1986a; Balesdent *et al.*, 1988). A significant loss in the bioavailable SOM pool may decrease the inherent soil fertility status, mineralization potentials, C and N cycling and microbial activities (Sikora and McCoy, 1990). However, these changes may not be apparent from the analysis of total SOM content as affected by cultivation (Dalal and Mayer, 1986a).

Woods (1989) reported that within one year of cultivation of a Wyoming high plains virgin grassland soil, the amount of readily mineralizable C, as determined by total CO_2 evolution after a 20 day incubation period, decreased markedly, as did soil microbial C and N in the surface 15 cm. After 4 years of wheat/fallow rotation, Woods (1989) reported a 71% and 46% reduction in the average concentration of the mineralizable C and N, respectively, in the surface 15 cm of soil.

Rates of SOM loss and changes in total SOM composition with cultivation depend on soil type, the management system used, extent of soil erosion, biomass productivity, amount of crop residue incorporated into the soil, climate, topography, soil texture (Shiel, 1986), and time (Rasmussen *et al.*, 1980; Dalal and Mayer, 1986a; Balesdent *et al.*, 1988; Burke *et al.*, 1989). Rates of organic matter and total N depletion are rapid in the initial 10 to 30 years of cultivation; the bioavailable SOM content, microbial populations, and microbial activity decrease significantly within one year of cultivation of virgin grasslands (Woods, 1989). Within approximately 50 to 100 years of cultivation under similar management systems SOM levels stabilize and a new SOM equilibrium level is attained (Rasmussen *et al.*, 1980; Aguilar *et al.*, 1988; Balesdent *et al.*, 1988).

In Missouri, Balesdent *et al* (1988) studied the residence time of labile forms of organic matter of prairie origin (native SOM) in a Udollic Ochraqualf cultivated approximately 100 years under two management systems: annual wheat and perennial grass (timothy). Historical soil samples collected from experimental plots in 1915, 1928, 1938, 1962 and 1975, and fresh soil samples from a virgin prairie (control) on the same soil type were used for the study. Balesdent reported that the labile SOM of prairie origin was exhausted after 30 to 40 years of cultivation. After the initial period of 30 to 40 years, mineralization rates of the SOM of prairie origin slowed, and all other forms of the SOM were considered to decompose at similar rates.

The extent of depletion of the labile SOM depended on the crop type. The rate of decline was observed to be more rapid for soils cultivated under wheat than for soils cultivated under timothy grass. After approximately 100 years of cultivation, a stable pool of the prairie SOM persisted at 49% and 61% of the total SOM content of the non-cultivated prairie (control) cropped under wheat and timothy, respectively. It was assumed that any continued mineralization of SOM involved the decomposition of easily mineralizable organic matter of crop origin.

Organic Residue Incorporation and New Soil Organic Carbon and Nitrogen Equilibrium Levels

Incorporation of crop residues is an important factor in establishing new SOM equilibrium levels in cultivated soils. The effect that organic matter incorporation has on both the rate of SOM decline and the new SOM equilibrium level attained is highly related to the amount of crop residue, but it is weakly related to the type of residue (Horner *et al.*, 1960; Rasmussen *et al.*, 1980; Reganold *et al.*, 1987). Rasmussen *et al* (1980) documented changes in soil C and N content in a wheat-fallow cropping system with various residue treatments (peavine, manure or wheat straw only) over a 45 year period. Soil organic C and total N continued to decline with time for all treatments except the manure treatment. The changes in soil organic C and total N were confined to the surface 20 cm of the soil, and were correlated with the amount of organic C supplied in the residue treatment (peavine, manure or wheat straw), regardless of residue type.

Larson *et al* (1972) also found that changes in soil organic C levels were correlated with the amount of organic C supplied with residue treatments, regardless of residue type (alfalfa, corn stalks, oat straw, sawdust and bromegrass) in an Iowa Hapludoll cultivated under corn for 12 years.

The total amount of SOM gained or lost from a system depend on the original SOM level, the climate and the intensity of cropping. It is possible, therefore, to use regression techniques to estimate the amount of plant residue biomass required to prevent further losses of the stable SOM fraction and to predict the amount of C and N retained (Larson *et al.*, 1972; Rasmussen *et al.*, 1980). Rasmussen *et al* (1980) placed the amount of residues necessary for zero change in native SOM in a range from approximately 2,000 to 1,180 kg of C ha^{-1}. This was determined by examining the data from several independent studies of residue incorporation rates and soil organic C response under semi-arid conditions (Horner *et al.*, 1960; Hobbs and Brown, 1965; Larson *et al.*, 1972; Rasmussen *et al.*, 1980). The variability in SOM response to residue incorporation was due to differences in climate, inherent SOM content and cultural system. In general soils with greater inherent SOM contents and warmer or more humid climates experience more rapid changes in SOM contents, needing higher rates of organic matter incorporation to reach new equilibrium levels.

Residue or manure incorporation has increased SOM levels under some management systems (Dick *et al.*, 1988b). Gotoh *et al* (1984) conducted a 13 year study on the effects of incorporation of three different residues on SOM content in a sandy loam cultivated to rice. They reported that 13 to 25% of the organic residues incorporated into the soil appeared in the SOM fraction. This resulted in a 70, 55 and 53% increase in SOM content for the compost, rice straw and Italian ryegrass treatments, respectively. The treatment effects were concentrated primarily in the surface two horizons (0-22 cm depth).

Maintenance of SOM above natural equilibrium levels is difficult to achieve. After organic matter additions are stopped, SOM content will ultimately return to natural equilibrium levels (Brady 1990). Shiel (1986) reported that although SOM contents in soils cropped to hay on the Palace Leas experimental plots, Tyne, United Kingdom, increased, maintenance of elevated levels required prolonged treatment with ammonium sulfate. Further, the majority of new SOM was found in the sand and coarse silt-sized fraction and was considered to be quite bioavailable and of short duration. An increase in SOM content after 6 years of heavy straw residue incorporation in a silt loam soil was documented in Germany. However, after the residue treatment was discontinued, the SOM content returned to the original level within 13 to 21 years. Only a small percentage of the incorporated organic C entered into the stable C fractions of the soil (Sauerbeck, 1982; Rasmussen and Collins, 1992-In press).

Total Nitrogen and Soil C:N Ratio

Changes in total N due to cultivation of a virgin, undisturbed soil parallel closely changes in TOC and SOM composition. Cultivation of a virgin soil results in a loss of total soil N. However, soil C:N ratios are often reduced (Gotoh, *et al.*, 1984; Burke *et al.*, 1989; Soudi *et al.*, 1990). Decreased soil C:N ratios suggest that a greater proportion of organic C is mineralized and lost from the system relative to N, and that an accumulation of humified materials enriched in N occurs over time (Aguilar and Heil, 1988). As with TOC, these changes are confined to the surface 20 cm of the soil profile (Rasmussen *et al.*, 1980; Gotoh, *et al.*, 1984; Burke *et al.*, 1989; Soudi *et al.*, 1990). Total N contents and C:N ratios are minimally affected in the subsoil horizons, regardless of the TOC and total N dynamics in the surface horizons (Gotoh *et al.*, 1984).

The rate of total N loss, like the rate of soil organic C loss, depends on the soil management practice and the amount of organic matter input, but it is minimally affected by the type of crop residue or the residue N-content

(Rasmussen *et al.*, 1980; Dick, 1983). However, Rasmussen *et al* (1980) showed a decrease in the rate of N loss from a silt loam soil cutivated to wheat with inorganic N fertilizer applications. they postulated that this decrease in the rate of N loss is a response to an increase in crop residue biomass and lignin produced with fertilizer N application.

Soil Organic Matter Association with Soil Texture

Upon cultivation, soil organic C losses occur from all particle-size fractions in most soils. However, loss rates of soil organic C due to cultivation differ considerably among the soil particle fractions. Analyses of cultivated virgin soils indicate that the greatest SOM losses are associated with sand- (Dalal and Mayer, 1986d) and silt-sized (Balesdent *et al.*, 1988) fractions, with lowest relative losses, or even enrichment of SOM, associated with clay-sized fractions (Aguilar *et al.*, 1988; Balesdent *et al.*, 1988; Shiel, 1986; Burke *et al.*, 1989).

The SOM associated with the sand- and silt-sized fractions consists of coarse textured, bioavailable, partially decayed plant and animal debris which is rapidly decomposed. The decay products are then re-associated with the clay-sized fraction (Dalal and Mayer, 1986d). The virgin SOM associated with the clay-sized fraction is minimally affected by cultivation because of its inherent microbial resistant characteristics (Balesdent *et al.*, 1988).

Enzyme Activity

Numerous studies (Biederbeck *et al.*, 1980; Dick 1984; Dick *et al.*, 1988b) have shown that different long-term soil management systems including tillage, residue incorporation, fertilization and burning, have marked effects on soil microbial activity, and therefore soil enzyme activity. Because of the high correlation of enzyme activity with soil total organic C and total N, changes in enzyme activity are generally consistent with changes in soil organic C and total N content induced by soil management. Any changes in enzyme activity are predominantly confined to the Ap horizons of plowed agricultural soils, or within 0 - 7.5 cm of no-till agricultural soils (Dick *et al.*, 1988a; Dick *et al.*, 1988b).

Enzyme activity is related to soil organic C and N content. Therefore enzyme activities generally respond positively to long-term management systems that incorporate organic residues into the soil (Verstraete and Voets, 1977; Reganold *et al.*, 1987; Dick *et al.,* 1988a). Dick *et al.* (1988a) showed that the extent of enzyme activity response depends on both organic residue type and amount. In most cases residues highest in organic N content have a stronger effect on soil enzyme activity. For example, soils treated with manure regularly showed higher enzyme activity as compared to soils treated with pea-vine residues or straw residues. Trends in enzyme activity were correlated with soil organic C and total N. Dick *et al* (1986b) also found significant correlations between inorganic N application and activity of enzymes directly involved in the N cycle, for example urease and amidase.

Enzyme activity may also be affected by other changes in soil chemical and physical properties also induced by soil management system including soil pH, inorganic salt concentrations and bulk density. For example, Dick *et al.* (1988b) found that both manure residue and inorganic N applications had a significant effect on soil enzyme activity because of changes in the soil pH levels. The lowest soil pH was recorded for soils treated with inorganic N applications, and the highest for manure treatments. Soil pH showed significant positive correlations with alkaline phosphatase, arysulfatase, urease and amidase enzymes activity, and a negative correlation with acid phosphatase. β-glucosidase activity was not correlated with soil pH.

In contrast, Eivazi and Tabatabai (1990) found that β-glucosidase activity was significantly, but negatively correlated with soil pH. They also reported β-glucosidase activity was partly inhibited by several different inorganic salts (laboratory incubation at concentration of 8 m*M*).

Increased soil bulk density is often a result of soil compaction due to the use of heavy machinery. Increased soil bulk density in compacted soils affects other soil physical properties by reducing the soil gas and water diffusion rates, impeding water drainage, and decreasing soil porosity. These effects may cause an associated decrease in microbial activity, and therefore enzyme synthesis and activity in the soil (Whisler *et al.*, 1965; Dick *et al.*, 1988a).

No-till management systems utilize herbicides intensively to control weed problems. Dick (1984) studied the effect of pesticide application and accumulation under a no-till system on microbial populations and enzyme activity. The primary herbicides used in the study were triazine, simazine, atrazine, roundup and 2,4-D. Results showed that enzyme activity was not affected by repeated pesticide applications.

The Effects of Crop Residue Burning on Soil Organic Matter and Related Properties

Two primary benefits to field burning crop residues are disease control and weed control (Hardison, 1964). Other benefits include economic and efficient residue removal, more rapid nutrient cycling, decreased nitrogen fertilizer requirement, stimulation of seed yield and facilitation of seed bed preparation (Conklin *et al.*, 1989; Hardison, 1964; Meland and Boubel, 1966). However, there are several potential problems with field burning including air pollution related to respiratory and other health effects, smoke impact on visibility and global climate change (Conklin, *et al.*, 1989). In addition, there has been concern over the effects of burning on soil properties and long-term sustainability and productivity of the soil as a non-renewable resource (Biederbeck *et al.*, 1980; Dick *et al.*, 1988b).

There are both long-term and short-term effects of burning grassland, forest, and agricultural land on soil properties. Results from numerous studies on annual burning have shown long-term effects on soil chemical, physical and microbiological properties, including lower total soil organic C and N content, and decreased microbial populations and activities (Biederbeck *et al.*, 1980; Dick *et al.*, 1988b; McNabb and Cromack, 1990). In contrast, results from single burn studies have shown significant, but short-term increases in the microbial population and activity, exchangeable NH_4^+-N and bicarbonate extractable P, as well as nonsignificant trends of increasing NO_3^--N (Debano, *et al.*, 1979; Biederbeck, *et al.*, 1980).

Long-term effects on soil properties documented for forest fires also include increased soil bulk density, soil hydrophobicity and clay mineral alteration (Biederbeck *et al.*, 1980; Boyer and Dell, 1980; Giovannini and Lucchesi, 1983). Forest fires, both prescribed and wild, may be less frequent, and of higher levels of organic matter consumption and longer duration than agricultural fires. For these reasons, care must be taken in extrapolating the information of long-term effects of forest fires to long-term effects of agricultural fires (DeBano, 1990; McNabb and Cromack, 1990).

Fire Characteristics and Soil Heating

The extent of fire related changes in soil properties depends on the fire characteristics (temperature and rate), and the quantity of biomass consumed which influences total soil heat flux. Fire characteristics are determined by fuel type, chemistry, quantity, packing and fuel moisture content (Meland and Boubel, 1966; Raison, 1979). Thermal diffusivity of soils are influenced by the soil organic matter content, soil moisture and soil texture. In general heat transfer is greater within a profile of coarse gravelly soils than fine-textured soils. Soil moisture is an important factor in limiting heat penetration into the soil profile. Generally less soil heating and heat penetration into the soil profile occurs in a wet soil than in a dry soil (Barnett, 1989).

Rasmussen *et al* (1986) studied burn effects of wheat residue fuel loads on soil temperature in a semiarid climate. Fuel loads averaged approximately 6.5 Mg

ha^{-1}. Wheat residues consisted of approximately 60% standing stubble and 40% residues deposited on the soil surface. Results showed that surface soil temperatures depended on the completeness of fuel combustion. Incomplete combustion of fuels resulted in surface soil temperatures seldom exceeding 120 °C. Complete combustion of fuels corresponded with surface soil temperatures ranging from 170 to 330 °C. Soil temperatures were not affected significantly below 2.5cm depth.

A similar study conducted by Biederbeck *et al* (1980) for which approximately 6.3 Mg ha^{-1} and 7.6 Mg ha^{-1} of wheat straw residues were on the soil surface as mulch. The maximum surface soil temperatures were between 338 and 422 °C. The variation depended on the fuel load. Heat from burning did not penetrate below the top 1 cm of the soil's surface.

In the Willamette valley of Oregon, Meland and Boubel (1966) studied fire characteristics and heat transfer under varying environmental conditions when approximately 5.2 Mg ha^{-1} of English ryegrass straw residues were burned. Average fire temperatures were 444 °C at the soil surface, 385 °C at 15.25 cm above the soil surface, and 46.6 and 25.5 °C at 1.4 cm and 5 cm below the soil surface, respectively. The rate of spread was 19.6 meters $minute^{-1}$. The burn rate was was influenced by wind speed, air temperature and moisture of the fuel load (affected by the number of days after harvest). The level of fuel combustion was related to soil and residue moisture. The amount of residue remaining from the initial 3.7 Mg ha^{-1} of straw following the burn was approximately 0.75 Mg ha^{-1}.

Soil Organic Carbon and Related Nutrient Losses

Burning of crop residues affects soil nutrient content and nutrient cycling by rapidly mineralizing crop residue organic C and other nutrients that would otherwise be incorporated into the soil organic matter and stabilized into the soil by natural decomposition processes. Crop residue nutrients may be lost either by volatilization or by convection of ash particulate in the smoke plume, or they may be transformed from organic forms to readily available inorganic forms. The available nutrients in residue ash that is deposited on the soil surface are then susceptible to loss by leaching or erosoin by wind (McNabb and Cromack, 1990).

The amount of C and N lost from crop residues during burning are substantial. Rasmussen *et al* (1980) reported a 65% C loss from burning wheat straw residues at Pendleton, Oregon. Meland and Boubel (1969) reported an average of 52% organic C loss during burning of perennial ryegrass in the Willamette valley, Oregon. The amount of N lost is generally directly related to the amount of organic matter combusted (Boyer and Dell, 1980; Kauffman *et al.*, 1992-In press).

Burning may destroy SOM and humus. However, the effects of this destruction on soil nutrients are generally minimal for agricultural burns. This is because soil temperatures under agricultural burns are rarely high enough to allow extensive combustion of SOM and volatilization losses of SOM and related nutrients (McNabb and Cromack, 1990).

Volatilization of a specific nutrient occurs when the burn temperature is adequate to convert an element into its gaseous form. The extent of nutrient loss depends on fire intensity and efficiency of fuel combustion (Wells *et al.*, 1979). The nutrients of primary concern are C, N, P and S. Carbon, N, P, K and S are volatilized at temperatures of 650, 200, 360, 204 and 444 °C, respectively, Ca and Mg are not volatilized until temperatures reached are greater than 1100 °C (Boyer and Dell, 1980; Kauffman *et al.*, 1992).

Most studies on the long-term effects of field burning of agricultural residues have been focused on changes in crop yields (Biederbeck, *et al.*, 1980; Elliot and Lynch,1984; Christian and Bacon, 1988; Rasmussen and Rhode, 1988; Mellbye, 1991). Relatively few researchers have reported on the effects of burning on SOM, nutrient content, nutrient cycling, (C, N, P, S), and biology (Biederbeck, *et al.*, 1980; Rasmussen *et al.*, 1980; Dick *et al.*, 1988b; Powlson *et al.*, 1989).

However, Biederbeck *et al* (1980) documented accelerated losses of total soil organic C and significant decreases in total N as a result of long-term burning fields cropped to wheat under a no-till management system in Saskatchewan, Canada. Corresponding with soil thermal conductivity characteristics determined for the same study, the changes in soil organic C and total N levels occured primarily in the upper 2.5 cm of the soil profile. Rasmussen *et al* (1980) reported substantial losses of soil organic C and total N in the top 20 cm as a result of fall burning of non-fertilized soil plots cropped under an annually cultivated wheat-fallow agricultural system.

In contrast, Powlson *et al* (1989) showed no changes in soil organic C or N as a result of 18 consecutive years of spring barley residue burning. Their results, however, did show a slight increase in soil organic C and N and significant increases in microbial C and N where residues were annually incorporated into soils that previously had been burned. Over the 18 year period, a total of 37.8 Mg C ha^{-1} was incorporated into the soil. Results showed a 5% increase in total soil organic C and 10% increase in total soil N. Microbial biomass C and N increased by 45 and 37% respectively.

Temporary soil nutrient changes may occur immediately after burning plant residues. These changes result from the transformation of organic nutrients in plant residues to inorganic forms. These forms either are deposited directly on the soil surface in the ash or are translocated by convection currents that result from differences in temperature gradients. The soluble forms of inorganic nutrients deposited in the ash may also be leached with the soil solution through the soil profile (DeBano and Conrad, 1978). For example, burning may temporarily increase ammonium, and to a lesser extent nitrates in the soil (McNabb and Cromack, 1990). Much of the NH_4^+-N is translocated through the soil profile in transvection currents. NO_3^- is leached in soil solution downward through the soil profile. NO_3^- accumulation in post-fire soils is minimal because of its susceptibility to leaching, and possibly because of a reduction in the *Nitrosomonas* bacteria populations and activity levels (McNabb and Cromack, 1990).

Phosphorus is not translocated through the soil; instead it is concentrated in the ash and immobilized by soil particles. Generally increased levels of available P decrease to pre-fire levels within a year (DeBano and Klopatek, 1988).

The cations Ca, K, Mg and Na present in fuels prior to burning are deposited as ash in readily available form. The amount of any particutlar nutrient depends on the type of plant residue burned. Calcium is generally present in the highest concentration. The concentration of cations present in the ash is reduced by leaching through the soil profile. However, if leached, these nutrients could be adsorbed to clay and organic matter particles (McNabb and Cormack, 1990).

The release of basic cations from plant residues with burning may increase soil surface pH (Wells *et al.*, 1979; Boyer and Dell, 1980; Dick *et al.*, 1988b). In grasslands and cropland changes in soil pH are generally not significant, however, and persist for less than two years (Ehrenreich and Aikman, 1963; Laurent, 1979).

