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Agronomic quantification of potential soil organic matter increase with direct seeding in Ukraine

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Abstract

Agricultural carbon (C) sequestration may be one of the most cost-effective ways to slow processes of global warming. Numerous environmental benefits may result from agricultural activities that sequester soil C and contribute to environmental security. As part of no-regret strategies, direct seeding practices that sequester soil C help reduce soil erosion and improve water quality and are consistent with more sustainable and less chemically dependent agriculture. This review will address potential soil organic matter increases in direct seeded or no till systems in Ukraine. While we learn more about soil C storage and its central role in direct environmental benefits, we must better understand the role of intensive tillage contributions to the secondary environmental benefits and what they mean to production agriculture. Increasing soil C storage can increase infiltration, increase fertility and nutrient cycling, decrease wind and water erosion, minimize compaction, enhance water quality, decrease C emissions, impede pesticide movement and generally enhance environmental quality. The sum of each individual benefit adds to a total package with major significance on a global scale. The ratification and enactment of the Kyoto Protocol will provide economic incentives for more rapid acceptance of conservation agriculture practices. Incorporating C storage in conservation planning with an understanding of less intensive tillage and crop residue management presents some challenges, but demonstrates concern for our global resources and presents a positive role for soil C that will have a major impact on our future quality of life.

Key Words: soil organic matter, soil quality, water quality, environmental quality, no-till, zero tillage, direct seeding, carbon sequestration

I. Introduction

Soil quality is the fundamental foundation of environmental quality. Soil quality is largely governed by soil organic matter (SOM) content, which is dynamic and responds effectively to changes in soil management, primarily tillage and C input. Maintaining soil quality can reduce problems of land degradation, decreasing soil fertility, and rapidly declining production levels that occur in large parts of the world needing the basic principles of good farming practice. This review will primarily address effects of no till (NT), zero till (ZT), and direct seeding (DS) on soil C and its associated environmental benefits within conservation production systems.

The terminology being developed for such systems is "Conservation Agriculture" (CA). Conservation agriculture implies conformity with all three of the "keys" supporting CA in figure 1. These three principles are minimum soil tillage disturbance, diverse crop rotations and/or cover crops, and continuous plant residue cover. The foundation underlying the three principles is how they interact with and contribute to soil C, the primary determinant of soil quality. Conservation agriculture includes concepts of NT, ZT and DS as the ultimate form of CA. These terms are often used interchangeably to denote minimum soil disturbance. Reduced tillage methods, sometimes referred to as conservation tillage, such as strip tillage, ridge tillage, and mulch tillage disturb a small volume of soil and partially mix the residue with the soil are intermediate on their soil quality effects. These terms require explicit definition of the tillage equipment and operation characteristics as they relate to soil volume disturbed and degree of soil-residue mixing. The extreme forms of intensive inversion tillage that include the moldboard plow, disk harrow and certain types of powered rotary tillage tools cannot be considered a form of conservation. This review will primarily address effects of NT, CT and DS on soil C and its associated environmental benefits within conservation production systems with emphasis on the three "keys" of CA. Other recent reviews on the role of C sequestration in CA were presented by Robert (2001), Uri (1999), Tebrugge & Guring (1999), Lal et al. (1998) and Lal (2000). Agriculture has an opportunity to offset some CO_2 emissions and will be a small, but significant player in sequestering C.

