Direct Seeding and Soil Quality on the Prairies

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The growing and general acceptance among policy makers, the public and farmers that land should be management in a sustainable way has created the need for quantitative information about the impact of agricultural practices on the environment. Since it is clearly impossible to measure all of the effects of land management on environmental quality (including soil, water and air) indicators of change have been developed to provide that type of information (Huffman et al., 2000).

Soil quality is one aspect of environmental quality. It is an abstract characteristic that is difficult to define because it encompasses both a soil's productive capacity and environmental capability (Wander et al., 2002). Measurable soil properties can be used as indicators of a soil's quality, which depends on the intended function of the soil (Doran and Parkin, 1994). The indicators should be properties that respond to land management within a relatively short period of time and reflect conditions as they exist in the field (Larson and Pierce, 1991; Turco et al., 1994; Doran and Parkin, 1994).

Various lists of soil quality indicators have been proposed. Granatstein and Bezdicek (1992) suggest that improved soil quality for crop production is indicated by increases in infiltration, macropores, aggregate size and stability, soil organic matter, biological activity and aeration, and decreases in runoff, bulk density, erosion, nutrient losses, soil resistance, diseases and production costs. The list proposed by Doran and Parkin (1994) includes: soil texture, depth of rooting, bulk density, infiltration, water holding capacity, structure, temperature, organic carbon, nitrogen, pH, electrical conductivity, mineral N, P, and K, microbial biomass C and N, potentially mineralizable N, and soil respiration. Parr et al. (1992) listed crop yield, plant vigour, rooting patterns and surface and groundwater quality as further indicators of soil quality from crop production, but Granatstein and Bezdicek (1992) warn that crop yield may not be a good indicator of soil quality. They note that crop yields can be maintained or even increased despite soil degradation, if yield loss is prevented by increasing use of fertilizer and other inputs or through new technologies. They suggest that stability of yield over time

In the following section of the paper, the effects of tillage systems on soil quality, based on several indicators of chemical, physical and biological soil quality, are discussed.

The Effects of Soil-Conserving Practices on Soil Quality

There is general agreement among soil scientists that prairie soils have degraded since their conversion to agriculture. Conservation tillage practices that are tailored to local soil and climatic conditions can reverse that trend. Throughout most of the Canadian prairies, direct-seeding, reduced or conservation tillage practices are a feasible alternative to conventional fallow and tillage systems in terms of crop yield and economics and for improving soil quality (Soon and Clayton, 2002; Zentner et al., 2000; Schillinger et al., 1999; Larney et al., 1994;

Thomas and Derkson, 1990; Mortensen et al., 1990). VanderBygaart et al (2003), in a review of published Canadian studies of direct-seeding and no-till systems, found that crop yields tended to exceed or equal those of conventional tillage systems on the Prairies, although in more humid regions, yields under no-till were more variable compared to conventional tillage.

Soil Organic Matter. Soil organic matter is a key attribute of soil quality (Doran and Parkin, 1994). The amount and quality of organic matter in a soil are controlled by physical, chemical, biological and management factors (Anderson, 1979; Boyle et al., 1989; Wood et al., 1990; Ismail et al., 1994). Management controls include cultural practices such as tillage, residue management, cropping intensity and fertilization.

There are six major management factors that contribute to the long term and gradual decline of organic matter in cultivated soils: disruption of the A horizon; reduced biomass inputs and removal of crop and crop residues; increased rate of organic matter decomposition and C mineralization; the breakdown of soil aggregates which exposes protected organic matter to microbial attack; and, increased erosion (Haas et al., 1957; Ridley and Hedlin, 1968; Bauer and Black, 1981; Pennock and Anderson, 1992; Wood and Edwards, 1992). The first two factors may be inevitable, although the magnitude of C loss will depend on the methods used to clear the land (Pennock and Anderson, 1992; Woods and Edwards, 1992). The latter four causes depend on management, and can therefore be minimized.

When grassland soils are first cultivated, there is a large, rapid decrease in organic matter due to the degradation of the substantial reserve of living and dead roots in the soil (Van Veen and Paul, 1981; Lynch, 1984; Richter et al., 1990). Following this initial flush of decomposition, organic matter declines slowly until the soil reaches a new equilibrium for the types of cultivation and crop rotation that are used (Tiessen et al., 1982). The time required to approach a new equilibrium after cultivation has been estimated at 30 to 50 years (Mann, 1986), 60 to 70 years (Martel and Paul, 1974) or longer (Paul and Van Veen, 1978; Tiessen et al., 1982). The amount of C in a soil at its equilibrium depends on how much C has been added from crop residue and other amendments versus how much has been lost due to microbial decay, erosion, etc. – it represents the balance between additions and losses.