Soil Organic Carbon Bioavailability

Research indcates that long-term burning of crop residues could decrease the biovailable soil C fraction relative to the total C pool (Rasmussen *et al.*, 1980; Powlson *et al.*, 1989). Long-term burning of crop residues causes the volatilization of active or bioavailable C compounds, which serve as important energy sources for microbial activity, and result in a buildup of biologically inert or carbonized C derived from the crop residue ashes (Klemmedson, 1976; Rasmussen *et al.*, 1980; White 1986). A decrease in the soil bioavailable C pool or an increase in carbonized C may not be apparent from the differences in TOC content between the virgin and cultivated soils, or between soils under different long-term management systems (Dalal and Mayer, 1986a; White, 1986). However, a decrease in C bioavailability may affect soil fertility by reducing microbial activity and therefore, C mineralization and nutrient cycling (Sikora and McCoy, 1990).

Rasmussen *et al* (1980) and Powlson *et al* (1989) documented increased soil C:N ratios as a result of annual burning of crop residues. Both of these studies attributed the increase in the C:N ratios to an increase in the carbonized C content.

Basal CO_2 respiration often is used as a quantitative index of microbial activity (Anderson, 1982). Powlson *et al* (1989) and Beiderbeck *et al* (1980) used CO_2 evolution from microbial respiration as an index to analyze the effects of annual crop residue burning on the total soil bioavailable C content. Both studies reported lower total CO_2 evolved during the laboratory incubation period for soils under a management system that burned crop residues annually than for soils under a management system that incorporated crop residues into the soil annually. These results indicate that the total amount of soil biovailable C was reduced by annual burning of crop residues.

Evolution of CO_2 from microbial respiration is highly correlated with the total amount of organic C in the soil. Therefore soils that have different levels of TOC content should have different levels of CO_2 evolved from microbial respiration during a laboratory incubation period. However, the total amount of CO_2-C evolved from microbial respiration during a laboratory incubation period, when expressed on a per gram C basis, provides an index of the relative amount of the total soil organic C that is bioavailable. In theory, if water content and temperature are held constant, a reduction in the proportion of the bioavailable C fraction (the readily decomposable fresh plant residues, root exudates, microbial C and water soluble C) or an increase in the proportion of recalcitrant material or carbonized C relative to the total C pool would reduce the amount of CO_2-C evolved when expressed on a per gram carbon basis (White, 1986). Using this method, Powlson *et al* (1989) found trends indicating that the proportion of bioavailable C relative to the total C pool was lower for annually burned soils than for soils for which straw residues were annually incorporated into the soil.

Soil Microbiolgy and Enzyme Activity

Microbial activity is directly affected by soil environmental factors such as temperature, moisture and pH. Temperature and moisture function together to influence microbial survival during a fire (Barnett, 1989). In general the higher the moisture content the lower the temperature, and the greater the survival. These effects are most pronounced in the uppermost soil layer. For example, Dunn and DeBano (1977) found that nitrifying bacteria, *Nitrosomonas* and *Nitrobacter*, were killed when soil temperatures reached 100 °C in dry soils (2.5% moisture content) and 140 °C in moist soils (4.5% moisture content). Generally there is no significant desiccation and direct killing of microbes by heat flux below 2.5cm soil depth regardless of soil moisture content (Dunn and DeBano, 1977; Biederbeck *et al.*, 1980).

As with soil nutrient content, species composition and soil microbial populations are affected differently by single burns and long-term burning of crop residues. The immediate impact of a single burn is to temporarily decrease all populations, but a rapid recovery generally occurs when the soil is moistened (Barnett, 1989). For single burns, heterotrophic microbial populations tend to survive soil heating better than do fungal populations (Wells *et al.*, 1979; Dunn and DeBano, 1977). For example, Beiderbeck *et al* (1980) reported an immediate 95% decrease in fungal and 70% decrease in bacterial populations in the top 1cm of soil cultivated under wheat, after a single burn in eastern Canada. In contrast, in the same study Beiderbeck *et al* found that fungal populations were only slightly reduced as a result of long-term burning. However, bacterial populations in the top 2.5cm of soil in long-term burn plots were permanently reduced by greater than 50% compared to plots with straw incorporated annually. Similar findings have been reported for Kenya grasslands by Meiklejohn. (1953).

Few studies have documented the effects of field burning on enzyme activity. However, Dick *et al* (1988b) reported that enzyme activity was consistently lower in long-term experimental plots where wheat straw had been annually burned in the fall than in both plots burned in the spring and plots for which wheat residues were annually incorporated into the soil. The differences in activity between plot treatments were not significant, but they were highly correlated with the soil organic C content, which was affected by residue treatment.

Changes in Soil Physical Properties

Infiltration and soil water storage capacity may be immediately reduced with consumption of soil surface organic layers and exposure of mineral soil (Debano, 1969; Wells *et al.*, 1979). Infiltration is affected by the deposition of repellent, long-chain aliphatic hydrocarbons formed from partially volatilized organic matter on the mineral soil surface. These hydrophobic compounds condense on soil particles as they are translocated through the soil profile, limiting water storage capacity (McNabb and Swanson, 1990).

The effect of burning on substances that aggregate soil particles is important for understanding long-term effects on soil structure and erodibility.

Studies by Unger *et al* (1973) and Dormear *et al* (1979) show that crop residue burning increased erodibility of soils as a result of decreased organic matter content and decreased polysaccharide and water stable aggregates, all of which help stabilize soil structure. Biederbeck *et al* (1980) reported a decrease in aggregate stability and found trends of higher soil bulk densities as a result of burning of crop residues.

FIELD AND LABORATORY PROCEDURES

Soil Type

Extensive acreage, consistency in historical land use, and agricultural importance were the main reasons for selecting Dayton soils cropped to annual ryegrass for this study. Approximately 44,500 hectares of Dayton silt loam (fine, montmorillonitic, mesic Typic Albaqualf) have been mapped in the Willamette valley (Mellbye-personal communication). The majority of this area has been surface drained and used for annual and perennial ryegrass seed production (SCS, 1982).

The Willamette valley is characterized by a temperate climate and is located in the mesic soil temperature regime and the xeric soil moisture regime. The annual precipitation is approximately 94 cm with an average winter temperature of 4 ^{o}C and an average summer temperature of 19 ^{o}C (SCS, 1982). The average annual frost free period is 165 to 210 days.

Dayton silt loam is a deep, poorly drained soil, formed in silty and clayey alluvial and lacustrine materials. It occurs on broad terraces of the Willamette valley, on level to slightly concave slopes of 0 to 2%, at an elevation of approximately 61 to 122 meters (SCS, 1982). Prior to agricultural development, the native vegetation consisted of open grasslands, scattered Oregon white oak, red alder, and shrubs of willow and wild rose (Boyd, 1986).

Dayton soils typically have a grayish brown (2.5 YR 6/2) silt loam A horizon over a dark grayish brown (2.5YR 4/2) clayey, $2Bt_1$ horizon. It is the presence of the clay pan that is responsible for the poor drainage (Balster and Parsons, 1968).

Three separate stratigraphic units, corresponding to the master horizons A, 2B, and 3C occur within the soil profile. In some areas the 3C horizon is underlain by gravelly or clayey substratum, or by bedrock. Pedogenic features have developed across the lithologic discontinuities since their formation in the late pleistocene period. These include organic matter accumulation, base eluviation, clay films, iron mottles and concretions, and structural development (Parsons and Balster, 1967).

Site Selection

Nine sites in total were selected with the aid of Linn County Agricultural Extension Agent Mark Mellbye, and local farmers. All nine sites were located in the south Willamette valley, in either Linn or Benton County.

Four sites were selected to represent each of the long-term management systems, burn and plow. Each site was located on Dayton silt loam soil and had been cropped to annual ryegrass for a minimum of 40 years. The four fields selected to represent the burn management system have been annually burned continuously for a minimum of 40 years. The four fields selected to represent the plow management system were annually burned continuously for approximately 30 years, after which they were managed to have straw residues annually incorporated into the soil for a minimum of 10 consecutive years. The crop management practices for each site, including period of cultivation, tillage frequency, plow depth, seeding technique, and rates of fertilizer and lime applications are summarized in Table 1. One native site (The Foster Cogswell

Table 1. History of farm management for Dayton silt loam under annual ryegrass for each site sampled.

Site[a]	Residue management practice	Years under management[b]	Tillage intensity[c]	Annual winter grazing	Rate of fertilizer application N Fall	N Spring	P	K	S	Lime Year
						($kg\ ha^{-1}\ yr^{-1}$)				
1	Burn	40+	2.5	No	22	168	44	44	22-29	1987
2	Burn	40+	2.0	Yes	18	151	23	76	41	1975/1985
3	Burn	40+	1.8	No	15	157	16	16	24	Never
4	Burn	40+	1.0	No	31	135	31	31	26	1988
5	Plow	17+	Annual	No	7	145	35	35	27	1970
6	Plow	10+	Annual	No	11	140	22	22	32	Never
7	Plow	10+	Annual	Yes	20	185	18	18	47	Never
8	Plow	15+	Annual	No	16	135	27	27	27	Never

[a] Information gathered via personal interviews with farm owners/managers.

[b] All sites have been cropped under annual reygrass for a minimum of 40 years. Sites selected to represent the burned management system have most likely been continuously burned for the total 40 years. Values shown here do not represent the amount of time the site has been under the same manager/operator. Sites selected to represent the plowed system were burned continuously for apporximately 30 years, after which they were managed to incorporate straw residues into the soil for the next 10 to 17 years.

[c] Values represent average number of tillage operations each 10 years for sites under burn system. Crop residues are removed by open burning prior to tillage operations.

Preserve) was selected to represent pre-cultivation conditions. This virgin site was most likely annually burned until the late 1830's by Native Americans prior to European settlement (The Nature Conservancy-personal communication).

Soil Sampling Pattern

Soil Conservation Service (SCS) maps were used to locate fields mapped predominantly as Dayton silt loam. In each field a soil pit was hand dug near the center of the Dayton silt loam delineation to facilitate describing and sampling the soil. All sampling was done after harvest in late summer, but before incorporation or burning of straw residues. Soil profiles were described using the methods from the Soil Survey Manual (Soil Survey Staff, 1975). Genetic soil horizons were described by depth, color, texture, mottling, structure, consistence, roots, pores and boundary distinctness. Selected morphological properties of the sites described are displayed in Table 2. Precise sampling locations and detailed profile descriptions are assembled in Appendix I.

Soil samples were collected at four different locations, between mid July through mid September, 1990 at each site. One set of samples was collected from the central portion of each genetic horizon described in the hand-dug pit. Three additional samples were collected from soil cores located randomly around the soil pit. The core locations, and their distance from the central pit, were determined by the size and shape of the particular delineation of Dayton silt loam, by the presence of delineations of other soil map units shown on the soil maps, and by micro-relief. As with the central pit, micro-highs, depressions, and shelves

Table 2. Selected morphological properties of Dayton silt loam (Fine, montmorillonitic, mesic Typic Albaqualf) for sites sampled.

Management (Site)	Soil Horizon	Depth (cm)	Texture[a]	Munsell[b] Color	pH
Burn	Ap	0-19	sil	10YR4/2	5.0
(1)	E	19-27	sil	10YR5/2	4.8[*]
	BE	27-34	sicl	10YR5/2	
	2Bt1	34-54	sic	2.5Y4/2	5.4
	2Bt2	54-68	sic	2.5Y4/2	
	2BCt	68-91	sicl	10YR5/3	
	3C	91-134+	sil	10YR5/3	
Burn	Ap	0-18	sil	10YR6/2	4.7
(2)	A	18-35	sil	10YR4/2	4.8[*]
	AB	35-55	sicl	10YR5/2	
	2Bt1	55-70	sic	10YR4/2	6.0
	2Bt2	70-95	sic	10YR5/4	
	BC	95-125	sicl	10YR5/3	
	3C	125-135+	sil	2.5Y5/3	
Burn	Ap	0-16	sil	10YR4/2	4.4
(3)	A	16-28	sil	10YR4/2	4.6[*]
	E	28-35	sicl	10YR5/2	
	2Bt1	35-57	sic	2.5Y4/2	5.9
	2Bt2	57-75	sic	2.5Y4/2	
	2Bt3	75-95	sicl	2.5Y5/4	
	2BCt	95-114	sicl	2.5Y5/4	
	3C	114-124+	sicl	10YR4/3	
Burn	Ap	0-17	sil	10YR5/2	4.9
(4)	A1	17-29	sil	10YR4/2	5.0[*]
	A2	29-39	sil	10YR5/2	
	2Bt1	39-51	sicl	2.5Y5/2	5.1
	2Bt2	51-78	sicl	2.5Y5/2	
	2BCt	78-110	sicl	2.5Y5/2	
	3C	110-132+	sicl	10YR5/4	

Table 2. continued

Management (Site)	Soil Horizon	Depth (cm)	Texture[a]	Munsell[b] Color	pH
Plow	Ap	0-18	sil	10YR4/2	4.4
(5)	A	18-35	sil	10YR5/2	5.0*
	AB	35-55	sicl	2.5Y5/2	
	2Bt1	55-70	sicl	10YR5/2	5.9
	2Bt2	70-95	sic	2.5Y5/2	
	2BCt	95-125+	sicl	10YR5/3	
Plow	Ap	0-16	sil	10YR4/2	3.9
(6)	A	16-26	sil	10YR4/2	4.3*
	E	26-43	sil	2.5Y5/2	
	2Bt1	43-66	sic	2.5Y5/2	5.9
	2Bt2	66-86	sic	2.5Y5/2	
	2Bt3	86-118	sic	2.5Y5/2	
	2BCt	118-128+	gsic	2.5Y5/2	
Plow	Ap	0-14	sil	10YR3/2	4.5
(7)	A1	14-20	sil	10YR4/2	5.0*
	A2	20-41	sicl	10YR4/2	
	ABt	41-48	sic	2.5Y4/2	
	2Bt1	48-66	sic	10YR4/2	5.6
	2Bt2	66-80	sic	10YR4/2	
	2BCt	80-92	sicl	2.5Y4/2	
	3C	92-102+	sil	10YR5/4	
Plow	Ap	0-16	sil	10YR7/1	4.5
(8)	A	16-25	sil	10YR4/4	5.0*
	AE	25-36	sil	10YR5/2	
	E	36-50	sil	10YR6/2	
	2Bt1	50-66	sic	2.5Y4/2	5.6
	2Bt2	66-83	sic	2.5Y4/2	
	2BCt	83-108	sicl	2.5Y5/2	
	3C	108-134	sicl	10YR4/4	

Table 2. continued

Management (Site)	Soil Horizon	Depth (cm)	Texture[a]	Munsell[b] Color	pH
Native	A	0-10	sil	10YR5/2	4.9
(9)	E	10-26	sil	10YR4/2	5.1[*]
	ABt	26-34	sicl	10YR5/2	
	2Bt1	34-48	sicl	10YR4/2	5.5
	2Bt2	48-70	sic	2.5Y4/2	
	2Bt3	70-108	sic	2.5Y3/2	
	3C	108-122+	sicl	2.5Y3/2	

[a] Field estimated textural classification.
[b] Value represents moist color. See appendix for complete soil description.
[*] Indicates pH value determined for the composite sample, E/transition.

were carefully avoided. The minimum distance between each core and the central pit was approximately 40 meters.

Each soil core was observed and sampled to a depth of 110 cm using a hand bucket auger. In each core, horizon colors, textures, and depths to lowerboundaries were noted and compared to the pit description for that site to be sure that samples taken from each horizon would be consistent with samples taken from the genetic horizons in the central pit. If the morphology of the core did not fit that of Dayton, it was assumed that an inclusion was found, and the cores were discarded and a new location was found to sample the soil.

Soil Preparation

Prior to laboratory analysis the fresh soil samples collected for the Ap horizon were passed through a 2 mm sieve to remove large inorganic and organic debris and then air dried. All other soil samples for each of the other horizons were air dried first, then mechanically ground to pass through a 2 mm sieve to remove large inorganic and organic debris. Only subsamples from the < 2 mm soil fraction were used for laboratory analysis.

Measurements of soil properties as affected by straw management system were to be made on the genetic soil horizons described for each site. It was of interest to make comparisons of treatment effects only between similar soil horizons described for the soil profile at each site. However, not all the nine site soil profile descriptions were identical to each other (Table 2). Only the genetic horizons Ap, $2Bt_1$, $2Bt_2$ and $2BC_t$ were common to each soil profile of each site sampled. Depending on the site, two or three master (A and E) horizons or transition (AE) horizons occured between the Ap and $2Bt_1$ horizons. A separate, composite soil sample, labeled E/transition, was made for each of the four individual sets of samples taken at each of the nine sites by combining sieved subsamples of equal weight from each of the horizons, master and/or transition, that were located between the Ap and $2Bt_1$ horizons. Each composite sample (36 in total; 16 burn, 16 plow and 4 virgin) was treated and analyzed as one horizon for the entire context of the present study.

Laboratory Analyses

Two chemical and two biological properties were measured on each soil sample. The chemical properties measured were total organic carbon (TOC) and total nitrogen (total N). The biological properties measured were microbial enzyme activity (β-glucosidase) and microbial respiration (CO_2-C evolution). TOC was measured on each soil sample taken for the Ap, E/transition, $2Bt_1$, $2Bt_2$ and $2BC_t$ horizons. The properties of total N, enzyme activity and soil respiration were measured on each soil sample taken for the Ap, E/transition and $2Bt_1$ horizons only. This was done under the assumption that straw residue management system would have minimal effects on soil properties below the $2Bt_1$ horizon.

Total Organic Carbon

Total organic Carbon was determined by dry combustion on a Rosemount Analytical Division, Dorman DC-80 (Santa Clara, CA). Prior to analysis of TOC the < 2 mm subsamples were hand ground to pass through a no. 60 sieve. The amount of soil sample used was dependent on the TOC content, due to intrument limitations. The weight for each soil sample used differed for each horizon and each site. An approximate weight of 3 to 5 mg was used for the Ap horizon, 5 to 10 mg for the E/transition horizon, 10 to 15 for the $2Bt_1$ and 20 to 30 for the $2Bt_2$ and $2BC_t$ horizons.

Total Nitrogen

Total N was determined by the Kjeldahl method (Bremner and Mulvaney, 1982). Soil sample digestion was performed as described by Nelson and Sommers (1982). The method was modified as follows: (1) use of 0.2 g soil sample, hand ground to pass through a no. 140 sieve (2) sample digestion of three hours, (3) digestion block temperature was set for 150, 250 and 350 °C for the first, second and third hour respectively. Titrations were performed with an ABU

13 autoburette, TTT60 titrater, and PHM84 research pH meter (Radiometer Copenhagen).

Enzyme Activity

Beta-glucosidase activity was assayed by the procedure of Eivazi and Tabatabai (1988). The soil subsamples from the < 2 mm fraction were stored at 4 °C until they were analyzed for enzyme activity. The assay method involves extraction and color determination of the *p*-nitrophenol released when 1 g of soil is incubated with buffered *p*-nitrophenol glucose solution (PNG) and toluene at 37 °C for 1 hour. This assay method measures the maximum potential of β-glucosidase activity in soil.

Gravimetric Water Content at Field Capacity

Approximations of gravimetric water content at field capacity were determined for the Ap, E/transition and $2Bt_1$ horizons using the procedures described by Klute (1986) and Cassel and Nielsen (1986). A composite sample was made from subsamples of equal volume from each of the Ap, E/transition and $2Bt_1$ horizon samples that had been taken from the hand dug pit.

The composite soil samples was ground, passed through a 2 mm sieve, and packed in small rings to a known bulk density. The bulk density values used were 1.05 g cm^{-3}, 1.10 g cm^{-3} and 1.2 g cm^{-3} for the Ap, E/trans and 2Bt1 horizons respectively. These values were previously determined for other Dayton silt loam soil samples by Oregon State University Soil Physics Lab (unpublished data). The repacked soil samples were wetted to saturation, placed in a pressure chamber, and subjected to 33 kPa pressure for 3 days, until soil moisture content reached equilibrium. The average moisture contents for the air dried soil samples used in the calculation of water content at field capacity were and 2.8%, 3.3% and 8.4% for the Ap, E/transition and $2Bt_1$ horizons respectively. The approximate gravimetric water content at field capacity was determined to be 40%, 32% and 45% for the Ap, E/transition and $2Bt_1$ horizons respectively.

Microbial Respiration

Basal microbial respiration is often used to study the effects of physical and chemical properties on rates of soil organic matter decomposition. For the present study, microbial respiration was measured, using the parameter of CO_2-C evolved, to examine organic C mineralization and stabilization of soil organic matter (Anderson, 1982). The procedure used was a modified version of those procedures described by Myrold (1979) and Levi-Minzi *et al* (1990).

In preparation, 125 g of soil from each soil sample (air dried, ground and sieved to pass through a 2 mm sieve) was moistened to the desired moisture content at field capacity, 40%, 32% and 45% for the Ap, E/transition and $2Bt_1$ horizons respectively, by adding an appropriate weight of distilled water to the soil sample by pipet. The weights of water used to moisten soils to field capacity were determined by gravimetric methods described by Gardner (1986). Two subsamples having an equivalent weight of 50 g of oven dried soil each, and a moistened weight of 68 g, 64 g and 68 g for the Ap, E/transition and $2Bt_1$ horizons respectively, were removed from the intial 125 g soil sample and used for the analysis of microbial respiration (Gardner, 1986). Each sample was incubated in a dark growth chamber, at 27 °C, for a period of 32 days.