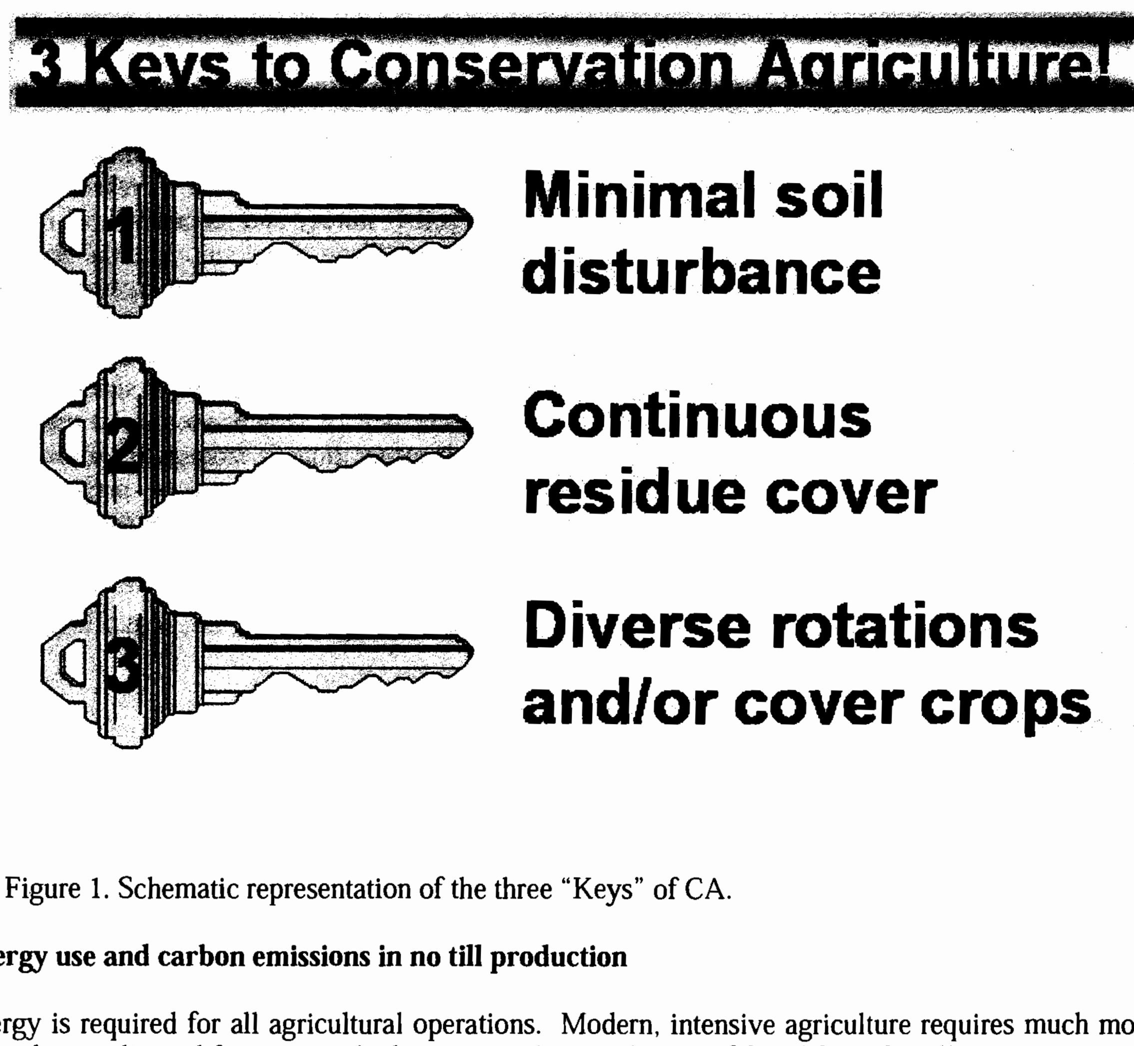

Figure 1. Schematic representation of the three "Keys" of CA.

Energy use and carbon emissions in no till production

Energy is required for all agricultural operations. Modern, intensive agriculture requires much more energy input than traditional farming methods since it relies on the use of fossil fuels for tillage, transportation, grain drying, and the manufacture of fertilizers, pesticides, and equipment used to apply agricultural inputs, and for generating electricity used on farms (Frye, 1984). Tillage and harvest operations account for the greatest proportion of fuel consumption within intensive agricultural systems. Frye (1984) found fuel requirements using NT or reduced tillage systems were 55 and 78%, respectively, of that used for conventional systems that included moldboard plowing. On an area basis, savings of 23 kg C ha^{-1} yr^{-1} in energy costs resulted from the conversion of conventional till to no-till. For the 186 million ha of cropland in the US, this translates to a potential C savings of 4.3 MMTCE yr^{-1}. Kern and Johnson (1993) calculated that conversion of 76% of the cropland planted in the US to conservation tillage could sequester as much as 286 to 468 MMTCE over 30 years and concluded that US agriculture could become a net sink for C. Lal (1997) provided a global estimate for C sequestration from conversion of conventional to conservation tillage that was as high as 4,900 MMTCE by 2020. Combining economics of fuel cost reductions and environmental benefits derived by converting to conservation tillage are positive first steps for agriculture toward decreasing C emissions into the atmosphere.

