Simpósio sobre

PLANTIO DIRETO E MEIO AMBIENTE

Sequestro de Carbono e Qualidade da Água

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ALTERNATIVES TO MITIGATE THE GREENHOUSE EFFECT: EMISSION CONTROL BY CARBON SEQUESTRATION

ALTERNATIVAS PARA MITIGAR O EFEITO ESTUFA: CONTROLE DAS EMISSÕES PELO SEQÜESTRO DE CARBONO

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Resumo

O carbono do solo é o principal determinante na qualidade do solo e é a base fundamental para a qualidade do meio ambiente. A qualidade do solo é governada pelo conteúdo da matéria orgânica do solo (MOS) e sua dinâmica e resposta é influenciada pela mudança no manejo do solo e pela adição de C via resíduo cultural.. A agricultura conservacionista pode melhorar a harmonia entre o homem e o meio ambiente através da redução das emissões do dióxido de carbono (CO_2). Embora esta contribuição seja ainda pequena no contexto geral das principais fontes emissoras, torna-se significativa do ponto de vista do armazenamento e seqüestro de C no solo. Preliminarmente as avaliações indicam que o sequestro de C no solo pode ser uma ferramenta de manejo para reduzir parcialmente as emissões derivadas da queima de combustíveis fósseis. Na agricultura nós temos um papel importante porque uma grande quantidade de C do ciclo de C está no solo e relacionada com os sistemas de produção. A não adoção da rotação de culturas associada ao preparo intensivo do solo reduz a qualidade do solo e o conteúdo da MOS resultando na perda de C. Qualquer operação que remove ou incorpora os resíduos culturais contribuem para o declínio do C do solo através de perdas diretas ou pela oxidação biológica. A agricultura é uma fonte importante para manutenção da qualidade da água dos rios, mananciais e lagos e tem um papel importante a serviço do ecossistema. Nutrientes como o nitrogênio e fósforo, os sedimentos e os patógenos são poluentes oriundos da agricultura. A agricultura não é considerada uma fonte de poluição, entretanto, a água da chuva escorre sobre o solo, carregando poluentes e depositando nos lagos, rios, pântanos, nas áreas da costa e nos mananciais utilizados para tratamento de água potável.

Praticas que proporcionam o seqüestro de C que possam reduzir a erosão do solo e o excesso de fertilizantes utilizados, pode dessa forma reduzir o escorrimento dos poluentes e contribuir para melhorar a qualidade da água e para prevenir as mudanças climáticas. Os produtores que adotam o plantio direto associando a práticas para seqüestrar o C podem proporcionar a melhor qualidade ambiental para as espécies de vida selvagem e mitigar o efeito dos gases que causam o aquecimento global. O seqüestro de C isoladamente não resolve o dilema das mudanças climáticas, mas, nós procuramos por avanços tecnológicos que nos permita criar energia com menor poluição e continuar a procurar a causa e o potencial do efeito das mudanças climáticas. Isso somente faz sentido porque nós estamos aumentando os processos naturais e sabendo que os benefícios da redução desses gases resulta na melhoria da qualidade da água, fertilidade do solo e da vida silvestre. Com a mudança para práticas de manejo conservacionista, os benefícios em propriedades do solo e na qualidade do meio ambiente aparecem de diversas maneiras. Em primeiro lugar melhora a estrutura do solo, tornando-se mais estável e menos susceptível ao encrostamento a erosão. Em adição, melhora a infiltração da água e menor escorrimento superficial. Com o aumento da MOS, ocorre o aumento da retenção da água no solo e capacidade de retenção de nutrientes de forma significativa. A resposta das culturas será melhor porque teremos maior infiltração e maior capacidade de retenção de água. A MOS está associada ao aumento da população de microrganismos e a sua biodiversidade e será ainda mais influenciada pela rotação de culturas.

A MOS pode ainda ligar-se com pesticidas, estimular microrganismos supressores e reduzir microrganismos patogênicos e aumentar a saúde e o vigor das culturas devido a diversidade da atividade biológica. Pode também melhorar a qualidade da água, reduzindo a erosão e o escorrimento de sedimentos devido ao aumento da agregação do solo, reduzindo a poluição do ar e finalmente melhorar a produtividade das culturas. Se aceitarmos o desafio de produzir alimentos e fibras com segurança com a adição de C via resíduos culturais e aumentar o armazenamento do C no solo através

de planos conservacionistas estaremos demonstrando a preocupação com os recursos globais para desenvolver um trabalho em harmonia com a natureza. Essa preocupação tem um papel positivo para a agricultura conservaçionista e será o principal impacto para a sustentabilidade global e para nossa futura qualidade de vida.