Narrow mouthed mason jars were used to contain soil samples during the incubation period. Each jar contained two small scintillation vials. One vial contained the soil sample. The second vial contained distilled water, to reduce evaporative loss of soil moisture during the experiment. The resulting air space remaining in the mason jar, used in the calculation of CO_2-C evolved, was determined by water displacement (Stotsky, 1960). Rubber septa were placed in a hole that was drilled into each mason jars lid, and the lids were closed to create an air-tight seal. During the incubation period gas samples were periodically withdrawn by inserting a needle through the septa.

CO_2 evolved was measured 6 times during the 32 day incubation period, day 1, 2, 4, 8, 16 and 32. A 0.5 ml gas sample was drawn from the headspace and analyzed for CO_2-C content by gas chromatography, (Porapak Q 1/8 inch mesh column with helium carrier gas (80 psi), oven temp at 85 °C). Each jar was opened on days 4, 8 and 16 to replenish the O_2 content and to prevent the inhibition of microbial activity due to anaerobic conditions. The ambient air CO_2 concentration was measured by the same method as described above prior to the incubation period and after each time the jars were opened to replenish the O_2 content and accounted for in the calculations of microbial respiration.

Statistical Analyses

For the present study there were 2 straw management systems or 'treatments', burn and straw incorporation (plow). Each treatment was replicated 4 times (the experimental units or sites), and four subsamples were randomly taken from each of the 4 experimental units. This gave a total of 32 observations, 16 burned units and 16 plowed units.

Statistical analysis of treatment effects on the four soil properties measured, TOC, total N, enzyme activity and microbial respiration, were performed by analysis of variance for the entire data set using the hierarchical classification procedure (nested ANOVA). For this statistical procedure the total variation is partitioned into three components: (1) variation among treatment means, (2) variation among experimental units within treatments and (3) the variation among the subsamples within the experimental units (Peterson, 1985). Summaries of all analyses of variance performed on the data are given in Appendix III.

The significance of treatment effects on TOC and total N were determined at the 0.05 probability level. The significance of treatment effects on enzyme activity and microbial respiration were determined at the 0.10 probability level.

Duncan's new multiple range test was applied to the set of 8 experimental unit means or site means (Tables 4, 6, 9, 11, 13 and 15). The significance of treatment effects on all of the soil properties measured were determined at the 0.05 probability level.

RESULTS AND DISCUSSION

Raw data for all laboratory measurements on all samples are given in Appendix II. Summaries of all analyses of variance performed on the data are given in Appendix III. The results have been condensed and summarized in Tables 3 through 15 and Figures 1 through 6 for the purposes of the discussion that follows.

Effects of Cultivation on Measured Properties

Although this study was designed specifically to evaluate the differences between burned and plowed management systems, one virgin, uncultivated site was sampled and analyzed to provide a baseline for, or potential values representative of an undisturbed soil. No additional undisturbed sites were sampled simply because none could be found -- virtually all of the Dayton soils in the southern Willamette valley have been cultivated. As a consequence, it is not possible to make statistical comparisons of cultivation with virgin levels distributions of the chemical and biological properties. Nevertheless, the data from the single undisturbed site are presented in Figures 1 through 6 to allow some comparisons.

These figures do suggest that cultivation of a virgin soil does indeed reduce the total organic C (TOC), total N, enzyme activity and microbial respiration in the Ap horizons, regardless of management system. These results are consistent with numerous studies that have documented similar changes in soil chemical and biological properties as a result of the cultivation and cropping of a virgin soil (Laurent, 1979; Rasmussen *et al.*, 1980; Dick, 1983; Shiel, 1986; Woods, 1989; Ramsay *et al.*, 1986; Agulilar *et al.*, 1988; Balesdent *et al.*, 1988).

Total Organic Carbon

Distributions of total organic carbon (TOC) under burned, plowed, and native soils are summarized in Figure 1. The corresponding statistical data are summarized in Tables 3 and 4. These data clearly show that TOC decreases with depth in the soil. This is normal for mineral soils (Nelson and Sommers, 1982; Shiel, 1986; Catroux and Schnitzer, 1987), and thus it is not of interest to compare the differences in these soil properties between horizons of the same soil profile.

Soils for which straw residues were incorporated by plowing had higher average TOC values in the Ap and E/trans horizons than soils for which straw residues were burned (Table 3). The effect is statistically significant ($p < .05$) only for the Ap horizon, but there does seem to be a consistent trend for the E/transition horizon. Deeper in the soil, there is no difference in TOC as a function of straw management system.

Further information on the variation of C content within treatments is given by the data in Table 4. Duncan's New Multiple Range Test (Peterson, 1985), when applied to the set of 8 site means across both treatments, permits a comparison of mean C values within and between treatments of the same soil horizon and determination of significant differences between each pair of means. These comparisons show whether the overall treatment mean is influenced to

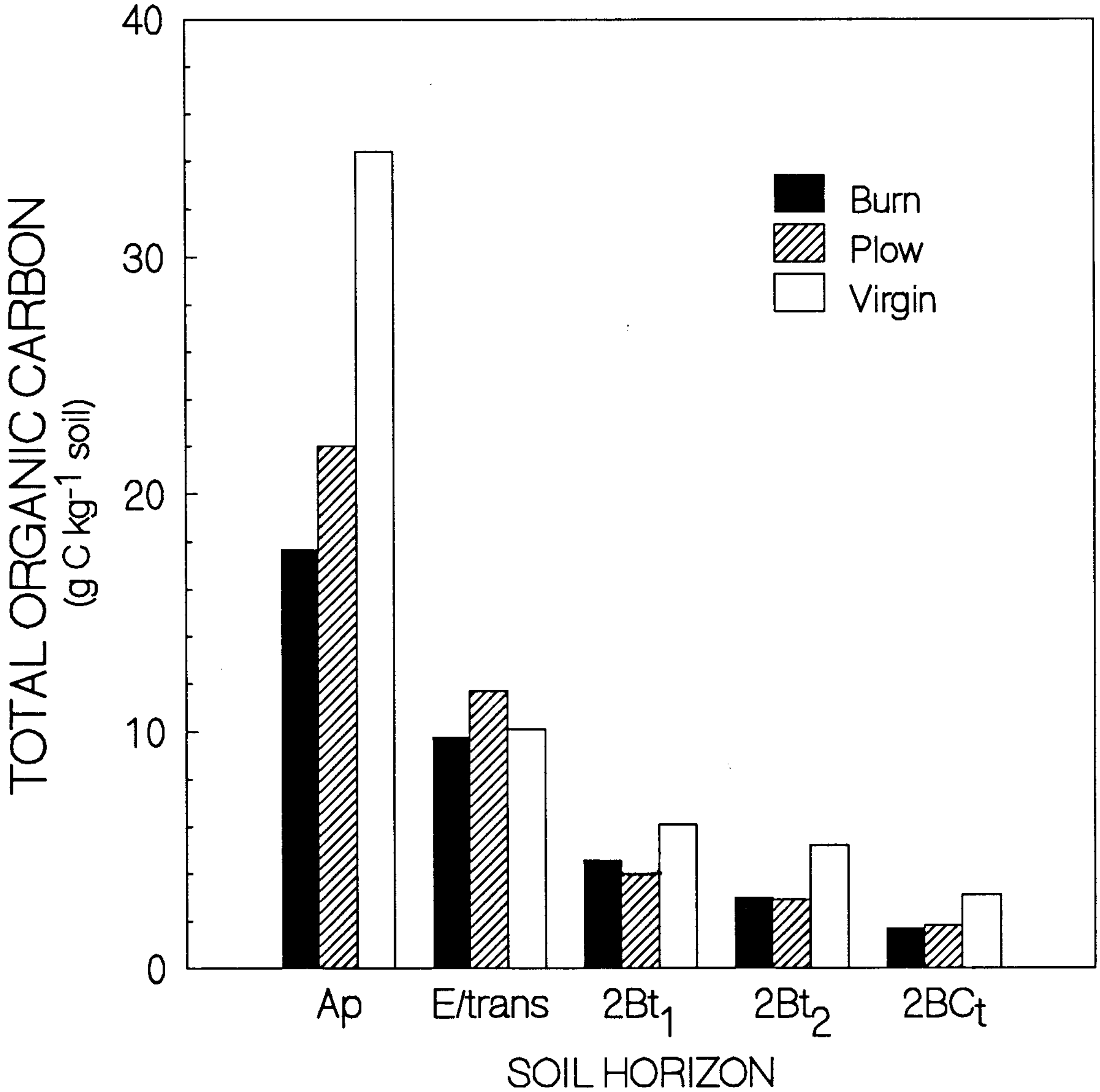

Figure 1. Comparison of total organic carbon content and distribution between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 3. Effect of straw residue management on total soil organic carbon content and distrubution (n=16).

Residue Management	Ap (0-17cm)	Soil Horizon[a] (Depth in cm) E/trans (17-40cm)	2Bt$_1$ (40-60cm)	2Bt$_2$ (60-75cm)	2BCt (85-120)
		---------- (g C kg^{-1} soil) ----------			
Burn	17.7^B	9.8^A	4.5^A	3.0^A	1.7^A
Plow	22.0^A	11.7^A	4.0^A	2.9^A	1.8^A
SE$^\dagger_{6df}$	1.0	1.52	1.45	0.35	0.32

[a] Values within the same soil horizon followed by different letters are significantly different at the 0.05 probability level.
[†] Standard error of treatment mean.

approximately the same extent by all four sites, or whether one site appears to be an outlier. They also show the extent to which sites having different treatments have similar C values, even though the overall treatment means may be statistically significant.

The data in Table 4 show that mean TOC values in Ap horizons of burned sites 1, 3 and 4 are similar, and that site 2 has a mean value significantly different only from site 3. For the plowed treatment, sites 5, 6, and 7 have similar TOC values, but site 8 has significantly lower TOC. As a result, the mean TOC value for plowed site 8 cannot be distinguished from the mean TOC value of any of the burned sites. Overall, however, TOC values for burned sites are consistently lower than TOC values for plowed sites, which is statistically significant overall.

Table 4. Comparison of mean total organic carbon values among all sites sampled using Duncan's new multiple range test (*n*=4).

Residue Mangmt	Site	Ap (0-17)	E/trans (17-40)	$2Bt_1$ (40-60)	$2Bt_2$ (60-75)	2BCt (85-120)
		Soil Horizon[a] (Depth in cm)				
		---------- ($g\ C\ kg^{-1}$ soil) ----------				
Burn	1	16.8 CD	7.2 D	3.9 CD	2.4 C	1.6 BC
Burn	2	19.9 BC	12.9 B	5.3 A	3.8 A	2.3 AB
Burn	3	16.6 D	10.8 BC	3.8 CD	2.5 BC	1.2 C
Burn	4	17.5 CD	8.4 CD	4.6 AB	3.4 ABC	1.8 ABC
Plow	5	23.2 A	7.5 D	2.8 D	2.2 C	1.0 C
Plow	6	22.2 AB	12.5 B	3.5 CD	2.5 BC	1.2 C
Plow	7	24.4 A	15.8 A	5.3 A	3.1 ABC	2.2 AB
Plow	8	18.6 CD	11.2 BC	4.2 B	3.7 AB	2.6 A
	$SE^{‡}_{24\ df}$	0.92	0.92	0.87	0.38	0.31

[a] Values within the same soil horizon followed by different letters are significantly different at the 0.05 probability level according to Duncan's new multiple range test.

† Standard error of site means.

Each of the other horizons below the Ap, excluding $2Bt_2$, has similar mean TOC values at burned sites 1 and 4. However, for each of the horizons below the Ap, excluding $2Bt_1$, mean TOC values at burned sites 2 and 3 are significantly different both from those at sites 1 and 4 and from each other. Data for the plowed treatment show no consistent trend for any horizon below the Ap with few significant differences.

Although cultivation and cropping decrease TOC, possible reasons for the observed difference between the burned and plowed treatments merit further consideration. The question is whether burning simply brings about a greater loss of C than plowing, or whether plowing straw residues into the soil has actually increased C levels above those that would have been found had the residues been continually burned. Data from this study alone are not adequate to answer this question, but these data, coupled with those from other studies in the Willamette valley and elsewhere, do suggest a plausible explanation.

Soils are dynamic systems, and if a virgin soil is disturbed by cultivation, soil organic carbon levels will adjust to the disturbance. The amount and rate of adjustment depend on factors such as climatic conditions, rates of added organic materials and tillage intensity (frequency of tillage operations, depth of tillage, type of tillage implement used). But in time, if cultivated under the same management system, the rate of soil organic C loss will decrease and stabilize at a new equilibrium level for that system (Rasmussen *et al.*, 1980; Aguilar *et al.*, 1988; Balesdent *et al.*, 1988).

Management systems that incorporate large quantities of organic residues into the soil help maintain original soil organic C levels, and the new equilibrium level may not be much different than the original one. In fact, incorporation of manure, straw residues (Rasmussen *et al.*, 1980; Dick *et al.*, 1988b), sod-like or grass seed crops (Stevenson, 1965; Russell, 1973) may even increase the soil organic C above the original level.

In contrast, management systems for which crop residues are annually burned lead to substantial losses of organic C and N through both volatilization and convection of ash particulate in the smoke. If it were not for burning, these nutrients otherwise would be incorporated into the soil and stabilized into the SOM through natural decomposition processes (McNabb and Cromack, 1990). Thus annual burning of crop residues can lead to accelerated losses of soil organic C and substantial net loss of soil organic C and N from the surface few cm of a soil (Biederbeck *et al.*, 1980; Rasmussen *et al.*, 1980). Under this kind of management, the new equilibrium level for organic C would be expected to be substantially lower than the original level.

The history of grass seed management in the Willamette valley sheds further light on the situation. Burning of grass seed residues began in the early 1940's, when it was discovered as a control measure for "blind seed", a disease that was threatening the very survival of the grass seed industry. Farmers also found that burning helped control weed and pest problems, stimulate seed yields, reduce fertilizer needs and facilitate seedbed preperation (Conklin *et al.*, 1989).

The greatest disadvantage of burning has been public displeasure with smoke from open field burns drifting into populated areas. By the early 1970's, public and political pressure had reached the point where some farmers were beginning to discontinue burning and opt for management systems that incorporated straw residues. This trend has increased to the present day, although there are still a large number of fields that are burned, if not annually every second or third year.

Thus we have 2 sets of histories for the fields investigated in this study (see Table 1). Fields selected to represent the burned treatment have been burned continuously for approximately 50 years. Fields selected to represent the plowed treatment were burned continuously for approximately 30 to 40 years, after which they were managed to incorporate straw residues for the next 10 to 20 years.

Given these histories, the most plausible explanation for the observed difference in TOC between the burned and plowed treatments is that burning reduced TOC to new levels that had reached eqilibrium in all annual ryegrass fields withing the first 30 years of burning. Then, when the management on some of those previouly burned fields was changed to stop burning and start incorporating straw residues, TOC levels began to rise and are moving toward a new equilibrium at a higher level. Thus the significant difference observed between burning and plowing is not due to greater losses from burning but rather shows that organic C levels in the plowed fields are now increasing as a result of a change in management.

Several lines of evidence support this conclusion. First, Dayton is a poorly drained soil, and high water tables, cool temperatures, and reducing conditions all would tend to keep decompositon rates of added residues low for long periods of time. Evidence of this was apparent during field sampling of plowed soils. Concentrations of partially decomposed straw residues from previous years' tillage were visible, both distributed throughout the Ap horizon and in mats located at the interface between the Ap and A_1 or E horizon below. Straw residues like these have been found to be high in lignin and phenolic compounds, which resist microbial decomposition and favor the formation of stable SOM compounds, such as humic acids (Levi-Minzi *et al.*, 1990).

Second, data from Laurent (1979) corroborate this hypothesis. Laurent measured organic C in samples of Dayton and several associated soils taken in both 1965 and 1975. He found that TOC levels in soils continually cultivated to annual ryegrass and burned annually for approximately 35 to 40 years had essentially stabilized. In some cases he noted small increases in TOC from 1965 to 1975, which he attributed to increases in root biomass brought about by high levels of nitrogen fertilizers. Laurent (1979) concluded that grass seed is a crop that helps maintain a relatively constant level of soil organic C.

Finally other studies have shown that incorporation of straw residues into the soil increases organic C levels over pre-study levels attained under a burned management system (Gotoh *et al.*, 1984; Skidmore *et al.*, 1986; Powlson *et al.*, 1989). Powlson's *et al* (1989) results also provide evidence that long-term incorporation of crop residues into the soil, rather than burning them, increases the quantity of mineralizable C.

In summary, the collective evidence suggests that cultivation does reduce soil organic C to new equilibrium levels, substantially lower than in virgin, uncultivated soils. Incorporation of straw residues for the past 10 to 20 years after burning for 30 to 40 years has increased soil organic C to levels that are significantly higher in the surface horizon than in the continually burned soils. These new levels may still be lower than in the original, native soil, but we don't know whether the new levels have yet reached their new equilibrium value.

Total Nitrogen

Patterns of distributions of total N (Figure 2; Table 5) parallel very closely those for TOC. This is an expected result because of the close relationship between soil organic C values and soil N values. The decrease in N with depth is also an expected result. The mean N content of the Ap horizon of the plowed sites was higher than for the burned sites, but perhaps because of small sample size, natural variability of soils, and natural variability in the N content of soil organic matter, this difference was not statistically significant.

The data in table 6 show that there are no horizons or treatments that appear to be outliers from any site. One exception is the E/transition horizon at plowed site 8, which had significantly greater total N than all the other sites of the E/transition horizon. This obviously affected the overall mean total N value for the plowed management system.

As with organic C, soil N content for the surface horizon of cultivated soils is less than the total N content of the virgin soil (Figure 2). This, too, is an expected result. Reasons for this observation include increased microbial degradation of soil organic matter following tillage, losses due to leaching of mineralized nitrogen, erosion, and denitrification. In time, however, assuming the soil management system remains the same, the rates of N loss can be expected to decline and reach a new equilibrium level (Biederbeck *et al.*, 1980; Rasmussen *et al.*, 1980).

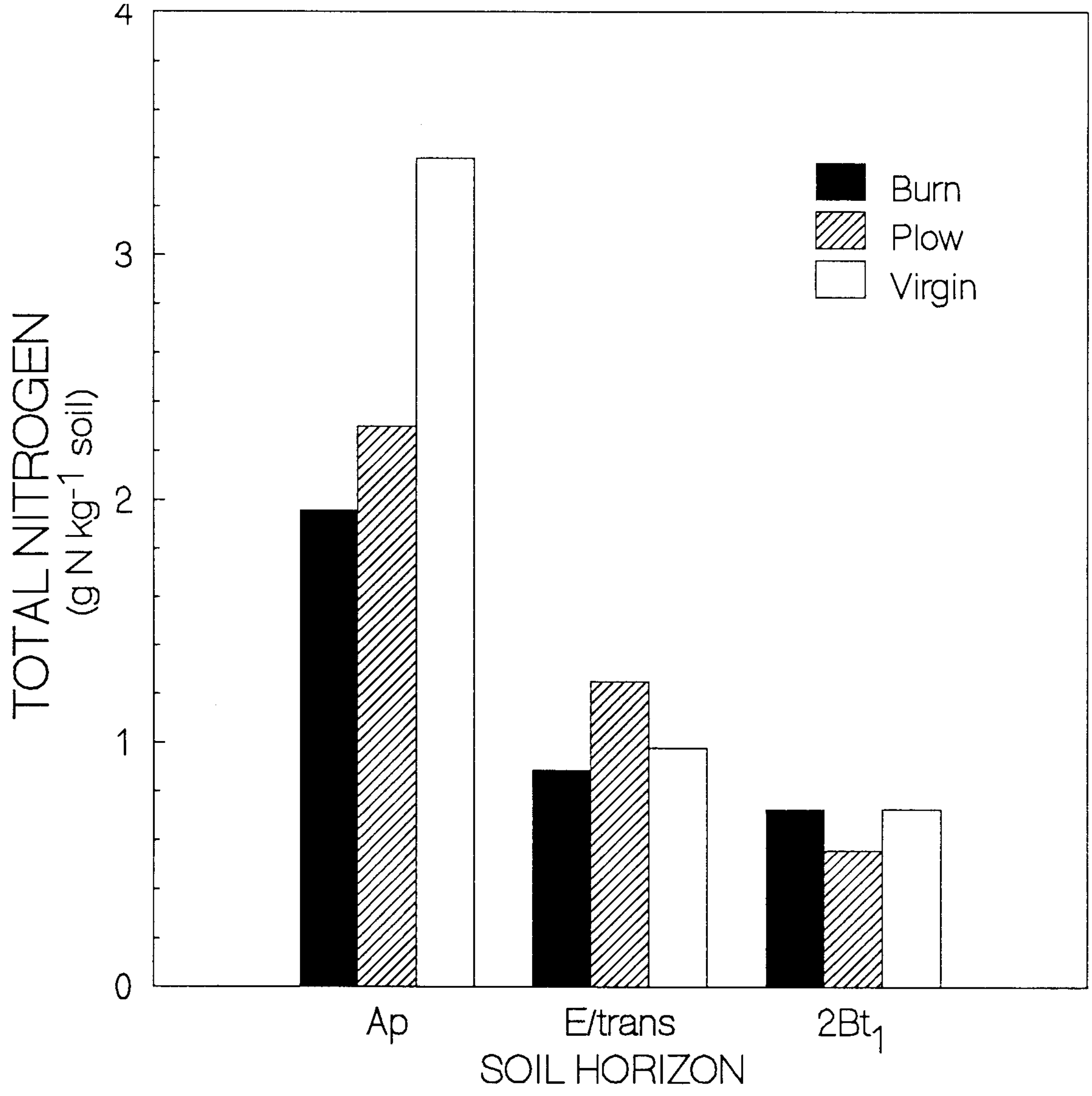

Figure 2. Comparison of total nitrogen content and distribution between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 5. Effect of straw residue management on soil nitrogen content and distribution (n=16).