Practices that require lower energy inputs, such as NT versus conventional-tillage, generally result in lower inputs of fuel and a consequent decrease of CO_2-C emissions into the atmosphere per unit of land area under cultivation. Emissions of CO_2 from agriculture are generated from four primary sources: manufacture of and machinery used for cultivating the land, production and application of fertilizers and pesticides, the SOC that is oxidized following soil disturbance largely dependent on tillage practices, and energy required for irrigation and grain drying. West and Marland (2002) conducted a full C cycle analysis for agricultural inputs, resulting in estimates of net C flux for three crop types across three tillage intensities. The full C cycle analysis includes estimates of energy use and C emissions for primary fuels, electricity, fertilizers, line, pesticides, irrigation, seed production, and farm machinery. They estimated that CO_2-C emissions from agricultural machinery used in farm operations for conservation-, reduced-, and no-tillage practices were 72, 45, and 23 kg C ha^{-1} yr^{-1}, respectively. Total C emissions values were used in conjunction with C sequestration estimates to model net C flux to the atmosphere over time. Based on US average crop inputs, no-till emitted less CO_2 from agricultural operations than did conventional tillage with 137 and 168 kg of C ha^{-1} yr^{-1}, respectively. The effect of changes in fossil-fuel use is the dominant factor 40 years after conversion to NT. This analysis of available data on US agriculture suggests that, on average, a change from conventional till to no-till will result in C sequestration in soil plus a savings in CO_2 emissions from energy use in agriculture. While the enhanced C sequestration will continue for a finite time until a new equilibrium is reached, the reduction in net CO_2 flux to the atmosphere, caused by the reduced fossil fuel use, can continue indefinitely, as long as the alternative practices are continued.

Lal (2004) recently provided a synthesis of energy use in farm operations and its conversion into C equivalents (CE). The principal advantage of expressing energy use in terms of C emission as kg CE lies in its direct relation to the rate of enrichment of atmospheric CO_2 concentration. The operations analyzed were C-intensive agricultural practices that included tillage, spraying chemicals, seeding, harvesting, fertilizer nutrients, lime, pesticide manufacture and irrigation. The emissions for different tillage methods were 35.3, 7.9, and 5.8 kg CE ha^{-1} for conventional till, chisel till or minimum till and NT methods of seedbed preparation, respectively. These results further support the energy efficiencies of no till. Conversion of plowed till to NT, using integrated nutrient management and pest management practices, and enhancing water use efficiency can save C emissions and at the same time increase the soil C pool. Thus, adopting conservation agriculture techniques is a holistic approach to management of soil and water resources. Conservation agriculture improves efficiency and enhances productivity per unit consumption of C based inputs and is a sustainable strategy that requires global policy support.

Carbon sequestration using no till

Conservation agriculture is receiving much global focus as an alternative to the use of conventional-tillage systems and as a means to sequester SOC (Garcia-Torres et al. 2001; Follett, 2001, Reicosky, 2001a). Conservation agriculture can work under many situations and is cost-effective from a labor standpoint. More importantly are the practices that sequester SOC contribute to environmental quality and the development of a sustainable agricultural system. Tillage or other practices that destroy SOM or causes loss and result in a net decrease in SOC do not result in a sustainable agriculture. Sustainable agricultural systems involve those cultural practices that increase productivity while enhancing C sequestration. Crop residue management, conservation tillage, efficient management of nutrients, precision farming, efficient management of water, and restoration of degraded soils all contribute to a sustainable agriculture.

Soil tillage practices are of particular significance to the SOC status of soils because they affect SOC dynamics directly and indirectly. Tillage practices which invert or considerably disturbed the surface soil reduce SOC by increasing decomposition and mineralization of biomass due to increased aeration and mixing a plant residues into the soil, exposing previously protected SOC in soil aggregates to soil fauna, and by increasing losses due to soil erosion (Lal, 1984; Dick et al., 1986a, b; Lal 1989; Blevens and Frye, 1993; and Tisdall, 1996). Conversely, long-term NT or reduced tillage systems increase SOC content of the soil surface layer as a result of various interacting factors, such as increased residue return, less mixing and soil disturbance, higher soil moisture content, reduced surface soil temperature, proliferation of root growth and biological activity, and decreased risks of soil erosion (Lal,1989; Havlin et al., 1990; Logan et al., 1991; Blevens and Frye, 1993; Lal et al.,1994a, b).