Key Words: no-till, CO_2 emissions, sustainability, soil carbon, soil organic matter, carbon credits

Introduction

World soils are important reservoirs of active carbon (C) and play a major role in the global C cycle. Intensive agriculture with tillage has contributed to changes in the concentration of greenhouse gases in the atmosphere. Agriculture is believed to cause some environmental problems, especially related to water use, water contamination, soil erosion and greenhouse effect (Houghton, Hackler & Lawrence, 1999; Schlesinger, 1985; Davidson & Ackerman, 1993). The soil contains two to three times as much C as the atmosphere. In the last 120 years, intensive agriculture has caused a C loss between 30 and 50%. By minimizing the increase in ambient carbon dioxide (CO_2) concentration through soil C management, we minimize the production of greenhouse gases and minimize potential for climate change. Recent results suggest scientific agriculture can also lessen environmental problems and mitigate the greenhouse effect. In fact, agricultural practices have the potential to store more C in the soil than agriculture releases through land use change and fossil fuel combustion (Lal, et al., 1998).

Conservation agriculture can enhance the harmony between man and the environment by offsetting some CO_2 emissions and will be a small, but significant player in storing or sequestering C (Reicosky, 2001). Preliminary assessments indicate that soil C sequestration can be a management tool to partially offset C emissions from burning fossil fuels. We in agriculture play a significant role because of the large amount of soil C in the C cycle within agricultural production systems. The limited use of crop rotations combined with the intensive tillage decreases soil quality and soil organic matter as a result of C loss. Any operation that removes or incorporates crop residue contributes to the decline of soil C through direct loss or increased biological oxidation. The drive to maximize profit in food and fiber production has created environmental problems that have slowly crept up on conventional agriculture that now requires new knowledge, research and innovation to overcome these concerns for sustainable production.

Over the past 150 years, the amount of CO_2 in the atmosphere has increased by 30%. Many scientists believe there is a direct relationship between increased levels of greenhouse gasses, especially CO_2 in the atmosphere and rising global temperatures. One proposed method to reduce atmospheric CO_2 buildup is to increase the global storage of C in soils. Additional benefits to this solution are the potential for simultaneous enhancement in agricultural production and ecosystem services for enhanced environmental quality. Soil C sequestration through conservation agriculture may be one of the most economical ways to reduce C emissions to buy time to help society develop cleaner fuels and produce in harmony with nature. Soil organic C is a valuable resource and is a renewable resource from which we can gain many environmental benefits by increasing its levels. Society needs to look at agriculture as part of the solution to an increasing concern, namely global climate change. Conservation agriculture can play a major role in enhancing soil C and environmental quality in our production systems.

Soil C is a major determinant of soil quality and 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. This review will primarily address soil C and water quality as they relate to environmental benefits. (See other recent reviews on the role of C sequestration in conservation agriculture were presented by Robert (2001), Uri (1999), Tebruegge & Guring (1999), Lal *et al.* (1998) and Lal (2000).)

Ecosystem services provided by soil carbon

Agriculture is an important source of water quality impairment for our rivers, streams and lakes and thus plays an important role in ecosystem services. Nutrients like nitrogen and phosphorus, sediments and pathogens are the primary agricultural pollutants. Agriculture is considered a non-point source of pollution, whereby rain water runs over and through agricultural soils and picks up pollutants, finally depositing them into lakes, rivers, wetlands, coastal waters, and even our underground sources of drinking water. Carbon sequestration practices that reduce soil erosion and excess fertilizer usage can decrease pollutant runoff and thus contribute to improved water quality, in addition to preventing climate change.

Understanding the role of soil C and biodiversity in agricultural ecosystems has highlighted the value and importance of a range of processes that maintain and fulfill human needs. These basic needs are called "ecosystem services" that are the basis of our economic and social system. Ecosystem services are the processes by which the environment produces resources that we often take for granted. An ecosystem is a community of people, animals and plants interacting with one another and with their physical environment. Ecosystems include physical, chemical and biological components such as soils, water, and nutrients that support the biological organisms living within them. Agricultural ecosystem services include production of food, fiber and biofuels, provisions of clean air and water, natural fertilization, nutrient cycling in soils, mitigation of climate, pollination, genetic resources, recreational, cultural and social benefits and many other fundamental life support services required for our existence. These services may be enhanced by increasing the amount of C stored in soils. Our agricultural ecosystems help moderate weather extremes and their impacts, mitigate natural droughts and floods, protect stream and river channels and coastal shores from erosion, control agricultural pests, maintain biodiversity, generate and preserve soils and renew their fertility, detoxify and decompose wastes, purify the water and air, regulate disease carrying organisms, to name a few. Conservation agriculture through its impact on soil C is the best way to enhance ecosystem services. Recent analyses have estimated national and global economic benefits from ecosystem services of soil formation, nitrogen fixation, organic matter decomposition, pest bio-control, pollination and many others. Intensive agricultural management practices damage or destroy ecosystem services, in the form of changes in nutrient cycling, primary productivity, species diversity, species dominance, and population fluctuation in exchange for economic productivity (Smith *et al.*, 2000). Soil C plays a critical role in the harmony of our ecosystems providing these services.