Residue Management	Soil Horizon[a] (Depth) Ap (0-17cm)	E/trans (17-40cm)	$2Bt_1$ (40-60cm)
	(g N kg^{-1} soil)		
Burn	2.0^A	0.9^A	0.7^A
Plow	2.3^A	1.3^A	0.6^A
SE$^{\dagger}_{6df}$	0.14	0.17	0.06

[a] Values within the same horizon followed by different letters are significantly different the 0.05 probability level.
† Standard error for treatment mean.

Laurent's (1979) comparative study of Dayton and other soils used for annual ryegrass production suggest that new equilibrium levels for total N had already been reached by 1965, and that 10 years later the total N content was actually significantly higher than it had been. Carryover of fertilizer N was not considered the cause of this increase because of its susceptibility to leaching. Rather the increase was attributed to organic N associated with an increased soil biomass, a result that is consistent with soil organic C trends over the same time period.

Table 6. Comparison of mean total nitrogen values among all sites sampled using Duncan's new multiple range test ranks (n=4).

Residue management	Site	Soil Horizon[a] (Depth in cm) Ap (0-17)	E/trans (17-40)	2Bt[1] (40-60)
		---------- ($g\ N\ kg^{-1}$ soil) ----------		
Burn	1	1.7 D	0.8 B	0.7 AB
Burn	2	2.2 ABC	1.0 B	0.8 A
Burn	3	2.0 CD	0.8 B	0.6 AB
Burn	4	2.0 CD	1.0 B	0.7 AB
Plow	5	2.5 AB	1.0 B	0.5 AB
Plow	6	2.1 BCD	1.1 B	0.7 AB
Plow	7	2.6 A	1.0 B	0.4 B
Plow	8	2.0 CD	2.0 A	0.6 AB
	$SE^{‡}_{24\ df}$	0.13	0.24	0.15

[a] Values within the same horizon followed by different letters are significantly different at the 0.05 probability level according to Duncans new multiple range test.
‡ Standard error for site means.

Both Laurent (1979) and Stevenson (1965) conclude that the total N levels in poorly drained Dayton soils can be maintained and perhaps increased under a sod-like crop such as annual ryegrass. The data in Table 6, when compared to Laurent's data, support this conclusion. Laurent reports a mean total N content of Dayton soils used for ryegrass production and burned annually of 1.3 g N kg^{-1} soil.

Soil C:N Ratios

The mean C:N ratios for both the virgin and cultivated soils are given in Table 7. The data indicate that cultivation of a virgin soil has reduced the C:N ratio for the Ap horizon. These results are consistent with other studies that have shown a decrease in soil C:N ratios with cultivation. This decrease is associated with the decomposition of the virgin SOM and the formation of new, more humified SOM products, proportionally lower in TOC than the original SOM (Laurent, 1979; Aguilar and Heil, 1988).

Soil C:N ratios typically decrease with depth. A decrease in the C:N ratio with depth is indicative of a change in the subsoil organic matter composition. Subsoil organic matter is proportionally lower in TOC and has an increased resistance to microbial decomposition as compared to surface SOM (Soudi *et al.*, 1990). Narrower C:N ratios may also result from an increase in mineral-nitrogen occurring with depth (Young, 1962; Laurent, 1979). In the subsoil, mineral-nitrogen

Table 7. The effect of straw residue management on soil C:N ratios (n=16). Values reported are units of carbon per unit of nitrogen.

	(Depth)		
Residue Management	Ap (0-17cm)	E/trans (17-40cm)	$2Bt_1$ (40-60cm)
Burn	9.1	11.1	6.3
Plow	9.8	11.7	5.9
Undisturbed	10.1	10.5	8.8

in the form of NH_4^+ present in the interlayer position of 2:1 type clay minerals may account for > 30% of the total N in comparison to the surface soil mineral N that accounts for 10% of the total N (Keeney and Nelson, 1982).

The data in Table 7 show smaller soil C:N ratios for the $2Bt_1$ horizon than the Ap horizon for both the virgin and cultivated soils, but C:N ratios increased from the Ap to the E/transition horizon in both cultivated soils, when compared to the virgin soil.

Possible reasons for the increase in the C:N ratios for the E/transition horizons include lateral leaching of inorganic N from the E/transition horizon due to the clayey impermeable $2Bt_1$ horizon,small sample size, and the high variability in the data.

Soil C:N ratios for the Ap and $2Bt_1$ horizons of the burned treatment are slightly lower than those of the plowed treatment. These results are inconsitent with the results of both Rasmussen *et al* (1980) and Powlson *et al* (1989), which showed an increase in the surface soil C:N ratios as a result of straw residue burning in comparison to incorporation of straw residues. Rasmussen *et al* (1980) and Powlson *et al* (1979) attributed the wider C:N ratios to an accumulation of carbonized C, which is relatively inert and has little bioavailability, in the Ap horizon due to the annual incorporation of the ash residues into the soil by tillage.

For the present study, ash residues were incorporated into the soil by tillage on an average of every 4 to 5 years. Without mechanically mixing the ash into the soil, the ash residues left on the soil's surface are susceptible to loss by wind and surface runoff. Therefore, the ash residues probably had less effect on soil C:N ratios than in the studies reported by Rasmussen *et al* (1980) and Powlson *et al* (1989).

During a burn, there is a transformation of the straw residue organic N to inorganic N, which then may be translocated in convection currents, increasing the inorganic N content in the soil (DeBano and Conrad, 1978). This increase however, is considered temporary because of its susceptibility to leaching. Therefore, the accumulation of post-burn inorganic N is minimal compared to the total N content of most soils and would also have a mimimal effect on the soil C:N ratios (McNabb and Cromack, 1990).

For the reasons mentioned above, it may be assumed that burning of crop residues has a minimal affect on the soil C:N ratios. Therefore, the most plausible explaination for the observed difference in the C:N ratios of soils under burned and plowed management systems is that incorporation of staw residues into the soils favors the formation of SOM with wider C:N ratios in comparison to SOM stabilized under the burned management system.

Laurent's (1979) comparative study of Dayton and other soils used for annual ryegrass production support this conclusion. His results suggest that soil C:N ratios had already stabilized by 1965. Straw residues have a wide C:N ratio (approximately 50:1 to 100:1) and a high content of lignin-cellulose complexes resistant to microbial degradation (Levi-Minzi *et al.*, 1990). Under the reducing conditions of Dayton soils, the naturally slow decomposition of straw residues may be further inhibited, resulting in an accumulation of partially decayed straw residues and SOM high in C relative to N (Levi-Minzi *et al.*, 1990).

The data in Table 7 also agree with the results of Gotoh *et al* (1984) and Allison and Killham (1988), who conluded that C:N ratios of soils are increased under management systems that incorporate straw residues into the soil in comparison with management systems that remove straw residues. Allison and Killham (1988) also showed that an increase in the biomass C:N ratio was significant in soils for which straw residues were annually incorporated into the soil in comparison to mechanically removed.

Soil Respiration Expressed on a Per Gram Soil Basis

CO_2-C evolution from soil respiration was used to evaluate the effects of soil management on soil microbial activity and on mineralizable C content. The total amount of CO_2-C evolved during any laboratory incubation represents both a portion of the total amount of mineralizable C in the soil sample and a portion of the organic C mineralized during the incubation period. Microorganisms use carbon compounds for biosynthesis, and the portion of C assimilated is not accounted for by measuring CO_2-C evolved.

For this laboratory study it was assumed that the microbial inoculum potential of soil prepared in the laboratory (air dried and sieved) is not limiting to the mineralization rate, regardless of soil treatment. Air drying of soils does cause microbial activity and biomass to be reduced by > 80% of the original levels, but rewetting of the soils restores their original levels within 7 days (Gupta and Germida, 1989).

Distributions of total CO_2-C evolved during a 32 day incubation period, on a per gram soil basis, for burned, plowed and virgin soils are summarized in Figure 3. The corresponding statistical data for burned and plowed soils are summarized in tables 8 and 9. The patterns of distributions of the total amount of CO_2-C evolved during the 32 day incubation period (Figure 3) parallel closely those of TOC and total N content distributions.

Figure 3 indicates that the total CO_2-C evolved was markedly lower in the surface horizon of the cultivated soils, regardless of management. These results support Laurent's (1979) conclusion that cultivation of Dayton and several other associated soils in the Willamette valley has resulted in a net reduction of the labile soil organic C fraction. Using chemical SOM fractionation procedures, Laurent showed that soluble C, soluble N and the humin fraction had been reduced with cultivation, indicating that a greater humification of the SOM had taken place under cultivation. It was not determined if burning was a contributing factor in the differences Laurent detected.

Figure 3 clearly shows that microbial respiration decreases with soil depth. This is typical of most soils, not only because of a decrease in the TOC, total N, microbial population and rates of 0_2 diffusion, and because of a change in the SOM composition with depth. This change is generally associated with an increase in the humic:fulvic acid ratios (humic acid is relatively more polymerized than fulvic acid, and therefore at a more advanced stage of humification) and an increase in resistance to microbial degradation (Shoenau and Bettany, 1987).

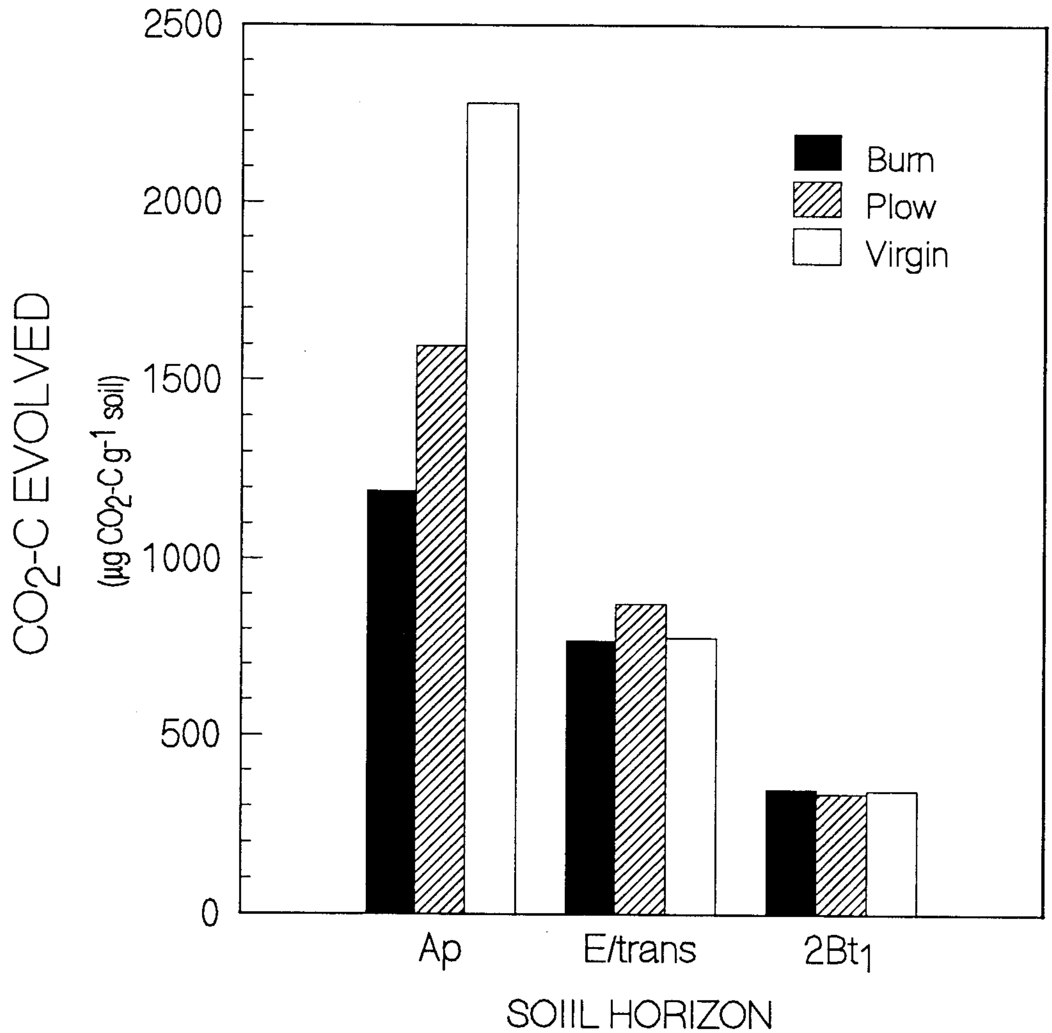

Figure 3. Comparison of total CO_2-C g^{-1} soil evolved from microbial respiration during a 32 day incubation period between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 8. Effect of straw residue management on the total amount of CO_2-C evolved g^{-1} soil from microbial respiration during a 32 day incubation period (*n*=16).

Residue Management	Soil Horizon[a] (Depth) Ap (0-17cm)	E/trans (17-40)	$2Bt_1$ (40-60cm)
	(μg CO_2-C g^{-1} soil)		
Burn	1193^B	773^B	351^B
Plow	1598^A	873^B	337^B
$SE^{\dagger}_{6\ df}$	78	123	41

[a] Values within the same horizon followed by different letters are significantly different the 0.10 probability level.
† Standard error for treatment mean.

The total amount of CO_2-C evolved during the 32 day incubation period was significantly greater ($p < 0.10$) for the Ap horizon of the plowed soil than the burned soil (Table 8). Differences in mean CO_2-C evolved were not significant for the E/transition horizon, although there was evidence of slightly higher amounts evolved from the plowed soils. There was no difference in CO_2-C evolution as a function of straw management system for the $2Bt_1$ horizon.

Variability among the mean site CO_2-C evolution values within the same treatment (Table 9) was low for both the Ap horizon and the $2Bt_1$ horizon. The mean plowed site CO_2-C values for the Ap horizon were consistently higher than the burned site means, and in agreement with the statisical analysis

Table 9. Comparison of mean total CO_2-C evolved g^{-1} soil from mircrobial respiration during a 32 day incubation period among all sites sampled using Duncan's new multiple range test ranks (n=4).

		Soil Horizon[a] (Depth in cm)		
Residue management	Site	Ap (0-17)	E/trans (17-40)	$2Bt_1$ (40-60)
		(μg CO_2-C g^{-1} soil)		
Burn	1	1039 D	622 D	293 B
Burn	2	1360 BCD	1018 B	330 B
Burn	3	1246 CD	740 CD	289 B
Burn	4	1126 D	701 CD	492 A
Plow	5	1536 ABC	535 D	255 B
Plow	6	1389 BCD	884 BC	322 B
Plow	7	1788 A	1320 A	385 AB
Plow	8	1677 AB	753 CD	387 AB
	$SE^{‡}_{24\ df}$	113	77	41

[a] Values within the same horizon followed by different letters are significantly different at the 0.05 probability level according to Duncan's new multiple range test.

‡ Standard error for site means.

of treatment effects. Variability of the site means within the same treatment for the E/transition horizon was high. The mean for burned site 2 was significantly greater than for each of the other burned sites. The mean for plowed site 7 was markedly greater than for any of the other sites, burned or plowed.

The trends in CO_2-C evolution as affected by straw management system were consistent with those of TOC and total N contents. This would be expected because of the close relationship between microbial activity, C mineralization and the levels of soil organic C and total N (Myrold, 1979).

Mineralization of organic C, using CO_2 evolution from soil respiration as an index, has been found to be reasonably well described by first-order rate kinetics, meaning that the amount of C mineralized is linearly proportional to the soil organic C content (Allison and Klein, 1962; Alexander, 1977; Myrold, 1979; Paul and Clark, 1989). Thus, during a laboratory incubation, evolution of CO_2-C from microbial respiration should typically be greater for a particular soil higher in total organic C and total N content.

These results support previous studies on the effects of straw residue incroporation on the mineralizable C content of soil that had been previously burned annually. Powlson *et al* (1989), Allison and Killham (1988) and Ocio *et al* (1991) showed that both microbial biomass and CO_2-C evolution from microbial respiration are stimulated by an increase in the readily available organic C content of soils due to straw residue incorporation.

These increases mean more mineralization of soil organic C, which should increase the soil's potential to cycle and provide nutrients for plant growth. A potential agronomic significance of an increase in organic C mineralization is a reduction in fertilizer applications (Powlson *et al.*, 1989; Sikora and Mccoy, 1990; Ocio *et al.*, 1991). For example, Powlson *et al* (1989) showed that an increase in N mineralization by 40 to 50%, coupled with an increase in C mineralization for a straw treated soil over the burn treated soil during a laboratory incubation period of 60 days, was equivalent to more than 20 kg N ha^{-1}.

Burning of crop residues in the field can also cause rapid soil desiccation and permanently reduce microbial populations and microbial activity by greater than 50% in the surface 2.5 cm of soils if not annually tilled (Beiderbeck *et al.*, 1980). However, the present study was not designed to sample and analyze separately the top 2.5 cm of the soil. The surface soil samples were collected from the entire depth of the Ap horizon (approximately 15 to 19 cm), air dried, sieved and thoroughly mixed. Because of the fast growth rates of the soil biomass, which would allow for a rapid re-inoculation of any portion of the soil that had been sterilized from burning, it is possible that any direct effects of burning on the soil microflora in the top 2.5 cm of the soil were completely masked by analyzing the entire Ap horizon. Had the surface few cm of soil been tested separately, it is possible that significant differences in CO_2-C evolution between the two management systems could have been detected.

Enzyme Activity Expressed on a Per Gram Soil Basis

Soil enzyme activity (β-glucosidase) was also used as an index to evaluate the effects of straw management practice on microbial growth and activity. The assay method used (Eivazi and Tabatabai, 1988) for this study provides an indirect measurement of the maximum potential of β-glucosidase activity.

Distributions of β-glucosidase activity expressed on a per gram soil basis under burned, plowed and virgin soils are summarized in Figure 4. The corresponding statistical data for burned and plowed soils are summarized in Tables 10 and 11. The trends of enzyme activity data parallel closely those of TOC, total N and CO_2-C evolved from soil respiration. The data in Figure 4 indicate that enzyme activity has been markedly lowered in surface horizons of cultivated soils, regardless of management. The data also clearly show that enzyme activity decreases with soil depth.

Straw management system had a significant impact on the soil enzyme activity potential (Table 10). β-glucosidase activity was significantly greater ($p < 0.10$) in the Ap horizon of soils for which straw residues have been incorporated annually. There were no consistent trends in enzyme activity for the E/transition horizon. In contrast, enzyme activity was significantly greater ($p < 0.10$) in the $2Bt_1$ horizon of the burned soils than the plowed soils.

The data in Table 11 show that the mean enzyme activities for the burned sites of the Ap horizon are similar to each other, and are consistently lower than those of the plowed treatment. Plowed site means 5, 6 and 8 are similar to each other. The mean for plowed site 7 was significantly higher, and appears to have highly influenced the overall treatment mean and the statisitcal analysis of a significant difference in enzyme activity between the burned and plowed soils.