Cambardella and Elliott (1992) observed for a loam soil that SOC content in the 0- to 20- cm depth was 3.1, 3.5, 3.7, and 4.2 kg m^{-2} for bare fallow, stubble mulch, no till and native sod, respectfully. They observed that tillage practices can lead to losses of 40% or more of the total SOC during a period of 60 years. Edwards et al. (1992) observed that conversion from MP till to NT increased SOC content in the 0- to 10-cm layer from 10 g kg^{-1} to 15.5 g kg^{-1} in 10 years, an increase of 56%. Lal et al. (1998) stated "A summary of the available literature indicates that the SOC sequestration potential of conversion to conservation tillage ranges from 0.1 to 0.5 metric tons ha^{-1} yr^{-1} for humid temperate regions and from 0.05 to 0.2 metric tons ha^{-1} yr^{-1} for semi arid and tropical regions." They further estimate that the SOC increase may continue over a period of 25 to 50 years, depending on soil properties, climate conditions, and management.

Carbon sequestration in the soil has benefits beyond removal of CO_2 from the atmosphere. No- till cropping reduces fossil fuel use, reduces soil erosion, and enhances soil fertility and water-holding capacity. Beneficial effects of conservation tillage on SOC content, however, may be short-lived if the soil is plowed, even after a long time under conservation tillage (Gilley and Doran, 1997; Stockfisch et al., 1999). Stockfisch et al. (1999) concluded that organic matter stratification and accumulation as result of long-term minimum tillage were completely lost by a single application of inversion tillage in the course of a relatively mild winter. Tillage accentuates C oxidation by increasing soil aeration and soil residue contact, and accelerates soil erosion by increasing exposure to wind and rain (Grant, 1997). Several experiments in North America have shown more SOC content in soils of conservation tillage compared to plow till seed beds (Doran, 1980; Doran et al.1987; Rasmussen and Rohde, 1988; Tracy et al. 1990; Havlin et al. 1990; Kern and Johnson, 1993; Lafond et al., 1994; Reicosky et al., 1995; Reicosky, 2001b).

Similar to the merits of NT reported in North America, Brazil and Argentina (Lal, 2000; Sa et al., 2001), several studies have reported a high potential for SOC sequestration in European soils. In an analysis of 17 European tillage experiments, Smith et al. (1998) found that the average increase of SOC, with a change from conventional tillage to NT was 0.73 ±0.39% per year and that SOC may reach a new equilibrium in approximately 50 to 100 years. Analysis of some long-term experiments in Canada (Dumanski et al., 1998) indicated that SOC can be sequestered for 25 to 30 years at a rate of 50 to 75 g C m^{-2} yr^{-1}, depending on the soil type in well fertilized Cherozem and Luvisol soils cropped continuously to cereals and hay. Analysis of these Canadian experiments focused on crop rotations, as opposed to tillage, and is unique in that it considered rates of C sequestration with regard to soil type.

On a global basis, West and Post (2002) suggested that soil C sequestration rates with a change to NT practices can be expected to have a delayed response, reach a peak sequestration rate in five to 10 years, and then decline to nearly 0 in 15 to 20 years based on regression analysis. This agrees with a review by Lal et al. (1998) based on results from Franzluebbers and Arshad (1996) that there may be little or no increase in SOC in the first two to five years after a change in management practice, followed by a large increase in the next five to 10 years. Campbell et al. (2001) concluded that wheat rotation systems in Canada will reach an equilibrium following a change to no till, after 15 to 20 years, provided average weather conditions remain constant. Lal et al. (1998) estimate that rates of C sequestration may continue over a period of 25 to 50 years.

The different estimates of C sequestration may be expected partly based on different rotations and rotation diversity.

The concept that each soil has a finite C storage capacity is being revisited. This has important implications on soil productivity and the potential of using soil to enhance soil C storage and reduce greenhouse gases in the atmosphere. Most agricultural and degraded soils can provide significant potential sinks for atmospheric CO_2. However, soil C accumulation does not continue to increase with time with increasing C inputs but reaches an upper limit or carbon saturation level which governs the ultimate limit of the soil C sink (Goh, 2004). The relation between NT and CT in the way they affect soil C stocks is open to further debate and definition of carbon pools. The relationship between tillage-induced changes in soil structure and subsequent effect on C loss was reviewed by Six, et al. (2002) within the framework of a newly proposed soil C-saturation concept. They differentiate SOM that is protected against decomposition by various mechanisms from that which is not protected and discuss implications of changes in land management on processes that affect C release. This new model defines a soil C-saturation capacity, or a maximum soil C storage potential, determined by the physicochemical properties of the soil and is differentiated from models that suggest soil C stocks increase linearly with C inputs. Presumably, this C saturation capacity will be soil, climate, and management specific. This causes a change in the thinking about C sequestration and that a soil dependent natural limit may exist both in natural and managed systems. Superimposed on this analysis is the role of glomalin, a sticky substance produced by fungal hyphae that helps glue soil aggregates together (Nichols and Wright, 2004). No till is one management practice that has been successful in increasing the hyphal fungi that produce glomalin. The next researchable challenge will be to determine if the C saturation and glomalin over the entire profile in NT and CT systems is substantially different. Presumably with less tillage-induced breakdown of soil aggregates, NT may have an advantage over CT. The final answer awaits further research.