Carbon sources and sinks in agricultural systems

Agricultural systems contribute to C emissions through several mechanisms including direct use of fossil fuels in farm operations, indirect use of energy inputs for manufacturing chemicals (typically fertilizers), irrigation and grain drying and through intensive tillage of soils resulting SOM loss. With conservation agriculture techniques, soils can accumulate C to offset other C losses. Thus, the soil can be converted from a "source" of C to a "sink" for C with improved soil and crop management.

Preliminary assessments indicate that soil C sequestration can be a tool to offset C emissions from burning fossil fuels. We in agriculture play a significant role because of the large amount of soil C in the C cycle within agricultural production systems. The limited use of crop rotations combined with intensive tillage decreases soil quality and soil organic matter. Any operation that removes or incorporates crop residue contributes to the decline of soil C through increased biological oxidation.

A case for conservation agriculture and zero tillage

Tillage or soil preparation has been an integral part of traditional agricultural production. Tillage is also a principal agent resulting in soil perturbation and subsequent modification of the soil structure with soil degradation. Intensive tillage loosens soil, enhances the release of soil nutrients for crop growth, kills the weeds that compete with crop plants for water and nutrients and modifies the circulation of water and air within the soil. Intensive tillage can adversely affect soil structure and cause excessive break down of aggregates leading to potential soil movement via erosion. Intensive tillage causes soil degradation through C loss and tillage-induced greenhouse gas emissions that impact productive capacity and environmental quality (Reicosky, 2001). Intensive tillage also causes a substantial short-term increase in soil evaporation to rapidly deplete the surface layer.

Recent studies involving a dynamic chamber, various tillage methods and associated incorporation of residue in the field indicated major C losses immediately following intensive tillage (Reicosky & Lindstrom, 1993 & 1995). The moldboard plow had the roughest soil surface, the highest initial CO_2 flux and maintained the highest flux throughout the 19-day study. High initial CO_2 fluxes were more closely related to the depth of soil disturbance that resulted in a rougher surface and larger voids than to residue incorporation. Tillage associated with low soil disturbance and small voids caused lower CO_2 and water fluxes with no-till having the least amount of CO_2 and water loss during 19 days. The large gaseous losses of soil C following moldboard plowing compared to relatively small losses with direct seeding (no-till) showed why crop production systems using moldboard plowing have decreased SOM and why no-till or direct seeding crop production systems are stopping or reversing that trend. The short-term cumulative CO_2 loss was related to the soil volume disturbed by the tillage tools. Reicosky (1998) determined the impact of strip tillage methods on CO_2 and water loss after five different strip tillage tools and no-till. The highest CO_2 fluxes were from the moldboard plow and subsoil shank tillage. Fluxes from both slowly declined as the soil dried. The least CO_2 flux was measured from the no-till treatment. The other forms of strip tillage were intermediate with only a small amount of CO_2 detected immediately after the tillage operation. These results suggest that the CO_2 fluxes appear to be directly and linearly related to the volume of soil disturbed. Intensive tillage fractured a larger depth and volume of soil and increased aggregate surface area available for gas exchange that contributed to the vertical gas flux. The narrower and shallower soil disturbance caused less CO_2 and water loss suggest that the volume of soil disturbed must be minimized to reduce C loss and impact on soil and air quality. The results suggest environmental benefits and water and C storage of strip tillage over broad area tillage that needs to be considered in soil management decisions.

Reicosky (1997) reported that average short-term C loss from four conservation tillage tools was 31% of the CO_2 from the moldboard plow. The moldboard plow lost 13.8 times more CO_2 as the soil not tilled while conservation tillage tools averaged about 4.3 times more CO_2 loss. The smaller CO_2 loss from conservation tillage tools was significant and suggests progress in equipment development for enhanced soil C management. Conservation tillage reduces the extent, frequency and magnitude of mechanical disturbance caused by the moldboard plow and reduces the large air-filled soil pores to slow the rate of gas exchange and C oxidation. With tillage depths of 30 to 45 cm and adequate soil water, the long-term differences in evaporation were negligible.