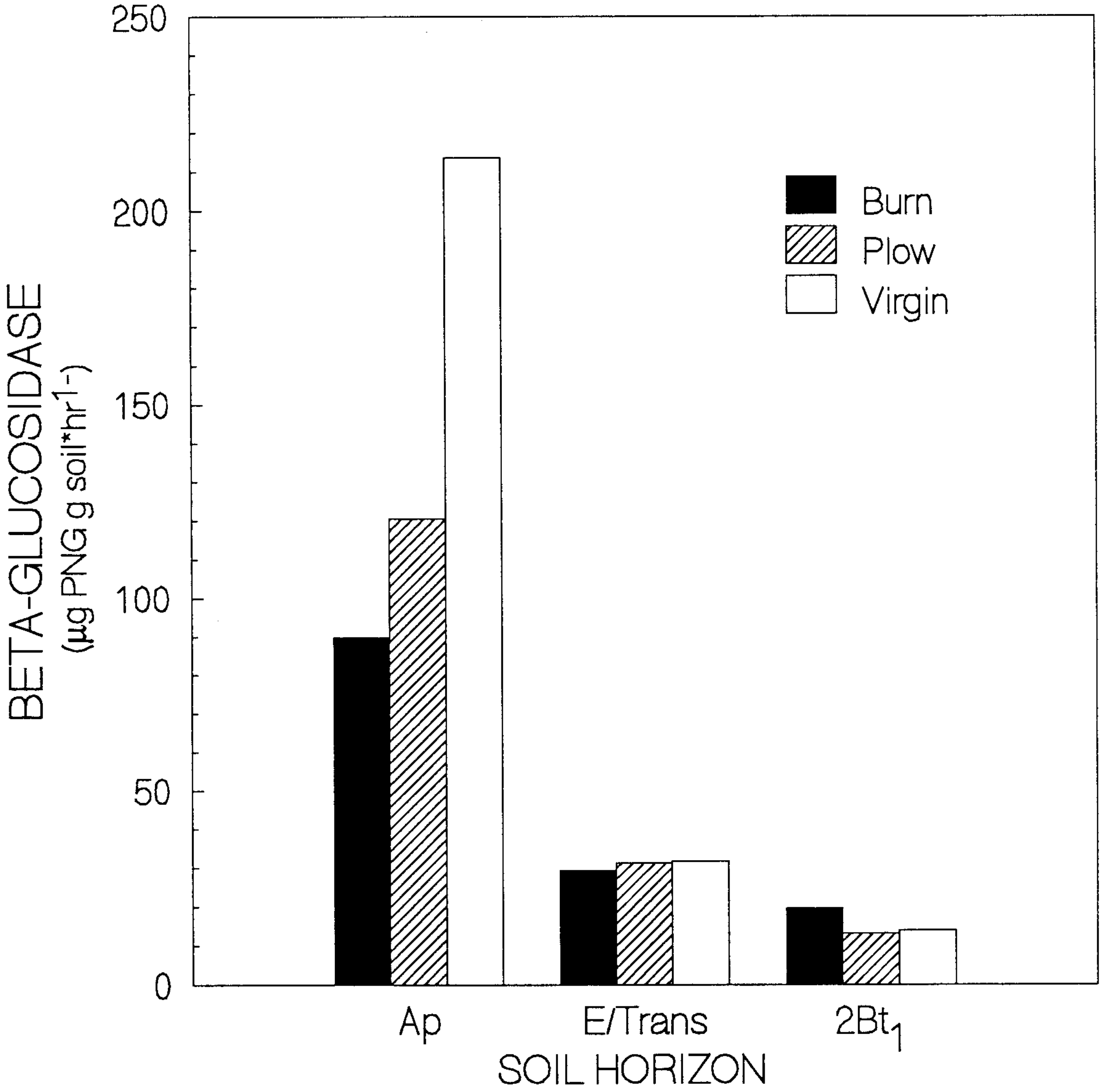

Figure 4. Comparison of β-glucosidase activity g^{-1} soil between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 10. Effect of straw residue management on β-glucosidase activity distributions expressed on a g^{-1} soil basis.

Residue Managememt	Ap (0-17cm)	E/trans (17-40cm)	$2Bt_1$ (40-60cm)
	Soil Horizon[a] (Depth in cm)		
	------------------- (μg PNG g^{-1} soil hr^{-1}) -------------------		
Burn	90.0^{B}	29.5^{B}	20.0^{A}
Plow	120.3^{A}	31.4^{B}	13.2^{B}
$SE^{\dagger}{}_{6df}$	10.4	5.5	2.2

[a] Values within the same horizon followed by different letters are significantly different the 0.10 probability level.
† Standard error for treatment mean.

Variability of the site mean values of enzyme activity within the burned treatment for the horizons below the Ap was low in comparison to the plowed site means, which were highly variable. Plowed site 7 mean for the E/transition horizon was significantly greater than any of the other sites, burned or plowed. However, plowed site 5 mean for the E/transition horizon was significantly lower than plowed sites 6 and 7, and all of the burned sites. Plowed site 5 mean for the $2Bt_1$ horizon was significantly lower then plowed sites 7 and 8, and all of the burned sites.

Because of the strong relationship between β-glucosidase activity and levels of soil organic C, total N, and microbial biomass and microbial respiration as measured by CO_2-C evolution (Frankenberger and Dick, 1983; Dick *et al.*, 1988b), higher enzyme activities observed in the Ap horizon of the plowed soils than in the

Table 11. Comparison of mean enzyme activity among all sites sampled using Duncan's new multiple range test ranks (n=4).

Residue management	Site	Soil Horizon[a] (Depth in cm) Ap (0-17)	E/trans (17-40)	2Bt$_1$ (40-60)
		(μg PNG g^{-1} soil)		
Burn	1	73.2 C	28.3 B	20.4 AB
Burn	2	98.4 BC	29.5 B	17.1 AB
Burn	3	93.7 BC	30.6 B	24.6 A
Burn	4	94.7 BC	29.6 B	15.5 AB
Plow	5	119.5 B	15.0 C	6.5 C
Plow	6	94.5 BC	29.8 B	12.4 BC
Plow	7	157.7 A	52.5 A	15.6 B
Plow	8	109.5 B	25.1 BC	18.1 AB
	SE[‡] 24df	9.2	3.8	2.8

[a] Values within the same horizon followed by different letters are significantly different at the 0.05 probability level according to Duncan's new multiple range test.

[‡] Standard error for site means.

burned soils were expected. These results also support those of other studies that have shown that the incorporation of straw residues increases the mineralizable C and N content of soils and also causes an associated increase in both microbial biomass and enzyme synthesis and activity (Verstraete and Voets 1977; Dick, 1983; Reganold *et al.*, 1987; Dick *et al.*, 1988b).

In summary, the trends of enzyme activity as affected by management system were consistent with those of soil organic C and total N contents and CO_2-C evolution from microbial respiration. The enzyme activity results indicate that the annual incorporation of straw residues into the soil has increased the level of biological activity in the Ap horizon in comparison to soils under the burned management system. As with an increase in soil respiration, an increase in the enzyme activity may also signify an increase in the potential of soils to cycle and provide nutrients for plant growth (Dick *et al.*, 1988b).

Soil Respiration Expressed on a Per Gram Carbon Basis

There has been concern that long-term burning of crop residues causes the volatilization of active or bioavailable C compounds, which serve as important energy sources for microbial activity, and results in a build-up of biologically inert or recalcitrant C derived from the crop residue ashes (Rasmussen *et al.*, 1980; Powlson *et al.*, 1989). A decrease in the soil bioavailable C pool, or an increase in recalcitrant C, may not be apparent from the differences in TOC content between the virgin and cultivated soils, or between soils under different long-term management systems (Dalal and Mayer, 1986a). Nonetheless a decrease in bioavailabile C could affect the soil fertility status by reducing the microbial activity and therefore, C mineralization and nutrient cycling (Sikora and McCoy, 1990).

The total amount of CO_2-C evolved during the 32 day incubation period, when expressed on a per gram carbon basis, provides an index for the relative amount of the total soil organic C that is bioavailable. In theory, if water content and temperature could be held constant, a reduction in the proportion of the bioavailable C fraction (the readily decomposable fresh plant residues, root exudates, microbial C and water soluble C), or an increase in the proportion of recalcitrant material or carbonized C relative to the total C pool, would reduce the amount of CO_2-C evolved when expressed on a per gram carbon basis (White, 1986). This assumption should be valid unless a greater proportion of C is immobilized into the microbial biomass for one soil system than for another soil system.

Distributions of CO_2-C evolved, expressed on a per gram carbon basis, under burned, plowed and virgin soils are summarized in Figure 5. The corresponding statistical data for burned and plowed soils are summarized in tables 12 and 13.

There were no differences in the mean CO_2-C evolution g^{-1} C values between the plowed and burned soils for any of the horizons (Table 12). Site means (Table 13) are relatively consistent except for somewhat higher values in the Ap horizon of plowed site 8 and the $2Bt_1$ of burned site 4. Even these anomalies, however, did not influence their respective means enough to create siginficant differences.

The data in Figure 5 indicate that cultivation has had no effect on the bioavailability of organic C in the Ap and E/transition horizons. There does appear to be a large difference in the $2Bt_1$ horizon, for which there is no good explaination. The data also indicate that there is no difference between burned and plowed treatments and suggest a slight increase in the bioavailability of organic C with depth. These results are inconsistent with other studies. Typically cultivation of a virgin soil not only results in a net loss of soil organic C, but the greatest proportion of that loss occurs in the readily decomposable fraction of the organic C (e.g. soluble C and the humin SOM fraction) relative to the total organic C pool (Laurent, 1979; Dalal and Mayer, 1986a; Balesdent *et al.*, 1988). Typically, when straw residues are incorporated

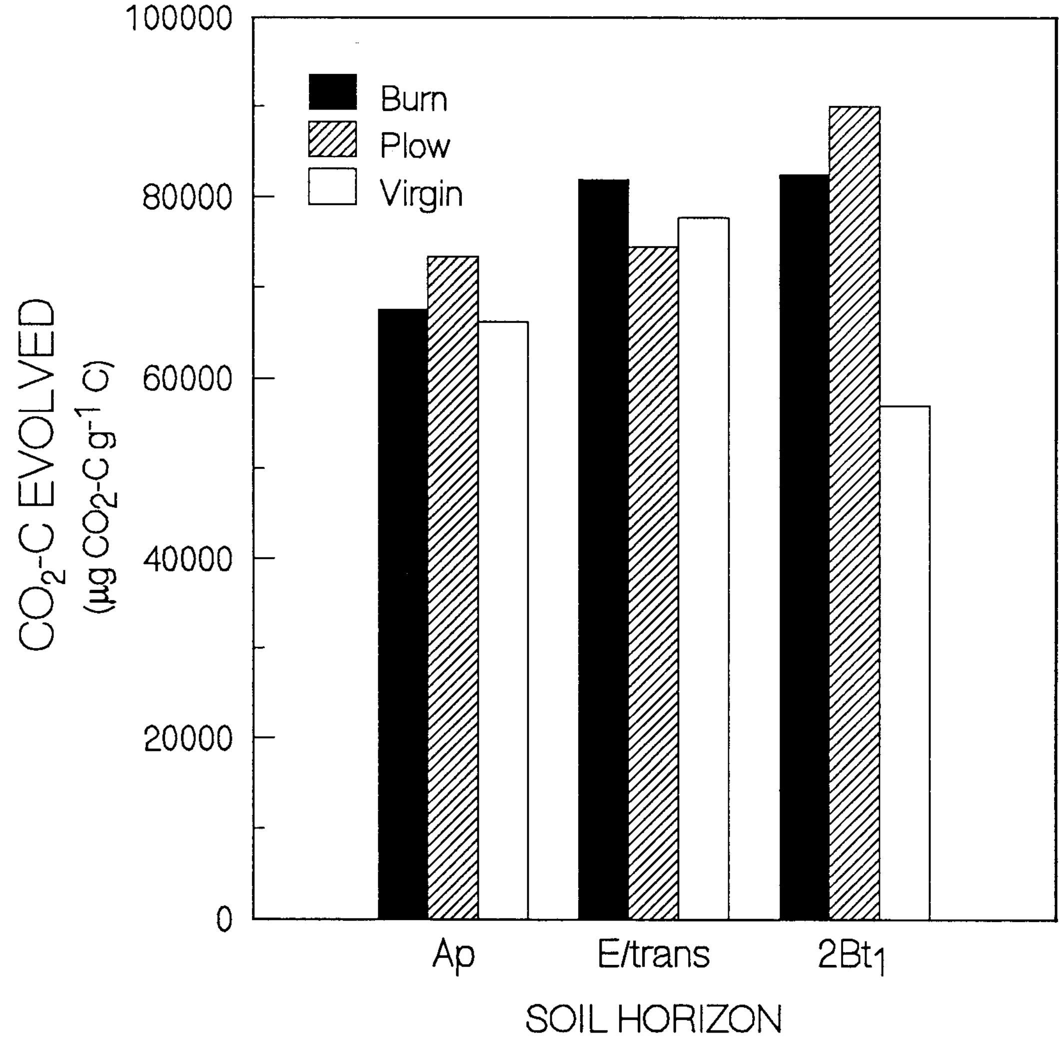

Figure 5. Comparison of total CO_2-C g^{-1} carbon evolved from microbial respiration during a 32 day incubation period between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 12. Effect of straw residue management on the total amount of CO_2-C evolved g^{-1} C during a 32 day incubation period from soil microbial respiration.

	Soil Horizon[a] (Depth in cm)		
Residue Management	Ap (0-17cm)	E/trans (17-40)	$2Bt_1$ (40-60cm)
	(μg CO_2-C g^{-1} C)		
Burn	67660^A	81937^A	82502^A
Plow	73442^A	74430^A	90052^A
$SE^{\dagger}_{6\ df}$	4743	4554	7955

[a] Values within the same horizon followed by different letters are significantly different the 0.10 probability level.
† Standard error for treatment mean.

annually most of the new organic C and N is associated with the readily available fraction and only a small amount is associated with the stable or microbe-resistant fraction (Shiel, 1986; Powlson *et al.*, 1989; Gotoh *et al.*, 1984). And typically, soil C bioavailability decreases with soil depth because of a change in SOM composition and an increased resistance of SOM to microbial degradation (Shiel, 1986; Paul and Clark, 1989; Soudi *et al.*, 1990).

Several factors may be involved in accounting for these apparent inconsistencies. First, Balesdent *et al.* (1988) concluded that the cropping of a virgin soil to annual ryegrass may help maintain the original proportion of

Table 13. Comparison of mean total CO_2-C evolved g^{-1} carbon from microbial respiration among all sites sampled during a 32 day incubation period using Duncan's new multiple range test ranks (n=4).

Residue management	Site	Soil Horizon[a] (Depth in cm) Ap (0-17)	E/trans (17-40)	2Bt$_1$ (40-60)
		($\mu g\ CO_2$-C g^{-1} C)		
Burn	1	62004 [B]	87250 [A]	75878 [AB]
Burn	2	69034 [B]	79161 [A]	62722 [B]
Burn	3	74932 [AB]	69493 [A]	79538 [AB]
Burn	4	64433 [B]	91845 [A]	111872 [A]
Plow	5	66099 [B]	72721 [A]	94232 [AB]
Plow	6	63158 [B]	71210 [A]	94691 [AB]
Plow	7	74266 [AB]	86470 [A]	77442 [AB]
Plow	8	90248 [A]	67319 [A]	93840 [AB]
	SE‡ $_{24df}$	5768	10012	11774

[a] Values within the same horizon followed by different letters are significantly different at the 0.05 probability level according to Duncan's new multiple range test.

‡ Standard error for site means.

bioavailable C, relative to non-available C, in cultivated systems. The data from this study support that conclusion.

Second, burning would be expected to produce a large amount of recalcitrant C in the ash, which if mixed into the soil, would add a source of carbon that is not bioavailable. But in this study the burned soils were plowed only once on an average of every 4 to 5 years. When ash residues are not mechanically mixed into the soil, but instead are left on the soil surface, they are susceptible to loss by wind and by surface runoff. Because of their hydrophobic nature, it is likely that only a minimal amount of the ash residues not removed by erosive forces, would be leached down through the soil profile in the soil solution (Laurent, 1979; Giovannini and Lucchesi, 1983). For these reasons it is reasonable to find no difference in C bioavailability between the burned and plowed soils.

Third, it is possible that during the incubation period, a greater proportion of the CO_2-C produced was immobilized into the microbial biomass for the plowed treatment than the burned treatment. This would reduce the amount of CO_2-C evolution measured, thereby lessening the difference between the plowed and burned treatments. Griffin (1972) and Allison and Killham (1988) observed a steady increase in the soil biomass size following regular straw incorporation, coupled with an increase in the fungal component relative to the total bacterial component in the Ap horizon.

Fungi are more efficient in the assimilation of CO_2-C into biomass, (i.e. more C incorporated into biomass versus CO_2-C evolved) relative to the bacterial component of the microbial population (Alexander, 1977; Griffin, 1972). If fungi did predominate in the Ap horizon of the plowed treatments, a greater proportion of organic C may have been immobilized relative to the amount evolved as CO_2-C of the plowed treatment than the burned treatment. Therefore, differences in the bioavailability of C between the soil treatments would have been masked (White 1986). Evidence that this change might have taken place in the plowed soil for the study was provided by visual observations of profuse fungal growth in the incubation jars of the plowed treatment during the latter part of the incubation period, while none were observed for the burned soil treatment.

Fourth, experimental error associated with the determination of moisture content used for incubating soils and measuring CO_2-C evolution may explain the anomalous depth distribution. Microbial activity and soil organic C mineralization are highly dependent on the moisture status of the soil (Parr and Papendick, 1978), and the optimal water content that supports maximum microbial activity, and therefore maximum C mineralization, varies with soil texture (Miller and Johnson, 1964).

For this study soil samples from each horizon were air dried, sieved, then brought to field capacity using the procedure described by Klute (1986). This procedure involved the use of estimated soil bulk densities (for other Dayton soil samples--previously determined by the Oregon State University Soil Physics Lab - unpublished data), of 1.05 g cm^{-3}, 1.10 g cm^{-3} and 1.2 g cm^{-3} for the Ap, E/transition and $2Bt_1$ horizons respectively. The gravimetric water contents at field capacity were determined to be approximately 40%, 32% and 45% for the Ap, E/transition and $2Bt_1$ horizons respectively.

An accurate, quantitative calculation of the percent moisture for field capacity for a soil that has been air dried and sieved is difficult to attain. A large amount of error could have been introduced either from the use of estimated bulk densities or during the addition of water to the air dried soils before incubation took place. For example, if the estimated bulk densities for the subsoil samples were less than the actual bulk densities, then the calculated amount of water to add to bring the soils to field capacity would exceed the actual water content at field capacity for those soil samples. Evidence that this occured was provided by the visual observation of soil samples that were progessively wetter from the Ap to the $2Bt_1$ horizons. This may explain the higher CO_2-C evolved from microbial respiration with depth (Parr and Papendick, 1978).

Enzyme Activity Expressed on a Per Gram Carbon Basis

β-glucosidase activity data have also been presented on a per gram C basis to analyze the effects of management system on the bioavailability of soil organic C. It has been assumed that a decrease in the proportion of the bioavailable fraction relative to the total organic C pool, or an increase in the proportion of recalcitrant or carbonized C relative to the total organic C pool, would reduce the amount of enzyme activity potential when expressed on a per gram C basis.

Figure 6 suggests that the bioavailability of the soil organic C in the Ap horizon has been only slightly reduced by cultivation. The difference is slightly more pronounced in the burned soil, but these differences were not statisically significant, and in that regard the data support the interpretations of effects on C bioavailability drawn from the CO_2-C data.

Straw management system had little effect on the bioavailabile soil organic C fraction (Table 14). There were no statistical differences in the mean soil enzyme activity values between the burned and plowed treatment for either the Ap or $2Bt_1$ horizons. However the data do indicate a higher level of C bioavailability and greater biological activity in the horizons below the Ap horizon of the burned

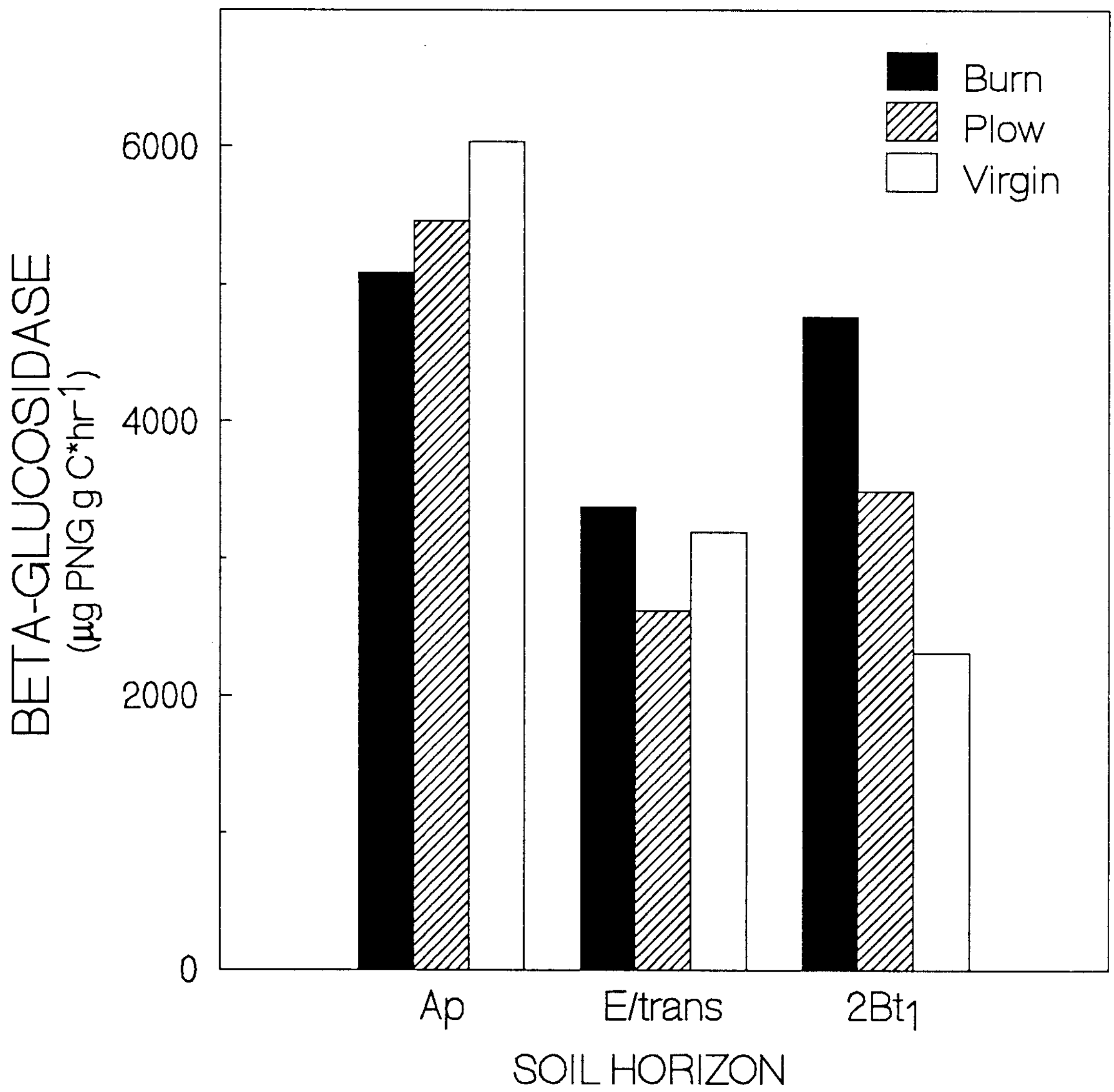

Figure 6. Comparison of β-glucosidase activity g^{-1} carbon between a virgin soil and soils cropped to annual ryegrass under a burned or plowed straw residue management system.