Agriculture alters the terrestrial nitrogen cycle as well. Through nitrogen fertilization, annual cropping, monocropping, and improper water management, nitrogen is more prone to being lost both to ground or surface water and the atmosphere. Nitrous oxide (N_2O), a common emission from agricultural soils, is a potent greenhouse gas (310 times more potent had than CO_2) that has increased its atmospheric concentration by 15% during the past two centuries (Mosier et al., 1998). Reductions can be achieved through improved nitrogen management, as well as with irrigation water management because N_2O is generated under both aerobic conditions (where nitrification occurs) and anaerobic conditions (where denitrification occurs) in the soil.

Due to the tightly coupled cycles of C and N, changes in rates of C sequestration and terrestrial ecosystems will directly affect N turnover processes in the soils and biosphere-atmosphere exchange of gaseous N compounds. Some data suggests that increasing N_2O emissions may be closely linked to increasing soil C sequestration (Robertson, et al. 2000; Mosier et al. 1991; Vinther, 1992; Mackenzie et al. 1998). If NT is a truly viable management practice, it must mitigate the overall impact of NT adoption by reducing the net global warming potential determined by the fluxes of all the greenhouse gases, including N_2O and CH_4 (methane). Six et al. (2004) assessed potential global warming mitigation with the adoption of NT in temperate regions, by compiling all available data reporting differences in fluxes of soil-derived C, N_2O, and CH_4 between conventional till and NT systems. Their analysis indicated that, at least for the first decade, switching from conventional till to NT would generate enhanced N_2O emissions for humid environments and somewhat lower emissions for dry environments which would offset some of the potential C sequestration gains; and that after 20 years, N_2O emissions would return to or drop below conventional tillage fluxes. They found, that N_2O emissions with a high global warming potential drive much of the trend in net global warming potential suggesting that improved N management is essential to realize the full benefit from C storage in the soil for purposes of global warming mitigation. They suggested caution in the promotion of NT agriculture to reduce greenhouse gas emissions and that the total radiative forcing needs additional consideration beyond just the benefit of C sequestration. They suggested that it is critical to investigate the long-term as well as short-term effects of various N management strategies for long-term reduction of N_2O fluxes under NT conditions. These results suggest the need for more basic research on N_2O emissions during the transition from conventional till to no till and after equilibrium conditions have been achieved to adequately quantify the C offsetting effects in global warming potential.

The literature holds considerable evidence that intensive tillage decreases soil C and supports increased adoption of new and improved forms of conservation tillage or direct seeding to preserve or increase SOM (Lal et al., 1998; Paul et al., 1997; and Reicosky et al., 1995). Based on the soil C losses with intensive agriculture, reversing the decreasing soil C trend with less tillage intensity should be beneficial to agriculture and the global population by gaining better control of the global C balance (Houghton et al., 1983; Schlesinger et al., 1985). The environmental and economic benefits of conservation tillage and DS demand their consideration in the development of improved management practices for sustainable production. However, the benefits of NT on SOC sequestration may be soil or site-specific, and the improvement of SOC may be inconsistent on fine textured and poorly drained soils (Wander et al., 1998). Six et al. (2004) indicated a strong time dependency in the GHG mitigation potential of NT agriculture, demonstrating that GHG mitigation by adoption of NT is much more variable and complex than previously considered.