Tillage causes an acceleration in the rate of organic matter loss because soil disturbance increases soil temperature, aeration and available moisture which promote microbial growth (Mann, 1986). The growing microbial population rapidly decomposes the crop material incorporated into the soil and in the process a significant amount of nutrients are released into the soil solution where they are either taken up by plants or lost due to leaching. In either case, the result is a relative depletion of the nutrient-rich and active pools of organic matter. Thus, the effect of cultivation is thus not so much the reduction of the total soil organic matter content, but rather the relative decline of the nutrient-rich, young pools compared to the older, resistant pools (Tiessen and Stewart, 1983).

Because of the high rate of decomposition in disturbed soils, compared to natural systems, more organic matter inputs are required just to maintain organic carbon levels in conventional tillage (Tiessen et al, 1982; Dalal and Mayer, 1986; Zielke and Christenson, 1986; Rasmussen et al, 1980). However, the opposite it likely to happen. Annual crops allocate a smaller fraction of carbon to roots than perennial grasses, so inputs of new carbon from roots to soil are much reduced under conventional tillage systems (Richter et al, 1990). In the Brown soil zone of Saskatchewan, it was estimated that 1000 kg C ha^{-1} yr^{-1} of litter and 1300 kg C ha^{-1} yr^{-1} of roots were input to the soil under native grassland (Van Veen and Paul, 1981). Under cultivated conditions, wheat plant residue and root carbon input rates were about 900 and 530 kg C ha^{-1} yr^{-1}, respectively (Van Veen and Paul, 1981).

When land management on the prairies shifts from conventional tillage to direct-seeding and zero tillage practices the organic matter content of the Ap horizon increases (Doran, 1980; Bauer and Black, 1981; Lamb et al., 1985; Janzen, 1987b; Bruce *et* al., 1990; Havlin *et* al., 1990; Carter, 1992; Wood and Edwards, 1992; Campbell and Zentner, 1993; Mahboubi et al., 1993; Beare *et* al., 1994b; Lal, 1999, Chan, 2002; McCallister and Chien, 2000; VanderBygaart et al., 2003). The increased organic matter is attributed to reduced erosion, to higher yields resulting in more crop residue added to the soil surface (Díaz-Zorita and Grove, 2002; Lützow et al., 2002), and to differences in the assimilation and decomposition of soil organic matter. Soils under no-till management are physically and chemically stratified, with a mulch of accumulated plant litter, rich in organic carbon and nutrients, at the soil surface (Dick, 1983; Dormaar and Lindwall, 1989; Halvin et al, 1990; Wood and Edwards, 1992). As much as 75% of the organic carbon from crop residue remains within 5 cm of the soil surface (Díaz -Zorita and Grove, 2002; Balesdent et al, 1990).

The quality of the organic matter in this surface layer is high and contains a high proportion of labile particulate organic carbon (Chan et al., 2002). Compared to conventional tillage systems, it contains more mineralizable carbon and nitrogen (Janzen et al, 1988; Campbell et al, 1991c). A greater proportion of the crop residue from no-till systems is converted to the more stable forms of organic matter (Gallaher and Ferrer, 1986; McCallister and Chein, 2000).

The surface mulch on no-till soils creates a stable environment for biological activity. It insulates the soil surface from temperature extremes and rapid desiccation and supports a large and active microbial population (Hendrix et al, 1988; Carefoot et al, 1990). The microbial populations of no-till systems are more like those of natural grasslands than conventionally managed soils. Dormaar and Lindwall (1989) found a 44% increase in fungal biomass in no-till soils. Fungi produce extensive hyphal networks that help in the formation of macro-aggregates (Dormaar and Lindwall, 1989).

Nitrogen Availability..3.1.2 Nutrient Availability When soil microorganisms consume organic matter, CO_2 is released. If the organic material contains more nutrients (N,P,S) that the microorganisms need for their own biomass growth, the excess is released to the soil solution (Smith, 1994). About 90% of the N released from organic matter by soil microorganisms is taken up by growing plants (Rosswall, 1976). The size of the N cycle in a soil is related to the size of the organic matter pool because that determines the size of the microbial population. To maintain N availability in agricultural soils, it is therefore just as important to manage the population of microorganisms as the quantity and quality of organic matter in a soil (Smith, 1994).