Table 14. Effect of straw management on β-glucosidase activity distributions expressed on a g^{-1} C basis.

Residue Managememt	Ap (0-17cm)	E/trans (17-40cm)	2Bt$_1$ (40-60cm)
	Soil Horizon[a] (Depth in cm)		
	(μg PNG g^{-1} C hr^{-1})		
Burn	5093^A	3381^A	4472^A
Plow	5465^A	2619^B	3496^A
SE$^{\dagger}_{6df}$	338	261	578

[a] Values within the same horizon followed by different letters are significantly different the 0.10 probability level.

† Standard error for treatment mean.

soils in comparison to the plowed soils. The mean enzyme activity value for the E/transition horizon was significantly greater ($p \leq 0.10$) in burned soil than the plowed soil.

Variability of the mean site enzyme activity g^{-1} C values within the same treatment for both the Ap and E/transition horizons was high (Table 15). The means for burned sites 1 and 2 for the Ap horizon were similar to each other, but markedly lower than both of the means for burned sites 3 and 4. The means for plowed sites 5 and 8 for the Ap horizon were similar to each other, but plowed site 7 was markedly higher than each of the other plowed sites and plowed site 6 was significantly lower than the means for plowed sites 7 and 8. For the E/transition horizon, burned site 2 was significantly lower than burned sites 1 and 4, and

Table 15. Comparison of mean enzyme activity g^{-1} C among all sites sampled using Duncan's new multiple range test ranks (n=4).

Residue management	Site	Soil Horizon (Depth in cm) Ap (0-17)	E/trans (17-40)	$2Bt_1$ (40-60)
		---------- (μg PNG g^{-1} C hr^{-1}) ----------		
Burn	1	4330 ^{C}	3972 ^{A}	5224 ^{AB}
Burn	2	4957 ^{BC}	2330 ^{CD}	3415 ^{BC}
Burn	3	5622 ^{ABC}	2956 ^{ABCD}	6604 ^{A}
Burn	4	5462 ^{ABC}	3607 ^{AB}	3535 ^{BC}
Plow	5	5183 ^{ABC}	2074 ^{D}	2303 ^{C}
Plow	6	4313 ^{C}	2455 ^{CD}	3661 ^{BC}
Plow	7	6470 ^{A}	3342 ^{ABC}	3263 ^{BC}
Plow	8	5893 ^{AB}	2601 ^{BCD}	4362 ^{BC}
	$SE^{\ddagger}_{24\ df}$	451	323	645

[a] Values within the same horizon followed by different letters are significantly different at the 0.05 probability level according to Duncan's new multiple range test.
‡ Variability of site mean.

plowed site 5 was significantly lower than plowed site 7. Otherwise the similarity within treatments is high, and the difference in treatment means is large enough to be statistically significant. Although the mean for the $2Bt_1$ horizon for burned site 3 was markedly higher than any of the other sites the overall variability was too high to show any insignificant differences between the treatment means.

These enzyme data are interesting because they are the only data for which there is no significant difference between treatments in the Ap horizon, but there is a significant difference in the subsoil. Data for TOC, CO_2-C evolved g^{-1} soil and enzyme activity on a per g soil basis suggest that the primary effects of straw management differences are manifest in the Ap horizon. There is nothing to suggest that if straw management effects cannot be detected in the Ap horizon, they might still have a significant effect deeper in the soil. It seems reasonable, therefore, to suspect that some factor other than straw management system is responsible for the greater enzyme activity in the E/transition and $2Bt_1$ horizons of the burned treatment in comparison to the plowed treatment. The most likely factor responsible for the observed differences is the soil bulk density of the plowed sites, which has been increased as a result of soil compaction from the frequent use of heavy tillage equipment.

Increased soil bulk density in compacted soils affects soil physical properties by reducing the soil gas and water diffusion rates, soil porosity, and soil permeability. These effects may cause an associated decrease in microbial activity, and therefore enzyme synthesis, in the soil. Bridge and Rixon (1976), Carter (1986) and Neilson and Pepper (1990) reported reduced levels of microbial activity due to compaction of agricultural soils. Dick *et al* (1988b) showed that enzyme activity was significantly reduced in compacted skid trails of a forested soil. Although there are no soil bulk density data in this study to support the assumption that differences in subsoil enzyme activity are due to bulk density differences, the results from these other studies do corroborate this hypothesis.

The trends of CO_2-C evolved g^{-1} C from microbial respiration (Figure 4) do not support this hypothesis, however. The most likely reason for the discrepancy in results between the two biological indices arises from differences between the two laboratory procedures used to determine indices of microbial activity.

The determination of microbial respiration using total CO_2-C evolution depends on a viable, proliferating microbial population in the soil sample during the actual laboratory incubation period. Because disturbed soil samples were used for the laboratory analysis (soil samples were air dried, sieved and thoroughly mixed) it can be assumed that any increase in the soil bulk density of the plowed soils from soil compaction would have been eliminated under the conditions of the laboratory procedure. Therefore any treatment differences in microbial respiration caused by soil compaction in the field (which may be apparent with the analysis of undisturbed soil samples) would not have been detected in this laboratory procedure.

In contrast, the assay of enzyme activity does not depend on a viable, proliferating microbial population. The assay method used for determination of enzyme activity involved the use of toluene to sterilize or inhibit microbial growth and therefore enzyme synthesis during the laboratory analysis (Tabatabai, 1982). Thus the amount of soil enzyme activity depends on the amount of enzymes synthesized and accumulated as free enzymes in the field over the long-term, in addition to enzymes released from lysing of microbial cells present in the soil sample. Soil preparation would have had no effect on the enzyme assay results, so differences due to bulk density could be reflected.

SUMMARY

Soil organic matter is a major factor responsible for soil chemical, physical and biological properties. The content and composition of soil organic matter found within the soil profile both reflect and control the inherent fertility of a given soil. Changes in management systems that alter the addition of organic residues to soils result in readjustments in the soil organic matter contents and properties.

The effects of two straw management systems, annual burning of straw residues and annual incorporation of straw residues into the soil, on the content, distribution and bioavailability of soil organic carbon were evaluated by measuring total organic carbon, total nitrogen, enzyme activity (Beta-glucosidase) and microbial respiration in several horizons of Dayton silt loam (fine, montmorillonitic, mesic, Typic Albaqualf) soil.

Four sites were selected to represent each of the two long-term management systems, burn and plow. Each site had been cropped to annual ryegrass for a minimum of 40 years. The four fields selected to represent the burn management system have been annually burned continuously for a minimum of 40 years. The four fields selected to represent the plow management system were annually burned continuously for approximately 30 years, after which they were managed to have straw residues annually incorporated into the soil for a minimum

of 10 consecutive years. One native site (The Foster Cogswell Preserve) was selected to represent pre-cultivation conditions.

Straw residue management system had a pronounced effect on both the chemical and biological properties measured for the Ap horizon. Soils managed to incorporate straw residues had significantly higher levels of soil organic carbon ($p < 0.05$) for the Ap horizon (0-17 cm depth) than soil managed by burning straw residues. A similar, consistent trend of management effects was evident for the E/transition (17-40 cm depth) and $2Bt_1$ (40-60 cm depth) horizons.

Trends of total nitrogen content, enzyme activity and respiration paralleled closely those of soil organic C levels. The total N content was generally higher for soils under the plowed management system. The C:N ratios were also slightly higher for soils under the plowed management system. Both enzyme activity and respiration, when expressed on a per gram soil basis, were significantly higher ($p < 0.1$) in the plowed soils. When expressed on a per g C basis, however, neither enzyme activity nor microbial respiration were significantly different between burned and plowed treatments. Yet there was a trend towards increasing C bioavailability in the Ap horizon of the annually plowed soils in comparison to the burned soils.

These results, coupled with results from other studies in the Willamette Valley suggest that the differences in the levels of soil organic carbon and related properties observed between the two residue management systems are not due to greater losses of soil organic C as a result of being burned. Rather they suggest that the organic C and N contents, and microbial activity, have increased in the Ap horizon of annually plowed soils as a result of incorporation of straw residues into the soil. Soil organic C bioavailability, however, has not been strongly affected by residue management system.

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APPENDICES

APPENDIX I

Sampling Locations and Soil Profile Descriptions

SITE 1

Soil Series: Dayton silt loam
Location: American Drive Peoria, OR
Soil Survey Legal Description: NE1/4 of SW1/4 Sec 33 T.13 S R.4 W. Linn County
Land Owner/Manager: Tim Van Leuwen
Land Use: Annual Ryegrass
Predominant Management System: Annual Burn

Pedon description

Ap 0 - 19cm. Dark grayish brown(10YR4/2) silt loam; light brownish gray (10YR6/2) dry; common fine faint yellowish brown (10YR5/8) mottles; weak fine subangular blocky structure, slightly hard, friable, slightly sticky and slightly plastic; many fine and very fine roots; many fine irregular pores; clear smooth boundary.

E 19 - 27cm. Grayish brown (10YR5/2) silt loam; light gray (10YR7/2) dry; many medium faint dark yellowish brown (10YR4/6) mottles; moderate medium subangular blocky structure; hard, friable, slightly sticky and slightly plastic; few fine black (10YR2/1)and reddish dark brown (10YR3/3) manganese and iron stains; clear smooth boundary.

BE 27 - 34cm. Grayish brown (10YR5/2) silty clay loam, light brownish gray (10YR6/2) dry; many fine faint yellowish brown (10YR5/6) and brown (10YR4/3) mottles; moderate medium subangular blocky structure; hard, friable, sticky and plastic; common fine and very fine roots; few fine interstitial pores; thin noncontinuous clay skins on ped faces; clear smooth boundary.

$2Bt_1$ 34 - 54cm. Dark grayish brown (2.5Y4/2) silty clay; moderate coarse prismatic structure; very hard, very firm, very sticky and very plastic; common fine black (10YR2/1) manganese stains and concretions; clear smooth boundary.

$2Bt_2$ 54 - 68cm. Dark grayish brown (2.5YR4/2) silty clay; weak medium prismatic structure; very hard, very fire, very sticky and very plastic; few fine roots exped; few very fine tubular pores; common fine black (10YR2/1) manganese stains and concretions; clear smooth boundary.

$2BC_t$ 68 - 91cm. Brown (10YR5/3) silty clay; common fine faint grayish brown (10YR5/2) and yellowish brown (10YR5/4) mottles; weak medium prismatic structure; very hard, very firm, very sticky and very plastic; few very fine and fine roots exped; few fine tubular pores; common fine black (10YR2/1) manganese stains and rounded concretions; thin non-continuous clay films exped; clear smooth boundary.

3C 91 - 134cm. Brown (10YR5/3) silt loam; common fine faint brown (10YR4/3) mottles; massive; firm; sticky and plastic; very few, very fine roots; few fine tubular pores.

SITE 2

Soil Series: Dayton silt loam
Location: Oak Ridge Rd. Peoria, OR
Soil Survey Legal Description: SW1/2 of NW1/4 and NW1/2 of SW1/4 Sec 30 T.13 S R.3W. Linn County
Land Owner/Manager: John Smith
Land Use: Annual Ryegrass
Predominant Management System: Annual Burn

Pedon Description

Ap — 0 - 17cm. light yellowish brown (10YR6/4) silty loam; light brownish gray (10YR6/2) dry; few medium faint dark yellowish brown (10YR4/6) mottles; weak fine subangular blocky structure; slightly hard, very friable, slightly sticky and slightly plastic; many fine roots; common fine tubular pores; clear smooth boundary.

A — 17 - 23cm. Dark grayish brown (10Y4/2) silty loam; common fine distinct dark brown (7.5YR4/4) mottles; moderate fine subangular structure; slightly hard, very friable, slightly sticky and slightly plastic; many very fine and fine roots; common fine and very fine tubular pores; few fine black (10YR2/1) manganese stains and small concretions; clear smooth boundary.

AB — 23 - 29cm. Grayish brown (10YR5/2) silty clay loam; light brownish gray (10YR6/2) dry; few fine faint dark grayish brown (10YR4/2) and dark yellowish brown (10YR4/6) mottles; weak moderate subangular blocky ; slightly hard, friable, sticky and slightly plastic; common fine to medium roots; few medium and common fine tubular pores; common fine black (10YR2/1) manganese stains and concretions; clear smooth boundary.

$2Bt_1$ — 29 - 70cm. Dark grayish brown (10YR4/2) silty clay; strong coarse prismatic structure; firm, sticky and very plastic; common fine to medium roots; few fine tubular pores; few fine black (10YR2/1) manganese stains and concretions; few thin clay films exped; abrupt smooth boundary.

$2Bt_2$ — 70 - 90cm. Yellowish brown (10YR5/4) silty clay; common fine faint very dark grayish brown (10YR3/2) mottles; moderate medium subangular blocky structure; friable, sticky and very plastic; common fine and very fine roots exped; common fine tubular pores; few fine black (10YR2/1) manganese stains; few thin clay skins exped; clear smooth boundary.

$2BC_t$ — 90 - 125cm. Brown (10YR5/3) silty clay loam; few fine faint dark yellowish brown mottles; weak medium subangular blocky structure; friable, sticky and plastic; few fine roots exped; common fine tubular pores; few fine black (10YR2/1) manganese stains; abrupt smooth boundary.

3C — 125^{+}cm. Grayish brown (2.5Y5/3) silt loam; few medium faint light olive brown (2.5Y5/6) mottles; massive; friable; slightly sticky and plastic; common fine interstitial pores.

SITE 3

Soil Series: Dayton silt loam
Location: Fayetteville, Shedd, OR
Soil Survey Legal Description: SE1/4 Sec 3 T.13 S. R.4 W. Linn County
and Owner/Operator: George Pugh
Land Use : Annual Ryegrass
Predominant Management System: Annual plow

Pedon Description

Ap 0 - 16cm. Dark grayish brown (10YR4/2) silt loam, light brownish gray (10YR6/2) dry; few fine faint dark yellowish brown (10YR4/6) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many fine and very fine roots; many very fine tubular pores; few fine distinct black (10YR2/1) manganese stains; clear smooth boundary.

A 16 - 28cm. Dark grayish brown (10YR4/2) silt loam, light grayish brown (10YR6/2) dry; common fine faint yellowish (10YR5/6) and dark yellowish brown (10YR3/6) mottles; moderate medium subangular structure; slightly hard, friable, slightly sticky and slightly plastic; many fine and very fine roots, common fine tubular pores; few fine dark brown (10YR3/3) manganese stains; abrupt smooth boundary.

E 28 - 35cm. Grayish brown (10YR5/2) silty clay loam, light gray (10YR7/2) dry; moderate fine to medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine to fine roots; common fine tubular pores; very few yellowish brown (10YR5/8) iron nodules; abrupt smooth boundary.

$2Bt_1$ 35 - 57cm. Dark grayish brown (2.5Y4/2) silty clay; few fine faint olive brown (2.5Y4/4) mottles; moderate medium subangular blocky; hard, firm, sticky and very plastic; many very fine roots, exped; common fine tubular pores; few medium very dark gray (2.5Y3/3) manganese stains; few, thin clay skins exped; gradual smooth boundary.

$2Bt_2$ 57 - 75cm. Dark grayish brown (2.5Y4/2) silty clay; common fine faint olive brown (2.5Y4/4) mottles; moderate medium prismatic structure; hard, for, sticky and very plastic; few fine roots exped; common very fine tubular pores; few thin clay skins on ped faces; clear smooth boundary.

$2Bt_3$ 75 - 95cm. Dark grayish brown (2.5Y4/2), olive brown (2.5Y4/4) and light yellowish brown (2.5Y6/2) silty clay loam; moderate medium prismatic parting to coarse subangular structure; hard, firm, very sticky and very plastic; few fine roots; few fine and many very fine interstitial pores; few fine faint olive brown (2.5Y4/4) manganese stains; common thin clay skins exped; clear broken boundary.

$2BC_t$ 95 - 114cm. Light olive brown (2.5Y5/4) silty clay loam; moderate medium subangular blocky parting to platty structure; slightly hard, friable, sticky and plastic; few fine roots; many fine interstitial pores; few fine black (2.5Y2/0) manganese stains; abrupt smooth boundary.

3C 114^{+}cm. Yellowish brown (10YR5/4) silty clay loam; massive stucture; few thin clay skins on sand grains; very few fine roots; very many fine interstitial pores.

SITE 4

Soil Series: Dayton silt loam
Location: Airport Rd. Corvallis, OR
Soil Survey Legal Description: SE1/4 of NE1/4 Sec 29 T.12 S. R.5 W. Benton County
Land Owner/Operator: Tom Wardon
Land Use: Annual Ryegrass
Predominant Management System: Annual burn

Pedon Description

Ap 0 - 17cm. Dark grayish brown (10YR4/2) silt loam, light gray (10YR7/2) dry; few fine faint yellowish brown (10YR5/6) and brown (10YR5/3) mottles; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine roots, common fine tubular pores; clear smooth boundary.

A_1 17 - 29cm. Grayish brown (10YR5/2) silt loam, light brownish gray (10YR6/2) dry; common fine faint dark yellowish brown (10YR4/6) mottles; moderate medium subangular structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine and fine roots; few fine tubular pores; few fine black (10YR2/1) manganese stains; clear smooth boundary.

A_2 29 - 39cm. Grayish brown (10YR5/2) silt loam; few fine dark yellowish brown (10YR4/4) mottles; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine and fine roots; common very fine and fine tubular pores; clear smooth boundary.

$2Bt_1$ 39 - 51cm. Grayish brown (2.5Y5/2) silty clay loam; common fine distinct dark yellowish brown (10YR4/4) mottles; moderate medium prismatic parting to subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common very fine and fine roots; common very fine and fine tubular pores; few fine black (10YR2/1) manganese stains and nodules; abrupt smooth boundary.

$2Bt_2$ 51 - 78cm. Grayish brown (2.5Y5/2) silty clay loam; few fine yellowish brown (10YR5/6) mottles; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and plastic; common fine roots; common very fine and fine interstitial pores; few medium black (2.5Y2/0) manganese stains; common thin clay skins on ped faces; clear smooth boundary.

2BC 78 - 110cm. Grayish brown (2.5Y5/2) silty clay loam; few fine yellowish brown (10YR5/6) mottles; moderate fine prismatic structure; slightly hard, friable, slightly sticky and plastic; common fine roots exped; common fine and many very fine interstitial pores; few fine very dark brown (10YR2/2) manganese stains; few thin clay skins on ped faces; clear smooth boundary.

3C 10 - 132cm. Yellowish brown (10YR5/4) silty clay loam; few fine faint dark yellowish brown (10YR4/4) mottles; massive structure; friable, slightly sticky and plastic; many very fine pores.