In Brazil most, but not all, studies indicate that the introduction of ZT increases SOM (Bayer, et al., 2000a, b; Sa et al., 2001). Sisti et al. (2004) evaluated changes in soil C in a 13-year study comparing three different cropping rotations under ZT and CT in a clayey Oxisol soil sampled to 100 cm. They found under a continuous sequence of winter wheat and summer soybean, the stock of soil C to 100 cm under ZT was not significantly different to that under CT. However, in rotations with a vetch crop, soil C stocks were significantly higher under ZT than under CT. They concluded that the contribution of N fixation by the legume crop was the principal factor responsible for the observed C accumulation in the soil under ZT. The results demonstrate the role of diverse crop rotations, especially including legumes supplying organic N under ZT for the accumulation of soil C. The dynamic nature of the C:N ratio may require additional organic N to increase C sequestration at depth. Sisti et al., (2004) found much of the N gain was at depths below the plow layer suggesting that most of the accumulated soil C was derived from crop root residues.

Cropping systems and N fertilization affect plant biomass production, partially controlling input of organic C to the SOM stocks. Further work in Brazil reflects the importance of soil and plant management affects on soil C and N losses to 1 m depth (Diekow et al. 2005). They evaluated C and N losses during a period of conventional cultivation that followed on native grassland and a 17-year no till cereal-and legume-based cropping systems with different N fertilization levels to increase C and N stocks. With N fertilization, the C and N stocks of oat/maize rotation were steady with time. However, they found increased C and N stocks due to higher residue input in the legume-based cropping systems. The long-term NT legume-based cropping systems and N fertilization improved soil C and N stocks of the previously cultivated land to the original values of the native grassland. Nitrogen and legume residues in a rotation were more effective for building soil C stocks than inorganic N from fertilizer applied to the grass crop in the rotation. In addition, legume N does not require the cost of using fossil fuel to manufacture N fertilizer. The dominant soil change took place in the surface layer; however deeper layers were important for C and N storage that leads to improved soil and environmental quality.

What is the Kyoto Protocol?

The Kyoto Protocol is an international agreement setting targets for industrialized countries to cut their GHG and may provide economic incentives for managing carbon. The Kyoto Protocol is an amendment to the United Nations Framework Convention on Climate Change (UNFCCC), an international treaty on global warming. It also reaffirms sections of the UNFCCC. Countries which ratify this protocol commit to reduce their emissions of CO_2 and five other GHGs or engage in emissions trading if they maintain or increase emissions of these gases, which have been linked to global warming. These gases are considered at least partly responsible for global warming - the rise in global temperature which may have catastrophic consequences for life on earth. The formal name of the proposed agreement, which reaffirms sections of the UNFCCC, is the Kyoto Protocol to the United Nations Framework Convention on Climate Change. (*http://www.cnn.com/SPECIALS/1997/global.warming/stories/treaty/*). The protocol was negotiated in Kyoto, Japan in December 1997, opened for signature on March 16, 1998, and closed on March 15, 1999. The agreement came into force on February 16, 2005 following its official ratification by Russia on November 18, 2004.

The detailed requirements for a C accounting system are still being developed by the Intergovernmental Panel on Climate Change (IPCC) under the UNFCCC. The IPCC is in the process of developing *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories.* This document is intended to be submitted for the 9[th] Conference of the Parties (COP9) to the UNFCCC. Any C accounting standard developed prior to the release of this document will need to be varied to be consistent with the IPCC document before C credits generated from C sinks can be used in an emissions trading regime under the Kyoto Protocol. The concept of carbon credits within the Kyoto protocol can be addressed several ways; Clean Development Mechanism (CDM) is project between Annex I and Annex II countries, Joint Implementation (JI) with projects between Annex I countries, Emissions Trading (ET) that allows transfer of assigned amount of units internationally and domestic carbon credit training. The two types of carbon credits and markets allow Emission Reduction Units (ERU) that are more permanent in nature and traded like a commodity. The Emission Removal Units (RMU) are not permanent and treated as a lease. The protocol sets a commitment period of 2008 to 2012. The 30 industrialized countries that signed up to reduce their emissions must prove they have done so as an average over the five years. The Kyoto Protocol aimed to reduce global emissions of GHG for those 30 countries by 5.2 % below 1990 levels (Grubb et al. 1999). At the present time, soil carbon credits are acknowledged but not considered part of the Kyoto protocol. The development of international carbon trading markets will provide economic incentives that will eventually allow soil carbon credits to be allowed along with the economic returns. For the present, there is a degree of uncertainty for investors and potential investors in forest related C sinks over the specific rules that will apply to implementation of the sinks provisions of the Kyoto Protocol. Investors and potential investors in C sinks need to be aware that there is uncertainty at the international level. Administration and transaction costs could play a key role in determining the success of any C credit trading system. Cost of these areas are expected to be minimized through improved techniques and services for measuring and reporting sequestered C, private sector consultants, economies of scale, and the emergence of market mechanisms and strategies such as C pooling or aggregating. There are risks involved in selling C credits in advance of any formalized international trading system and those participating in early trading need to clarify responsibilities and obligations. However, care should be taken in the design of these policies to ensure their success and to avoid unintended adverse economic and environmental consequences and to provide maximum social benefit.