Nutrient cycles in agricultural ecosystems are “leaky” compared to natural ecosystems – some N is lost to leaching, and some is lost as emissions to the atmosphere. Leakage occurs if N is available in the soil solution, either because of mineralization by microorganisms or additions of

N fertilizer, in amounts greater than the crop can take up (Campbell et al., 1976; Stewart and Bettany, 1982; Carefoot et al., 1990; Tracy et al., 1990; Geng and Coote, 1991).

The surface mulch layer associated with direct seeding and zero tillage soils is a source of biologically active and N-rich organic matter (Tracy et al., 1990; Wood et al., 1990; Chan et al., 2002). The amount of organic C and N in no-till soils tends to increase in direct proportion to the amount of crop residues produced and left on the soil surface after harvest (Rasmussen and Parton, 1994; Havlin et al., 1990; Zielke and Christenson, 1986). Compared to conventional tillage systems, in minimum tillage systems, a larger proportion of the fertilizer N added to a soil is taken up by the microbial population and therefore protected from loss due to leaching. Soils with low levels of organic matter also have relatively small populations of microorganisms and less potential for conserving N in an organic form (Cochran et al., 1980; Elliot, 1986; Gallaher and Ferrer, 1987; Janzen, 1987a; Nyborg and Mahli, 1989; Wood et al., 1991; Haugen-Kozyra et al., 1993). Therefore, as soil organic matter levels decline, nutrients levels also decline, making the system more "leaky" and vulnerable to even greater loss.

Because of the large amount of N immobilization associated with conservation tillage systems, higher rates of N fertilizer have been required to achieve yields comparable to traditional systems (Rice and Smith, 1984; Carefoot et al., 1990; Wood and Edwards, 1992), although there are reports that the amount of N fertilizer required gradually decreases over time (Soon and Clayton, 2002; Smith and Paul, 1990; Tessier et al., 1990; Dick, 1983). The concentration of biomass in the surface layer of zero tillage soils may be beneficial to plant roots competing with microorganisms for fertilizer N. With most of the biomass in the top 5 cm of the soil, it should be possible to place N fertilizer below this zone (Smith and Paul, 1990). The large amounts of N contained in the surface mulch may contribute an important part of the N available to plants by mineralization during the growing season (Dick, 1983).

pH..3.1.3 pH pH is a useful soil quality indicator because it influences, and is influenced by so many other soil properties. For example, the solubility of various compounds, the relative bonding of ions to exchange sites, and the activity of microorganisms all vary to some degree with soil pH.

Agriculture can cause major imbalances and rapid changes in soil pH by increasing chemical inputs and removing organic matter. Heenan and Taylor (1995) suggest that the removal of crop products, organic matter increase at the soil surface and leaching of nitrate are major causes of the acidification of agricultural soils. Many researchers have measured declines in the pH of soils under heavily fertilized and reduced tillage systems (Triplett and Van Doren, 1969; Blevins et al., 1977; Dick, 1983; Dick and Van Doren, 1985; Dick et al., 1986; Heenan and Chan, 1992; Ismail et al., 1994; Heenan and Taylor, 1995; Lal, 1999), although other researchers have not measured that effect (Chan et al., 1992; Standley et al., 1990; Rhoton et al., 1993; Lal et al., 1994). Declines in pH at the soil surface are generally reported because N fertilizer is generally placed near the surface (Tamm, 1991) and the conversion of N fertilizer and soil organic N to nitrate is an acidification process (Tamm, 1991).

Soil Aggregation. Aggregation is an important indicator of soil quality because the soil aggregate is the basic component of soil structure (Karlen and Stott, 1994). Good structure for crop growth depends on the presence of stable aggregates (Tisdall and Oades, 1982) which determine the susceptibility of soil to erosion, crust formation and compaction (Luk, 1979; Geng and Coote, 1991; Angers and Mehuys, 1993). Aggregates with diameters less than 0.5 mm are susceptible to water erosion (Evans, 1980), and wind can erode aggregates less than 0.84 mm (Bisal and Ferguson, 1968). Bisal and Ferguson (1968) suggest that wind erosion will occur if about 40% of soil aggregates are less than 0.84 mm, whereas Lindwall and Anderson (1981) report that winds of about 28 km h^{-1} will erode a soil in which 60% of particles are less than 1 mm in diameter at the soil surface.