SITE 5

Soil Series: Dayton silt loam
Location: Peoria Rd Peoria, OR
Soil Survey Legal Description: NE1/4 Sec 17 T.14S R.4W. Linn County
Land Owner/Manager: Stan Falk
Land Use: Annual Ryegrass
Predominant Management System: Annual Plow

Pedon Description

Ap 0 - 18cm. Dark grayish brown (10YR4/2) silt loam; light grayish brown (10YR6/2) dry; few fine faint yellowish brown (10YR5/8)) and distinct strong brown (7.5YR4/6) mottles; moderate fine to very fine subangular blocky structure; slightly hard, friable, slightly sticky and non-plastic; many fine and medium roots; few fine irregular pores; abrupt smooth boundary.

A 18 - 35cm. Grayish brown (10YR5/2) silt loam; few medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic,; common very fine and fine to medium roots; common fine to very fine irregular pores; clear smooth boundary.

AB 35 - 55cm. Grayish brown (2.5Y5/2) silty clay loam; few medium distinct dark yellowish brown (10YR4/4) mottles; strong medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine roots; common very fine and fine interstitial pores; gradual smooth boundary.

$2Bt_1$ 55 - 70cm. Grayish brown (10YR5/2) silty clay; common fine distinct dark yellowish brown (10YR4/4) mottles; strong medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; few fine rots; common fine and very fine interstitial pores; gradual smooth boundary.

$2Bt_2$ 70 - 95cm. Light brownish gray (2.5Y5/2) silty clay; common medium prismatic structure; firm, sticky and plastic; few fine black (10YR2/1) manganese stains; few fine roots; few fine and very fine interstitial pores; clear smooth boundary.

$2BC_t$ 95 - 125cm. Brown (10YR5/3) silty clay loam; common medium faint dark yellowish brown (10YR4/4) mottles; massive; slightly hard, firm, sticky and plastic; few fine black (10YR2/1) manganese stains; very few fine roots; few fine interstitial pores.

SITE 6

Soil Series: Dayton silt loam
Location: Rt. 34 Lebanon, OR
Soil Survey Legal Description: SW1/4, SW1/4 of NE1/4 sec 9 T.12 S R.2 W. Linn County
Land Owner/Operator: William Nofziger
Land Use: Annual Ryegrass
Predominant Management System: Annual Plow

Ap 0 -16cm. Dark grayish brown (10YR4/2) silty loam; light brownish gray (10YR6/2) dry; few fine faint dark yellowish brown (10YR4/6) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; abundant fine and medium roots; common very fine and fine irregular pores; abrupt smooth boundary.

A 16 - 26cm. Dark grayish brown (10YR4/2) silt loam; grayish brown (10YR5/2) dry; common fine faint yellowish brown (10YR5/8) mottles; moderate fine subangular blocky structure; slightly hard, slightly sticky and slightly plastic; many very fine and fine roots; common very fine irregular pores; abrupt smooth boundary.

E 26 - 43cm. Grayish brown (2.5Y5/2) silt loam; light gray (2.5Y5/2) dry; common fine distinct yellowish brown (10YR5/8) mottles; moderate fine to medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine roots; common fine irregular pores; few fine black (10YR2/1) manganese stains; abrupt smooth boundary.

$2Bt_1$ 43 - 66cm. Grayish brown (2.5Y5/2) silty clay; moderate to strong medium prismatic structure; firm, sticky and plastic; few fine roots exped; very few very fine interstitial pores; few fine black (10YR2/1) manganese stains; common thin clay skins exped and slikensides exped; clear smooth boundary.

$2Bt_2$ 66 - 86cm. Grayish brown (2.5Y5/2) silty clay; few fine distinct dark yellowish brown (10YR4/4) mottles; strong coarse prismatic structure; firm, very sticky and very plastic; few fine roots exped; very few fine interstitial pores; thin clay skins exped and pores; slikensides exped; clear smooth boundary.

$2BC_t$ 118^+cm. Grayish brown (2.5Y5/2) gravelly silty clay; very few fine dark brown (10YR3/3) mottles; moderate medium prismatic structure; firm, very sticky and very plastic; very few interstitial pores.

NOTE: Ap - fine gravel present (5-7%)
Ap and A - mats undecomposed straw from previous years tillage present in large quantities at horizon interface.
2Bt3 - fine gravel present (5-7%)

SITE 7

Soil Series: Dayton silt loam
Location: Priceboard Rd. Peoria, OR
soil Survey Legal description: NW1/4 of SE1/4 sec 15 T.15 S R.4 W. Linn County
Land Owner/Operator: John Hayworth
Land Use: Annual Ryegrass
Predominant Management System: Annual Plow

Pedon Description

Ap 0 - 14cm. Very dark grayish brown (10YR3/2) silty loam; light brownish gray (10YR6/2) dry; common fine faint brownish yellow (10YR6/8) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine roots; few fine and very fine tubular pores; abrupt smooth boundary.

A_1 14 - 20cm. Dark grayish brown (10YR4/2) silt loam; weak fine subangular blocky structure; hard, firm, slightly sticky and slightly plastic; many very fine and fine roots; few very fine and fine tubular pores; clear smooth boundary.

A_2 20 41cm. Dark grayish brown (10YR4/2) silty clay loam; common fine faint dark yellowish brown (10YR3/6) mottles; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many fine roots; common very fine and fine interstitial pores; few fine black (10YR2/1) manganese stains; clear smooth boundary.

AB_t 41 - 48cm. Dark grayish brown (2.5Y4/2) silty clay; few fine faint dark yellowish brown (10YR4/4) mottles; moderate fine subangular blocky parting to prismatic structure; slightly hard, friable, sticky and very plastic; common fine roots exped; common fine interstitial pores; few fine black (10YR2/1) manganese stains and concretions; clear smooth boundary.

$2Bt_1$ 48 - 66cm. Dark grayish brown (10YR4/2) silty clay; moderate medium prismatic structure; firm, stick and very plastic; common fine and medium roots exped; few very fine interstitial pores; few fine black (10YR2/1) manganese stains and concretions; common moderately thick clay skins exped and pores; clear smooth boundary.

$2Bt_2$ 66 - 80cm. Dark grayish brown (10YR4/2) silty clay common fine faint olive brown (2.5Y4/4) mottles; moderate medium prismatic structure; firm, sticky and very plastic; few fine roots exped; few fine interstitial pores; common moderately thick clay skins exped and pores; few fine black (10YR2/1) manganese stains; clear smooth boundary.

$2BC_t$ 80 - 92cm. Dark grayish brown (2.5Y4/2) silty clay loam; moderate platy structure; firm, very sticky and very plastic; few fine roots; common very fine interstitial pores; few fine very faint black (10YR2/1) manganese stains; clear wavy boundary.

3C 92 - 100$^+$cm. Yellowish brown (10YR5/4) silty clay loam; massive; hard, firm, sticky and plastic.

SITE 8

Soil Series: Dayton silt loam
Location: Irish Loop Rd. Peoria, OR
Soil Survey Legal Description: SW1/4 NW1/4 of SE1/4 Sec 31 T.14 S. R.4 W. Linn County
Land Owner/Operator: Tom Herndon
Land Use: Annual Ryegrass
Predominant Management System: Annual Plow

Pedon Description

Ap	0 - 16cm. Grayish brown (10YR5/2) silt loam; light gray (10YR7/1) dry; few fine faint brownish yellow (10YR6/8) mottles; weak medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine roots; common very fine and fine tubular pores. clear smooth boundary.
A	16 - 25cm. Dark yellowish brown (10YR4/4) silt loam; light brownish gray (10YR6/2) dry; common fine dark yellowish brown (10YR3/4) mottles; moderate medium to coarse subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine and fine roots; common very fine and fine interstitial pores; clear smooth boundary.
AE	25 - 36cm. Grayish brown (10YR5/2) silty clay loam; few fine faint yellowish brown mottles; moderate coarse subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; common fine and very fine roots; many fine and very fine interstitial pores; few fine distinct black (10YR2/1) manganese stains; clear smooth boundary.
E	36 - 50. Light brownish gray (10YR6/2) silty clay loam; few fine faint dark yellowish brown (10YR4/6) mottles; moderate medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many fine roots; many very fine and fine interstitial pores; abrupt smooth boundary.
$2Bt_1$	50 - 66cm. Dark grayish brown (2.5Y4/2) silty clay; few fine faint light olive brown (2.5Y5/6) mottles; moderate medium prismatic stucture, hard, firm, sticky and very plastic; few to common fine roots; common fine tubular pores; few fine distinct black (2.5Y2/0) manganese stains; clear smooth boundary.
$2Bt_2$	66 - 83cm. Dark grayish brown (2.5Y4/2) silty clay; common fine faint light olive brown (2.5Y5/6) mottles; moderate medium prismatic structure; hard, firm, sticky and very plastic; few fine roots; few fine tubular pores; few fine distinct black (10YR2/1) manganese stains; few thin clay skins on ped faces; clear smooth boundary.
$2BC_t$	83 - 108cm. Grayish brown (2.5Y5/2) and light olive brown (2.5Y5/6) silty clay loam; few fine prominent dark yellowish brown (10YR4/4) mottles; moderate medium prismatic parting to medium subangular blocky structure; friable, sticky and very plastic; few very fine roots; many fine tubular pores; few fine distinct black (2.5Y2/0) manganese stains; few thin clay skins exped; clear smooth boundary.
3C	108 - 134cm. Yellowish brown (10YR4/4) silty clay loam; massive structure; few very fine roots, abundant fine tubular pores.

SITE 9

Soil Series: Dayton silt loam
Location: Powerline Rd. Peoria, OR
Soil Survey Legal Description: SW1/4 of NW1/4 sec 24 T.14 S R.4 W. Linn County
Land Owner/Operator: Nature Conservancy (Cogswell Foster Preserve)
Land Use: Preserve dedicated for scientific and educational purposes
Predominant Management System: Undisturbed (minimum 80 years)

Pedon Description

A_1 0 - 10cm. Grayish brown (10YR5/2) silt loam; light gray (10YR7/2) dry; few fine faint (10YR4/6) mottles; weak fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; very many fine and medium roots; many fine and medium irregular pores; abrupt smooth boundary.

A_2 10 - 26cm. Dark grayish brown (10YR4/2) silt loam; light brownish gray (10YR6/2) dry; few fine faint dark brown (10YR4/3) mottles; moderate fine subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many fine and medium roots; few fine medium irregular pores; few fine black (10YR2/1) manganese stains and concretions; clear smooth boundary.

AB_t 26 - 34cm. Grayish brown (10YR5/2) silty clay loam; few fine faint dark yellowish brown mottles; moderate medium subangular blocky structure; slightly hard, firm, slightly sticky and slightly plastic; common fine and medium roots; many fine interstitial pores; few fine dark reddish brown (5Y3/3) iron stains and concretions; clear smooth boundary.

$2Bt_1$ 34 - 48cm. Dark grayish brown (10YR4/2) silty clay loam; few fine faint dark yellowish brown (10YR4/6) mottles; weak medium to coarse subangular blocky parting to prismatic structure; hard, firm, sticky and plastic; common fine and medium roots; few fine interstitial pores; few fine black)10YR2/1) manganese stains; few thin clay films exped; clear smooth boundary.

$2Bt_2$ 48 - 70cm. Dark grayish brown (2.5Y4/2) silty clay; few fine distinct dark yellowish brown (10YR4/4) mottles; weak medium to coarse prismatic structure; firm, sticky and plastic; common fine and medium roots; few fine and medium interstitial pores; few fine black (10YR2/1) manganese stains and concretions; few fine clay skins exped; gradual smooth boundary.

$2Bt_3$ 70 - 108cm. Very dark grayish brown (2.5Y3/2) silty clay; few fine distinct dark yellowish brown (10YR4/4) mottles; weak medium to coarse prismatic structure; firm, sticky and plastic; few fine clay skins exped; common fine interstitial pores; few fine black (10YR2/1) and dark reddish brown (5YR3/3) manganese and iron stains and concretions; few thin skins exped; clear smooth boundary.

3C 122^{+}cm. Very dark grayish brown (2.5Y3/2) silty clay loam; moderate fine to medium subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic, few fine interstitial pores; very few fine black (10YR2/1) manganese stains.

APPENDIX II

Raw Data for all Laboratoy Measurements on all Samples

Table II-1. Total organic carbon distribution by horizon of sites sampled in g kg^{-1} soil.

Practice (Site)	Horizon	Depth (cm)	Subsamples within site: Pit	A	B	C	Site Mean	Std. Dev.
			------------ g C kg^{-1} soil ------------					
Burn	Ap	0-19	17.3	18.8	16.4	14.8	16.8	1.7
(1)	E	19-27	9.7	8.5	12.4	7.9	9.6	2.0
	BE	27-34	5.1	5.6	3.8	4.6	4.8	0.8
	2Bt1	34-54	3.8	4.3	3.9	3.4	3.9	0.4
	2Bt2	54-68	2.0	2.1	3.0	2.3	2.4	0.4
	2BCt	68-91	1.4	1.4	1.9	1.8	1.6	0.2
	3C	91-134	0.7	0.8	0.8	1.1	0.9	0.2
Burn	Ap	0-17	17.3	18.6	24.7	19.1	19.9	3.3
(2)	A	17-23	17.7	12.0	18.9	15.9	16.1	3.0
	AB	23-29	9.6	8.5	9.8	11.0	9.7	1.0
	2Bt1	29-70	3.8	4.6	7.1	5.8	5.3	1.5
	2Bt2	70-90	2.8	3.0	5.5	4.0	3.8	1.2
	2BCt	90-125	1.5	1.9	3.1	2.8	2.3	0.7
	3C	125-135	1.1	1.2	1.3	1.2	1.2	0.1
Burn	Ap	0-16	15.8	17.7	16.7	16.4	16.6	0.8
(3)	A	16-28	11.7	13.1	18.4	16.8	15.4	3.1
	E	28-35	6.1	6.6	6.4	7.5	6.7	0.6
	2Bt1	35-57	3.3	3.3	3.6	4.8	3.8	0.7
	2Bt2	57-75	2.2	2.3	2.3	3.0	2.5	0.4
	2Bt3	75-95	1.7	1.8	1.5	2.0	1.7	0.2
	2BCt	95-114	1.0	1.5	1.1	1.2	1.2	0.2
	3C	114-124	0.9	0.8	0.7	0.8	0.8	0.1
Burn	Ap	0-17	18.9	16.8	17.3	17.1	17.5	1.0
(4)	A1	17-29	11.4	16.7	10.8	6.8	11.4	4.1
	A2	29-39	6.6	5.8	4.6	4.5	5.4	1.0
	2Bt1	39-51	6.2	4.3	4.3	3.7	4.6	1.1
	2Bt2	51-78	4.5	3.2	2.9	3.0	3.4	0.7
	2BCt	78-110	1.5	2.8	1.2	1.5	1.8	0.7
	3C	110-132	1.0	0.8	0.8	1.2	1.0	0.2

Table II-1. Continued

Practice (Site)	Horizon	Depth (cm)	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
			------- g C kg^{-1} soil -------					
Plow	Ap	0-18	23.6	24.0	20.0	25.2	23.2	2.2
(5)	A	18-35	8.7	11.6	6.8	9.5	9.1	2.0
	AB	35-55	3.3	6.0	6.8	7.1	5.8	1.7
	2Bt1	55-70	2.3	2.9	3.6	2.3	2.8	0.6
	2Bt2	70-95	2.1	1.5	2.3	2.9	2.2	0.6
	2BCt	95-125	1.0	1.0	0.8	1.3	1.0	0.2
Plow	Ap	0-16	21.9	19.7	21.5	25.0	22.0	2.2
(6)	A	16-26	19.1	17.3	22.1	21.6	20.0	2.3
	E	26-43	4.2	4.0	4.5	7.2	5.0	1.5
	2Bt1	43-66	3.8	2.9	4.1	3.0	3.5	0.6
	2Bt2	66-86	2.6	2.3	2.6	2.4	2.5	0.1
	2Bt3	86-118	1.2	1.2	1.1	1.0	1.1	0.1
	2BCt	118-128	1.3	1.3	1.1	1.1	1.2	0.1
Plow	Ap	0-14	23.7	25.7	26.8	21.3	24.4	2.4
(7)	A1	14-20	21.7	26.5	26.8	20.2	23.8	3.4
	A2	20-41	10.3	14.8	16.9	15.2	14.3	2.8
	ABt	41-48	5.0	11.7	10.9	9.8	9.4	3.0
	2Bt1	48-66	3.3	7.9	4.3	5.6	5.3	2.0
	2Bt2	66-80	2.0	3.2	2.3	4.9	3.1	1.3
	2BCt	80-92	1.4	2.3	1.2	3.9	2.2	1.2
	3C	90-102	0.6	1.7	1.0	2.4	1.4	0.8
Plow	Ap	0-16	18.5	18.3	18.1	19.4	18.6	0.6
(8)	A	16-25	16.4	18.0	17.1	15.7	16.8	1.0
	AE	25-36	7.0	12.8	10.0	10.4	10.0	2.4
	E	36-50	5.3	9.1	7.0	5.4	6.7	1.8
	2Bt1	50-66	3.7	4.6	4.4	3.9	4.2	0.4
	2Bt2	66-83	3.3	4.4	3.4	3.5	3.7	0.5
	2BCt	83-108	2.2	3.4	2.4	2.5	2.6	0.5
	3C	108-134	1.1	1.5	2.3	1.2	1.5	0.5

Table II-1. Continued

Practice (Site)	Horizon	Depth (cm)	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
				------- g C kg^{-1} soil -------				
Virgin	A	0-10	3.9	30.1	35.4	33.0	34.5	3.9
(9)	E	10-26	1.1	13.7	11.5	11.9	12.0	1.2
	ABt	26-34	0.7	9.8	8.0	7.7	8.1	1.3
	2Bt1	34-48	0.6	6.5	5.9	5.9	6.1	0.3
	2Bt2	48-70	0.6	4.9	5.2	5.2	5.2	0.3
	2Bt3	70-108	0.5	2.2	2.8	2.8	3.1	1.1
	2BCt	108-122	0.5	1.6	2.2	2.2	2.7	1.4
	3C	122-32	0.3	1.3	1.9	1.9	2.1	0.8

Table II-2. Total nitrogen by horizon of sites samped in g kg^{-1} soil.

Practice (Site)	Horizon	Depth (cm)	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
			---------- g N kg^{-1} soil ----------					
Burn	Ap	0-19	2.0	1.6	1.4	1.7	1.7	0.3
(1)	E/trans	19-34	0.7	0.7	0.9	0.8	0.8	0.1
	2Bt1	34-54	1.2	0.6	0.5	0.6	0.7	0.3
Burn	Ap	0-17	2.2	2.2	2.5	2.0	2.2	0.2
(2)	E/trans	17-29	0.9	0.8	1.1	1.1	1.0	0.1
	2Bt1	29-70	0.5	0.7	0.8	1.2	0.8	0.3
Burn	Ap	0-16	1.6	2.1	2.1	2.2	2.0	0.3
(3)	E/trans	16-35	0.7	0.9	0.8	0.8	0.8	0.1
	2Bt1	35-57	0.7	0.5	0.6	0.7	0.6	0.1
Burn	Ap	0-17	1.9	1.9	2.1	1.9	2.0	0.1
(4)	E/trans	17-39	0.6	1.1	1.2	1.2	1.0	0.3
	2Bt1	39-51	0.8	0.6	1.1	0.5	0.7	0.3
Plow	Ap	0-18	2.2	2.8	2.4	2.7	2.5	0.2
(5)	E/trans	18-55	0.9	1.0	1.0	1.2	1.0	0.1
	2Bt1	55-70	0.5	0.4	0.5	0.5	0.5	0.0
Plow	Ap	0-16	2.3	2.1	2.3	1.6	2.1	0.3
(6)	E/trans	16-43	1.0	1.0	1.0	1.3	1.1	0.1
	2Bt1	43-66	0.9	0.7	0.7	0.6	0.7	0.2
Plow	Ap	0-14	3.1	2.6	2.8	2.1	2.6	0.4
(7)	E/trans	14-48	0.8	1.2	0.9	1.0	1.0	0.2
	2Bt1	48-66	0.3	0.7	0.3	0.4	0.4	0.2
Plow	Ap	0-16	1.9	1.9	2.0	2.0	2.0	0.1
(8)	E/trans	16-50	1.9	1.9	2.0	2.0	2.0	0.1
	2Bt1	50-66	0.8	0.7	0.6	0.4	0.6	0.2
Virgin	Ap	0-10	3.3	3.1	3.6	3.7	3.4	0.3
(9)	E/trans	10-34	0.8	1.2	0.9	1.0	0.9	0.2
	2Bt1	34-48	0.7	0.7	0.9	0.6	0.7	0.1

Table II-3. β-glucosidase activity by horizon of sites sampled in μg PNG g^{-1} soil hr^{-1}.