Policies for carbon and water management

Agricultural policy should play a prominent role in agro-environmental instruments to support a sustainable development of rural areas with limited water and respond to society's increasing demand for environmental services. Environmental protection and nature conservation require enhanced management skills that create extra work and cost for the farmers, but in no other sector can so much be achieved for the environment with so little input. We must no longer take for granted the contribution made to society by farmers through environmental measures but must compensate them appropriately through stewardship payments. Farmers using conservation techniques stand to gain from protecting the environment because it is in their fundamental economic interest to conserve natural resources for the future. It is in all our economic interests to have healthy and sustainable ecosystems to enhance our quality of life. The true economic benefits can only be determined when we assign monetary values to externalities of environmental quality. It makes more economic sense to take account of nature conservation from the outset than to repair damage after it is done, and in many cases the repair may not even be possible. Conservation agriculture without intensive tillage can play a major role in sequestering soil C and conserving soil water providing long-term global economic and environmental benefits.

There are four broad opportunities that should be pursued by national policies to prevent soil degradation and water pollution. These opportunities are to (1) conserve and enhance soil quality as the first step toward environmental improvement; (2) increase nutrient, pesticide, and irrigation use efficiencies in farming systems; (3) increase the resistance of farming systems to erosion and runoff; and (4) make greater use of field and landscape buffer zones. Realizing those opportunities depends on the ability and willingness of producers to change their management and production practices. Producers, however, do not make isolated changes in these practices. A change in one production or management practice affects other components of the farming system that producers manage. Programs and policies that pursue these four opportunities, therefore, should also incorporate a systems perspective.

The agricultural practices used to increase soil C sequestration include some of today's most advanced conservation and production practices. No-till, for example, is one of the most powerful means of sequestering C. No-till is being adopted by leading producers for its ability to increase production where water is limiting, reduce fuel use, and reduce soil losses from erosion and also helps sequester C and store greenhouse gases. Conservation agriculture with enhanced soil C and water management is a win-win strategy. Agriculture wins with improved food and fiber production systems and sustainability. Society wins because of the enhanced environmental quality. The environment wins as improvements in soil, air and water quality are all enhanced with increased amounts of soil C that result in increased water use efficiency.

Summary

Direct seed farming and associated C sequestration practices can lead to better water and air quality, better wildlife habitat and mitigate the greenhouse effect and possibly serve as an additional revenue source for farmers in the Ukraine. Carbon sequestration alone can not solve the climate change dilemma, but as we search for technological advancements and economic incentives that allow us to create energy with less pollution, and as we continue to research the cause and potential effects of climate change, it only makes sense that we enhance a natural process we already know has the benefit of reducing existing concentrations of greenhouse gases, particularly when this process also improves water quality, soil fertility and wildlife habitat. As management changes, benefits in soil properties and environmental quality might appear in several ways as we better quantify soil carbon. The first is improved soil structure, with surface structure becoming more stable and less prone to crusting and erosion. Water infiltration could improve, meaning less surface runoff. As SOM increases, soil water and nutrient capacity increases significantly. And crops will fare better during drought because infiltration and water-holding capacity have improved. Soil organic matter and the associated soil biological population will increase in vigor and numbers with more diverse crop rotations. Organic matter also may bind pesticides, suppress disease organisms, and improve crop health and vigor as soil biological activity and diversity increase. Improvements can be expected in water quality as sediment and nutrient loads decline in surface water from better soil aggregation, in air quality as dust, allergens, and pathogens in the air decline, and in agricultural productivity. The ratification and enactment of the Kyoto Protocol will provide economic incentives for more rapid acceptance of conservation agriculture practices. Accepting the challenges of maintaining food security by incorporating C storage in conservation planning demonstrates concern for our global resources and our willingness to work in harmony with nature. This concern presents a positive role for conservation agriculture that will have a major impact on global sustainability and our future quality of life.

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