In undisturbed grassland soils, aggregates are stable because there are held together by organic materials that Tisdall and Oades (1982) describe as binding agents. The nature of the binding agents determines aggregate stability. Transient binding agents are mainly easily decomposed polysaccharides which hold together microaggregates (<250 μm diameter) and macroaggregates (>250 μm diameter). These aggregates are temporarily stable and easily disrupted by tillage. Roots and fungal hyphae are temporary binding agents, forming more stable macroaggregates that can persist for months to years (Beare et al., 1994b). However, their occurrence is highly dependent on farming practices such as cropping and tillage intensity which affect root and hyphae abundance and persistence in the soil (Weill et al., 1989). Persistent binding agents are organo-mineral complexes associated with relatively permanent microaggregates (<250 μm diameter) and are not influenced by tillage or cropping practices (Tisdall and Oades, 1982).

When grassland soil are tilled, the macroaggregates are shattered and dormant microorganisms, housed within soil aggregates, are activated. The newly active microbes consume the readily available organic substances that bind the macroaggregates together, causing rapid aggregate destruction (Elliott, 1986; Dormaar and Lindwall, 1989; Hendrix et al, 1988). In cultivated farming systems, there are less roots, hyphae, microbial polymers and other binding substances produced in the soil, compared to grassland, so the potential for forming macroaggregate structures is reduced (Tisdall and Oades, 1982). Eventually, only microaggregates remain, increasing the susceptibility of the soil to erosion, crusting and compaction (Chaney and Swift, 1984; Pojasok and Kay, 1990; Beare et al., 1994b).

Soil aggregation and soil tilth are closely related properties that can be sustained, improved or destroyed (Karlen et al.,1990). There are more stable aggregates in zero tillage or minimum tillage systems than in systems that include conventional tillage or fallow (Weill et al., 1989; Bruce et al., 1990; Carter, 1992; Layton et al., 1993; Mahboubi et al., 1993; Lal et al., 1994; Chan et al., 2002). Differences are attributed to the maintenance of straw residues on the soil surface. Aggregate formation also benefits from increased roots and root exudates, plant secretions, fungal mycelia and lysates under minimum tillage and continuous cropping conditions (Dormaar and Lindwall, 1989; Lal et al., 1994). Under zero tillage management, especially when combined with continuous cropping, the water-stable aggregate content of the surface soil was similar to that of native prairie (Dormaar and Lindwall, 1989).

Bulk Density. Bulk density is sensitive to management effects, and it provides information about soil characteristics which are important to plant growth and to water movement in soil (i.e. pore space and soil resistance). Farming systems that cause a decrease in the soil organic matter also reduce aggregation and pore space and increase soil bulk density (Bauer and Black, 1981, Tiessen et al., 1982; Blank and Fosberg, 1989; Boehm and Anderson, 1997).

Research reports about the effect of zero tillage or minimum tillage on bulk density have been contradictory. Bruce et al. (1990), Dao (1993) and Lal et al. (1994) found that bulk density decreased under minimum tillage. Other researchers found significantly higher bulk density under zero tillage than under conventional tillage (Gantzer and Blake, 1978; Ehlers et al., 1983; Mielke et al., 1986; Hammel, 1989; Grant and Lafond, 1993; Vyn and Raimbault, 1993). Blevins et al. (1977), Carefoot et al. (1990), Chang and Lindwall (1992), Mahboubi et al. (1993) and Lal (1999) report no differences among tillage treatments. The findings are inconsistent because soil texture, aggregation and organic C influence bulk density, in addition to tillage. It is likely that any reductions in bulk density due to tillage are short-term. In the long-term, tillage causes a loss of soil organic matter that leads to poor soil structure, including higher bulk density Karlen et al. (1990). Improper management of agricultural soils, for example, work carried out by machinery that is too heavy or too frequently used may also cause reduced porosity and increased bulk density (Fournier, 1989).

Although increased bulk density in tilled soils may indicate a trend toward lower soil quality, Bauer and Black (1981) suggest that even after many years of cultivation, most Chernozemic (Mollisol) soils still have only moderate bulk densities which do not adversely affect root or water penetration. Pierce et al. (1983) report that bulk density will not limit root growth until it is greater than about 1.3 g cm^{-3} in clayey soils or 1.6 g cm^{-3} in sandy soils.

Porosity..3.2.2.3 Porosity Soil structure determines the total porosity and geometry (shape and size) of individual pores in the soil. For plant growth, the soil is ideally a loose, friable and porous assemblage of aggregates which permit free movement of water and air and uninhibited root and microorganism growth (Hillel, 1982; Karlen et al., 1990).