Practice (Site)	Horizon	Depth cm	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
				--------- μg PNG kg^{-1} soil -----------				
Burn	Ap	0-19	79.5	87.4	63.9	61.8	73.2	12.3
(1)	E/trans	19-34	28.4	26.1	28.0	30.6	28.3	1.8
	2Bt1	34-54	30.4	26.2	13.2	11.7	20.4	9.3
Burn	Ap	0-17	71.4	84.7	108.7	128.8	98.4	25.5
(2)	E/trans	17-29	46.7	31.3	30.0	10.1	29.5	15.0
	2Bt1	29-70	19.3	11.3	13.6	24.3	17.1	5.9
Burn	Ap	0-16	90.7	105.1	88.2	90.6	93.7	7.7
(3)	E/trans	16-35	32.6	34.1	27.6	28.1	30.6	3.2
	2Bt1	35-57	25.4	23.0	18.7	31.5	24.6	5.3
Burn	Ap	0-17	62.2	108.6	90.6	117.2	94.7	24.3
(4)	E/trans	17-39	38.3	30.7	28.0	21.4	29.6	7.0
	2Bt1	39-51	13.5	19.4	16.9	12.4	15.5	3.2
Plow	Ap	0-18	110.	136.6	115.4	116.0	119.5	11.7
(5)	E/trans	18-55	14.5	10.2	18.3	16.8	15.0	3.5
	2Bt1	55-70	6.8	6.4	9.7	3.1	6.5	2.7
Plow	Ap	0-16	124.	90.9	68.5	94.7	94.5	22.8
(6)	E/trans	16-43	26.4	37.9	24.5	30.6	29.8	6.0
	2Bt1	43-66	9.9	13.5	14.5	11.6	12.4	2.0
Plow	Ap	0-14	161.	151.7	182.4	135.6	157.7	19.5
(7)	E/trans	14-48	40.3	64.7	48.2	56.8	52.5	10.6
	2Bt1	48-66	13.0	8.7	13.5	27.3	15.6	8.1
Plow	Ap	0-16	96.5	98.1	123.1	120.2	109.5	14.1
(8)	E/trans	16-50	24.8	18.5	28.5	28.6	25.1	4.7
	2Bt1	50-66	15.9	19.4	20.8	16.4	18.1	2.3
Virgin	Ap	0-10	314.	96.1	240.2	203.8	213.7	91.0
(9)	E/trans	10-34	29.3	29.6	32.0	36.3	31.8	3.2
	2Bt1	34-48	13.0	13.0	12.8	17.3	14.0	2.2

Table II-4. µg CO_2-C g^{-1} soil evolved from microbial respiration by horizon for each site sampled during a 32 day incubation period.

Practice (Site)	Day	Depth cm	Horizon	Subsamples within site Pit	A	B	C	Site mean	Std. Dev.
Burn	1	0-19	Ap	58.4	46.9	43.3	50.6	49.8	6.5
(1)	1	19-34	E/trans	38.6	34.6	38.5	35.7	36.9	2.0
	1	34-54	2Bt1	13.5	23.4	19.1	12.5	17.1	5.1
Burn	1	0-17	Ap	54.9	35.7	57.5	65.5	53.4	12.6
(2)	1	17-29	E/trans	63.5	32.0	80.4	149.5	81.4	49.7
	1	29-70	2Bt1	16.0	15.1	18.2	20.4	17.4	2.4
Burn	1	0-16	Ap	49.6	50.1	46.1	55.6	50.3	3.9
(3)	1	16-35	E/trans	45.2	39.5	36.7	34.2	38.9	4.7
	1	35-57	2Bt1	7.2	10.7	12.7	21.0	12.9	5.9
Burn	1	0-17	Ap	57.0	64.6	59.0	54.4	58.7	4.3
(4)	1	17-39	E/trans	20.7	40.1	31.1	38.0	32.5	8.7
	1	39-51	2Bt1	26.3	8.6	20.4	19.0	18.6	7.4
Burn	2	0-19	Ap	82.9	86.3	82.8	76.4	82.1	4.1
(1)	2	19-34	E/trans	82.9	86.3	82.8	76.4	82.1	4.1
	2	34-54	2Bt1	28.1	45.5	32.9	27.6	33.5	8.3
Burn	2	0-17	Ap	71.6	90.8	95.6	137.3	98.8	27.7
(2)	2	17-29	E/trans	71.6	90.8	95.6	137.3	98.8	27.7
	2	29-70	2Bt1	33.7	29.7	34.9	44.8	35.8	6.4

Table II-4. continued

Practice	Day	Depth (cm)	Horizon	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
				------------ μg CO_2-C g^{-1} soil ------------					
Burn	2	0-16	Ap	82.3	97.6	69.3	84.7	83.5	11.6
(3)	2	16-35	E/trans	59.0	60.1	65.9	76.5	65.4	8.0
	2	35-57	2Bt1	25.6	42.2	33.5	26.3	31.9	7.7
Burn	2	0-17	Ap	78.3	91.2	91.8	80.6	85.5	7.0
(4)	2	17-39	E/trans	50.9	70.6	68.9	66.4	64.2	9.0
	2	39-51	2Bt1	39.5	42.2	25.7	32.3	34.9	7.4
Burn	4	0-19	Ap	143.5	127.8	117.5	120.3	127.3	11.6
(1)	4	19-34	E/trans	83.4	75.0	83.3	78.8	80.1	4.0
	4	34-54	2Bt1	59.8	62.2	55.9	43.4	55.3	8.4
Burn	4	0-17	Ap	144.0	105.3	167.7	164.2	145.3	28.7
(2)	4	17-29	E/trans	130.1	110.2	121.7	175.2	134.3	28.5
	4	29-70	2Bt1	49.1	49.5	57.5	63.9	55.0	7.1
Burn	4	0-16	Ap	145.8	156.7	147.0	155.9	151.4	5.8
(3)	4	16-35	E/trans	96.0	88.8	98.3	118.4	100.4	12.7
	4	35-57	2Bt1	47.9	46.5	69.0	57.9	55.3	10.4
Burn	4	0-17	Ap	128.8	152.3	155.6	126.9	140.9	15.2
(4)	4	17-39	E/trans	76.3	109.4	97.2	102.9	96.4	14.3
	4	39-51	2Bt1	64.7	50.5	71.8	67.8	63.7	9.3

Table II-4. continued

Practice	Day	Depth (cm)	Horizon	Pit	A	B	C	Site Mean	Std. Dev.
				Subsamples within site					
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil ------------					
Burn	8	0-19	Ap	274.0	256.4	234.5	225.9	247.7	21.7
(1)	8	19-34	E/trans	146.1	132.6	137.6	137.3	138.4	5.6
	8	34-54	2Bt1	100.9	103.0	91.4	69.7	91.3	15.2
Burn	8	0-17	Ap	285.3	219.7	332.9	290.5	282.1	46.7
(2)	8	17-29	E/trans	238.8	198.4	242.7	321.2	250.3	51.4
	8	29-70	2Bt1	79.5	97.8	111.9	98.0	96.8	13.3
Burn	8	0-16	Ap	283.5	297.7	298.7	318.6	299.6	14.4
(3)	8	16-35	E/trans	165.4	169.4	165.0	210.4	177.6	22.0
	8	35-57	2Bt1	72.8	73.6	91.2	89.6	81.8	9.9
Burn	8	0-17	Ap	246.1	306.8	298.1	254.1	276.3	30.6
(4)	8	17-39	E/trans	127.2	194.1	166.0	171.0	164.6	27.8
	8	39-51	2Bt1	116.8	80.4	155.6	143.8	124.2	33.4
Burn	16	0-19	Ap	582.1	548.6	531.9	477.3	535.0	43.8
(1)	16	19-34	E/trans	290.2	266.2	270.2	282.9	277.4	11.1
	16	34-54	2Bt1	151.1	134.0	126.2	103.6	128.7	19.7
Burn	16	0-17	Ap	668.3	468.1	727.2	586.7	612.6	112.2
(2)	16	17-29	E/trans	496.0	395.7	451.8	711.8	513.8	138.2
	16	29-70	2Bt1	110.6	159.3	227.8	157.4	163.8	48.3

Table II-4. continued

Practice	Day	Depth	Horizon	Subsamples within site				Site	Std.
		(cm)		Pit	A	B	C	Mean	Dev.
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil ------------					
Burn	16	0-16	Ap	599.1	610.0	654.2	675.3	634.6	36.1
(3)	16	16-35	E/trans	356.4	348.8	337.9	449.9	373.2	51.7
	16	35-57	2Bt1	107.4	119.7	112.5	121.7	115.3	6.6
Burn	16	0-17	Ap	519.9	608.1	567.7	522.5	554.6	41.9
(4)	16	17-39	E/trans	249.4	419.0	326.6	361.8	339.2	71.0
	16	39-51	2Bt1	212.7	139.1	281.1	268.2	225.3	64.6
Burn	32	0-19	Ap	1104.1	1052.6	1063.7	937.5	1039.5	71.5
(1)	32	19-34	E/trans	625.9	641.3	594.8	626.1	622.0	19.5
	32	34-54	2Bt1	341.9	311.1	295.7	222.3	292.7	50.7
Burn	32	0-17	Ap	1386.9	946.2	1486.6	1621.8	1360.4	292.4
(2)	32	17-29	E/trans	1023.8	825.5	856.7	1367.7	1018.4	248.6
	32	29-70	2Bt1	248.0	336.6	461.8	274.9	330.3	95.1
Burn	32	0-16	Ap	1166.9	1198.8	1298.2	1318.6	1245.6	74.1
(3)	32	16-35	E/trans	648.9	675.9	751.8	884.7	740.4	105.7
	32	35-57	2Bt1	317.5	303.5	265.1	270.4	289.1	25.4
Burn	32	0-17	Ap	1089.3	1163.3	1101.1	1149.3	1125.7	36.0
(4)	32	17-39	E/trans	526.8	663.6	782.4	831.7	701.1	135.9
	32	39-51	2Bt1	487.5	289.6	552.0	640.6	492.4	149.1

Table II-4. continued

Practice (Site)	Day	Depth cm	Horizon	Subsamples within site Pit	A	B	C	Site Mean	Std. Dev.
Plow	1	0-18	Ap	62.2	71.8	71.7	88.9	73.7	11.1
(5)	1	18-55	E/trans	22.7	20.1	22.3	25.3	22.6	2.1
	1	55-70	2Bt1	4.9	13.2	13.4	7.3	9.7	4.3
Plow	1	0-16	Ap	93.8	62.2	52.1	68.9	69.3	17.7
(6)	1	16-43	E/trans	30.6	54.5	58.9	56.3	50.1	13.1
	1	43-66	2Bt1	8.5	5.3	12.0	9.4	8.8	2.8
Plow	1	0-14	Ap	82.2	74.6	97.3	69.2	80.8	12.2
(7)	1	14-48	E/trans	64.0	63.0	71.9	89.0	72.0	12.0
	1	48-66	2Bt1	5.2	13.4	18.6	18.3	13.9	6.3
Plow	1	0-16	Ap	80.2	62.0	80.1	69.1	72.8	8.9
(8)	1	16-50	E/trans	33.7	49.4	49.6	39.3	43.0	7.8
	1	50-66	2Bt1	17.9	19.7	18.6	14.8	17.7	2.1
Plow	2	0-18	Ap	107.2	110.8	111.7	134.7	116.1	12.6
(5)	2	18-55	E/trans	33.3	39.3	33.9	38.4	36.2	3.1
	2	55-70	2Bt1	19.4	26.2	28.9	13.7	22.0	6.8
Plow	2	0-16	Ap	118.6	95.7	71.1	109.8	98.8	20.7
(6)	2	16-43	E/trans	60.0	69.6	84.6	80.8	73.7	11.1
	2	43-66	2Bt1	18.4	12.1	21.8	19.4	17.9	4.1

Table II-4. continued

Practice	Day	Depth (cm)	Horizon	Pit	A	B	C	Site Mean	Std. Dev.
				Subsamples within site					
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil ------------					
Plow	2	0-14	Ap	117.6	109.0	138.5	102.8	117.0	15.6
(7)	2	14-48	E/trans	90.2	101.9	116.1	129.6	109.4	17.1
	2	48-66	2Bt1	21.3	27.6	30.0	24.3	25.8	3.8
Plow	2	0-16	Ap	115.6	100.2	128.6	113.1	114.4	11.6
(8)	2	16-50	E/trans	58.1	81.5	88.9	67.9	74.1	13.8
	2	50-66	2Bt1	32.6	35.2	33.6	26.0	31.8	4.1
Plow	4	0-18	Ap	220.5	184.4	186.3	210.3	200.4	17.9
(5)	4	18-55	E/trans	51.5	59.8	52.9	58.8	55.8	4.1
	4	55-70	2Bt1	35.7	38.6	41.5	38.5	38.6	2.4
Plow	4	0-16	Ap	273.3	168.1	115.1	168.6	181.2	66.3
(6)	4	16-43	E/trans	101.1	122.2	170.3	138.0	132.9	29.2
	4	43-66	2Bt1	34.0	27.5	37.9	32.3	32.9	4.3
Plow	4	0-14	Ap	220.1	197.5	285.5	190.4	223.4	43.3
(7)	4	14-48	E/trans	147.3	176.9	189.7	203.6	179.4	24.0
	4	48-66	2Bt1	42.7	50.9	46.5	47.8	47.0	3.4
Plow	4	0-16	Ap	191.0	172.5	258.6	210.8	208.2	37.0
(8)	4	16-50	E/trans	96.1	129.7	131.8	103.1	115.2	18.2
	4	50-66	2Bt1	56.8	61.7	52.1	45.1	53.9	7.1

Table II-4. continued

Practice	Day	Depth (cm)	Horizon	Subsamples within site: Pit	A	B	C	Site Mean	Std. Dev.
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil ------------					
Plow	8	0-18	Ap	460.6	359.5	358.4	455.1	408.4	57.2
(5)	8	18-55	E/trans	105.9	108.9	98.6	113.5	106.7	6.2
	8	55-70	2Bt1	64.4	68.9	75.4	69.1	69.4	4.5
Plow	8	0-16	Ap	500.8	325.9	226.1	332.0	346.2	113.9
(6)	8	16-43	E/trans	175.2	219.1	272.1	247.7	228.5	41.6
	8	43-66	2Bt1	57.6	52.5	59.9	54.0	56.0	3.4
Plow	8	0-14	Ap	460.7	380.5	507.9	394.8	436.0	59.3
(7)	8	14-48	E/trans	254.7	333.5	311.8	349.8	312.4	41.5
	8	48-66	2Bt1	75.9	102.9	77.2	73.5	82.4	13.8
Plow	8	0-16	Ap	365.9	345.0	541.4	424.3	419.1	88.1
(8)	8	16-50	E/trans	156.3	217.3	218.2	165.6	189.3	33.0
	8	50-66	2Bt1	106.8	124.8	79.5	78.2	97.3	22.6
Plow	16	0-18	Ap	947.4	696.6	691.2	978.9	828.5	156.0
(5)	16	18-55	E/trans	243.9	257.2	222.3	259.9	245.8	17.2
	16	55-70	2Bt1	119.3	112.7	149.2	109.1	122.6	18.2
Plow	16	0-16	Ap	941.5	620.8	483.5	738.8	696.2	194.0
(6)	16	16-43	E/trans	390.5	425.4	582.0	434.6	458.1	84.7
	16	43-66	2Bt1	132.5	114.1	108.8	113.1	117.1	10.5

Table II-4. continued

Practice	Day	Depth (cm)	Hroizon	Subsamples within site: Pit	A	B	C	Site Mean	Std. Dev.
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil			-------------		
Plow	16	0-14	Ap	968.5	768.0	958.1	873.2	891.9	93.0
(7)	16	14-48	E/trans	611.9	595.5	569.8	848.9	656.5	129.4
	16	48-66	2Bt1	131.9	202.6	136.3	123.6	148.6	36.4
Plow	16	0-16	Ap	720.6	688.4	1141.0	961.2	877.8	213.6
(8)	16	16-50	E/trans	313.2	402.4	426.4	337.1	369.8	53.4
	16	50-66	2Bt1	209.5	230.9	126.9	144.3	177.9	50.1
Plow	32	0-18	Ap	1845.6	1290.3	1269.6	1737.5	1535.8	298.8
(5)	32	18-55	E/trans	495.3	540.2	514.2	592.1	535.4	42.0
	32	55-70	2Bt1	253.3	260.8	271.9	233.0	254.8	16.4
Plow	32	0-16	Ap	1754.6	1240.0	1092.8	1468.6	1389.0	288.6
(6)	32	16-43	E/trans	780.0	787.1	1143.9	825.6	884.2	174.3
	32	43-66	2Bt1	366.4	320.1	313.5	286.5	321.6	33.2
Plow	32	0-14	Ap	1911.5	1571.9	1771.5	1898.8	1788.4	157.6
(7)	32	14-48	E/trans	1326.5	1204.0	1129.0	1619.7	1319.8	215.9
	32	48-66	2Bt1	318.9	457.6	353.7	408.5	384.7	61.0
Plow	32	0-16	Ap	1406.0	1382.0	2009.3	1910.2	1676.9	329.3
(8)	32	16-50	E/trans	662.4	828.0	901.3	619.1	752.7	133.9
	32	50-66	2Bt1	464.1	503.0	275.3	304.3	386.7	113.6

Table II-4. continued

Practice (Site)	Day	Depth cm	Horizon	Pit	A	B	C	Site Mean	Std. Dev.
				Subsamples within site					
				------------ $\mu g\ CO_2\text{-}C\ g^{-1}$ soil ------------					
Virgin	1	0-10	Ap	194.4	109.0	167.4	186.4	164.3	38.6
(9)		10-34	E/trans	44.2	59.2	59.9	46.7	52.5	8.2
		34-48	2Bt1	9.7	16.1	9.3	5.5	10.1	4.4
Virgin	2	0-10	Ap	318.2	208.1	163.7	265.0	238.7	67.2
(9)		10-34	E/trans	71.9	96.9	83.9	82.4	83.8	10.3
		34-48	2Bt1	29.0	36.6	27.9	19.1	28.1	7.2
Virgin	4	0-10	Ap	473.7	368.2	450.5	379.3	417.9	52.1
(9)		10-34	E/trans	99.2	134.6	121.6	110.5	116.4	15.2
		34-48	2Bt1	49.4	55.5	49.7	38.9	48.4	6.9
Virgin	8	0-10	Ap	786.7	521.9	731.3	609.1	662.3	119.4
(9)		10-34	E/trans	150.8	200.9	185.1	172.6	177.3	21.2
		34-48	2Bt1	86.8	92.3	74.5	68.8	80.6	10.8
Virgin	16	0-10	Ap	1400.0	884.2	1337.7	1084.0	1176.5	238.0
(9)		10-34	E/trans	253.5	357.6	360.8	281.0	313.2	54.3
		34-48	2Bt1	142.7	136.1	86.4	111.7	119.2	25.6
Virgin	32	0-10	Ap	2387.7	1997.2	2678.1	2052.5	2278.9	317.2
(9)		10-34	E/trans	683.5	795.8	869.2	762.3	777.7	77.0
		34-48	2Bt1	449.8	350.3	287.7	294.8	345.6	74.9

APPENDIX III

Summary of Statistical Analysis

Table III-1. Analysis of varience data for soil organic carbon.

Source	DF	Mean Square				
		Ap	E/trans	$2Bt_1$	$2Bt_2$	2BCt
Trt	1	147.8340	28.3316	6.4800	0.1800	0.0132
Site	6	17.2436	36.8889	33.7616	1.8912	1.6322
Sample	24	3.8686	3.3520	3.0402	0.5921	0.3641

Table III-2. Analysis of variance data for total nitrogen.

Source	DF	Mean Square		
		Ap	E/trans	$2Bt_1$
Trt	1	0.911531	1.036800	0.209628
Site	6	0.312651	0.467922	0.047019
Sample	24	0.074138	0.023068	0.044317

Table III-3. Analysis of variance data for enzyme activity (μg PNG g^{-1} soil hr^{-1}).

Source	DF	Mean Square		
		Ap	E/trans	$2Bt_1$
Trt	1	7366.8253	22.5129	333.1664
Site	6	1715.1434	489.2522	76.0703
Sample	24	336.1998	58.8381	31.0325

Table III-4. Analysis of variance data for enzyme activity (μg PNG g^{-1} carbon hr^{-1}).

Source	DF	Mean Square		
		Ap	E/trans	$2Bt_1$
Trt	1	1107857.4	4040001.5	11422332.8
Site	6	2409730.7	1089374.6	5346205.1
Sample	24	814986.8	416156.1	1662562.3

Table III-5. Analysis of variance data for total CO_2-C evolved g^{-1} soil during a 32 day incubation period

Source	DF	Mean Square		
		Ap	E/trans	$2Bt_1$
Trt	1	1310293.1	84126.9	1618.3
Site	6	99281.9	278274.6	26260.1
Sample	24	50406.4	23562.3	6561.3

Table III-6. Analysis of variance data for total CO^2-C evolved g^{-1} carbon during a 32 day incubation period.

Source	DF	Mean Square		
		Ap	E/trans	$2Bt_1$
Trt	1	273041059	450872673	455909022
Site	6	359982027	331861250	1012606536
Sample	24	133090349	401026764	554522364