Poor soil quality for plant growth is often caused by pore sizes that are too large or too small for the optimum retention and movement of water, and microorganism and plant root growth (Karlen et al., 1990). Soils with large pores retain less water, dry too quickly to sustain plant growth and are difficult to prepare into a suitable seedbed. Soils with small pores have limited aeration and may form crusts that restrict plant emergence, decrease infiltration, and increase surface runoff and soil erosional losses (Hillel, 1982).

Tillage changes the porosity characteristics of a soil, especially at the soil surface (Bruce et al., 1990). When surface aggregates break down during tillage they may form a layer which clogs the surface macropores and thus inhibits water infiltration and gaseous exchange Hillel (1982). The layer can form a dense, hard crust when it dries. These conditions can perpetuate a downward cycle of degradation, because tillage is used to break the crusts, but in doing so, more organic matter is oxidized and the problem is compounded (Karlen et al., 1990).

Drees et al. (1994) found that in zero tillage systems, extensive biological activity resulted in a greater mean aggregate size and increased pore size compared to conventional tillage systems. Lal et al. (1994) noted that, although zero tillage soils had a well-defined platy structure, there were more continuous pores and the zero tillage soils had a higher volume of pore space than the tilled soils. Pikul and Zizel (1994) found that pore volume of soils decreased over the winter in the absence of residue cover but not when the surface was completely covered with residue or snow.

Plant Available Water Holding Capacity. The ability to store and release water to plants is an important attribute of the soil, especially on the Prairies where a growing season moisture deficit is common in most regions and crop productivity is dependent on the soil's store of available water. Water retention is related to organic matter content, clay content and soil structure (Peterson et al., 1968; Bauer and Black, 1981; Emerson et al., 1986), as shown in Table 2.1.

The traditional wheat-fallow system was designed to conserve water, but it had, in fact, a low water storage efficiency (Tracy et al., 1990). Minimum tillage and zero tillage systems have been shown to improve the water retention capacity of soil, even if some chemical fallow is included in the management system (Nyborg and Mahli, 1989; Carefoot et al., 1990; Tracy et al., 1990; Dao, 1993). The differences are attributed to increases in organic C, pore size, infiltration and available water holding capacity in minimum tillage soils.

If more water is held in the soil, less nutrient-, soil particle- and pesticide-rich water is available to discharge into surface and ground water and the risk to water quality is reduced. As the hydrology of continuous-cropping, reduced tillage systems evolves to more closely resemble that of the grasslands, the number and size of water bodies, especially small sloughs, ponds and ephemeral streams may decline (Hayashi et al., 2003; Kamp et al., 1999, 2003). Although many of the water bodies now within the agricultural landscape are an artifact of agriculture, they have become wildlife habitats and their decline could limit the numbers of some wildlife species.

Soil Thickness and Rooting Depth. Shallow soils, or soils in which rooting depth is limited are generally less suited to plant growth than thicker soils. Rooting depth can be limited by erosion, dense or gravelly soil layers that impede root penetration, or layers that chemically inhibit root growth (Larson and Pierce, 1991).

Loss of surface soil by erosion reduces not only rooting depth, but also organic matter, available water holding capacity, soil fertility and yield (Olsen and Nizeyimana, 1988; Reganold, 1988). Gregorich and Anderson (1985) and Kiss et al. (1986) found that A horizon and solum thicknesses were reduced on upper slope positions by cultivation and consequent erosion, compared to native sites. Aguilar et al. (1988) found that where surface materials are lost to erosion, subsoil materials are incorporated into the Ap horizon of cultivated soils. This causes dilution of A horizon C, N and P, which reduces A horizon quality (Aguilar et al., 1988; Gregorich and Anderson, 1985). Gregorich and Anderson (1985) also suggest that solum thickness is reduced in cultivated soils because of increased bulk density in the Ap horizon.

Infiltration..3.2.5 Infiltration Pikul and Zuzel (1994) suggest that infiltration rate is a useful indicator of soil quality because it provides an integrated assessment of the influence of management practices on aggregation, porosity, surface crusting and soil density. Logsdon *et* al. (1993), Van Vliet et al. (1993), Tessier et al. (1990) and Lal (1999) found that infiltration and macroporosity increased and runoff declined as disturbance due to tillage declined. The differences were attributed to increased surface residue, increased organic C concentration, aggregate size and stability, and higher porosity in the minimum tillage soils (Tessier et al., 1990; Unger, 1992; Bruce et al., 1992; Dao, 1993).

Soil Temperature. Tillage, especially under fallow conditions, increases soil temperature and aeration, which are associated with an increase in the rate of organic matter decay (Mann, 1986; Hendrix et al*.,* 1988; Burke et al., 1989). The mulch layer that forms on the surface of minimum tillage soils tends to insulate the soil from temperature extremes and rapid desiccation, creating a more stable environment for biological activity (Hendrix et al. 1988). In Western Canada, soil temperatures in spring were lower under the surface mulch of minimum till than conventional tillage treatments (Carefoot *et* al., 1990; Nyborg and Mahli, 1989). Greater quantities of crop residues and increased soil water were responsible for the difference. Minimum or zero tillage systems may not be well suited to the coldest areas of the Prairies or Eastern Canada, if cool soil temperatures delay seeding or crop emergence (Schillinger et al., 1999; Arshad et al., 2002).

Soil Biological Properties..3.3 Soil Biological Properties Microbially mediated decomposition and transformations of soil organic matter are the primary driving forces that directly affect C mineralization, nutrient cycling and plant growth (Ocio and Brookes, 1990; Parr *et* al., 1992; Doran and Linn, 1994). Microbial biomass, potentially mineralizable N and soil respiration are good indicators of soil quality because they are affected by the size and activity of the soil microbial population, which, in agroecosystems is sensitive to tillage and cropping practices (Parr et al., 1992).

Microbial Biomass. The living fraction of soil organic matter, the microbial biomass, is a more sensitive indicator of changes in soil organic matter status than total soil organic C. The microbial biomass turns over within one to two years, so it is possible to detect changes due to management on this C pool long before they are detectable in the total organic matter (Carter, 1986; Sparling, 1992). Generally, a consistently high levels of microbial biomass C or N indicate good soil quality, whereas consistently low levels indicate poor soil quality (Duxbury and Nkambule, 1994).

The microbial biomass is both an agent of transformation of residues and soil organic matter and a sink or source for nutrients as the size of the population varies (Smith, 1994). In most ecosystems, C is the most limiting element for the microbial biomass (Doran and Linn, 1994) and population size and activity depend on how much plant C is added to the soil.

In highly disturbed soils, declining levels of soil organic carbon quantity and quality reduces the amount of “food” available for the microbial population and thus reduces the total microbial biomass in the soil (Granatstein et al., 1987; Smith and Paul, 1990; Dick, 1992). In a wheat-fallow rotation C inputs from roots, straw and exudates are often not enough to meet the C needs of the microbial biomass and the deficit is made up by decomposing soil organic matter. As a result both organic matter C and biomass are continually depleted (McGill et al., 1986).

The environment in the organic matter-rich surface layer of zero tillage soils results in a different type of microbial population than that found in the degrading environments of tilled soils. There is a higher water content, and higher levels of organic C and N in the surface soil under minimum tillage (Doran, 1980). Despite the availability of water and nutrients, the respiration rate of the microbial population is slower than in conventional tillage, mainly because the populations contain a higher proportion of fungi which are less decomposable and have greater growth efficiency than bacteria (Hendrix et al., 1986; Beare et al., 1992). The flush of nutrients that occurs following incorporation of residues into conventionally tilled soils is thus generally avoided in zero tillage systems.

Potentially Mineralizable Nitrogen and the Nitrifying Potential. Potentially mineralizable N is an indicator of the soil's capacity to supply N to crops. It is directly related to the amount of ‘young and active’ organic matter in a soil (Janzen, 1987b; Haider et al., 1991) which is higher under well fertilized, reduced tillage than conventional systems (Doran, 1980;Wood et al., 1990; Wood and Edwards, 1992). The nitrifying potential in zero tillage soils, tends to be higher throughout the A horizon (Groffman, 1985, Staley et al., 1990). Although nitrification tends to occur to a greater depth in the conventional tillage soils, the rate of nitrification in the surface layer is so much higher that total nitrification is greater in zero tillage soils.

Summary

Compared to conventional tillage systems, under direct-seeding, no-till management, soils generally are thicker with more organic matter and water-stable aggregates; there are higher rates of N mineralization and infiltration; and bulk density, pH, and soil respiration tend to be lower. The direct-seeded soils typically have larger and more diverse populations of soil microorganisms and a higher ratio of fungi to bacteria. Taken together, the indicators show that both the quantity and quality of soils organic C are improved under zero tillage. No-till soils have larger pools of young and active organic matter that strongly influences how the soils function, especially concerning nutrient cycling, resistance to erosion and water storage.

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