Carbon loss associated with intensive tillage is also associated with soil erosion and degradation that can lead to increased soil variability and yield decline. Tillage erosion or tillage-induced translocation, the net movement of soil down slope through the action of mechanical implements and gravity forces acting on the loosened soil, has been observed for many years (Lobb *et al.*, 2000). Papendick, et al., (1983) reported original topsoil on most hilltops had been removed by tillage erosion in the Paulouse region of the Pacific Northwest of the USA. The moldboard plow was identified as the primary cause, but all tillage implements will contribute to this problem (Govers *et al.*, 1994; Lobb & Kachanoski, 1999). Soil translocation from moldboard plow tillage can be greater than soil loss tolerance levels (Lindstrom, et al., 1992; Govers *et al.*, 1994; Lobb, et al., 1995; Poesen *et al.*, 1997). Soil is not directly lost from the fields by tillage translocation, rather it is moved away from the convex slopes and deposited on concave slope positions. Lindstrom, et al., (1992) showed that soil movement on a convex slope in southwestern Minnesota, USA could result in a sustained soil loss level of approximately 30 t ha^{-1} yr^{-1} from annual moldboard plowing. Lobb, et al., (1995) estimated soil loss in southwestern Ontario, Canada from a shoulder position to be 54 t ha^{-1} $yr^{-1}$from a tillage sequence of moldboard plowing, tandem disk and a C-tine cultivator. In this case, tillage erosion, as estimated through resident Cesium137, accounted for at least 70% of the total soil loss. The net effect of soil translocation from the combined effects of tillage and water erosion is an increase in spatial variability of crop yield and a likely decline in soil C related to lower soil productivity (Schumacher, et al., 1999).

Environmental benefits of soil carbon

True soil conservation is C management. By properly managing the C in our agricultural ecosystems, we can have less erosion, less pollution, clean water, fresh air, healthy soil, natural fertility, higher productivity, C credits, beautiful landscapes, and sustainability. An increase in SOM will not only reduce greenhouse gases, it also will have a beneficial effect on water quality and soil health. The main benefit of conservation agriculture or direct seeding is the immediate impact on SOM and soil water interactions. Soil organic matter is so valuable for what it does in soil, it can be referred to as "black gold" because of its vital role in physical, chemical and biological properties and processes within the soil system. Agricultural policies are needed to encourage farmers to improve soil quality by storing C that will also lead to enhanced air quality, water quality and increased productivity as well as to help mitigate the greenhouse effect. While technical discussions related to C trading are continuing, there are several other secondary benefits of soil C impacting environmental quality that should be considered to maintain a balance between economic and environmental factors.

The importance of soil C can be compared to the central hub of a wagon wheel. The wheel represents a circle, which is a symbol of strength, unity and progress. The "spokes" of this wagon wheel represent incremental links to soil C that lead to the environmental improvement that supports total soil resource sustainability. Many spokes make a stronger wheel. Each of the secondary benefits that emanate from soil C contributes to environmental enhancement through improved soil C management. Soane (1990) discussed several practical aspects of soil C important in soil management. Some of the "spokes" of the environmental sustainability wheel are described in following paragraphs.

The soil properly managed can be considered a huge "biofilter" in the way it can impact or surface and groundwater quality (Yaalon and Arnold, 2000). The soil filters, buffers, and moderates the quality of runoff and infiltrated waters. Soils capacity to absorb and store and release water at variable rates and its capacity to regulate and buffer the hydrologic cycle depends almost entirely on the soil organic carbon (SOC) pool. Through its impact on biological, chemical and physical processes, the SOM transforms, denatures, and filters pollutants and purifies water.

The SOC affects the soil hydrology by affecting plant available water-holding capacity, water retention and transmission, runoff, erosion and leaching. Increased SOM has a tremendous effect on soil water management because it increases infiltration and the water-holding capacity. Increased organic matter also helps stabilize the soil into larger aggregates and reduces the potential for wind and water erosion. The primary role of SOM in reducing soil erodibility is by stabilizing the surface aggregates through reduced crust formation and surface sealing, which increases infiltration (Le Bissonnais, 1990). Enhanced soil water-holding capacity is a result of increased SOM that more readily absorbs water and releases it slowly over the season to minimize the impacts of short-term drought. In fact, certain types of SOM can hold up to 20 times its weight in water. Hudson (1994) showed that for each one percent increase in SOM, the available water-holding capacity in the soil increased by 3.7% of the soil volume. The extra SOM prevents drying and improves water retention properties of sandy soils. In all texture groups, as SOM content increased from 0.5 to 3%, available water capacity of the soil more than doubled. Other factors being equal, soils containing more organic matter can retain more water from each rainfall event and make more of it available to plants. Increased water holding capacity plus the increased infiltration with higher organic matter and decreased evaporation with crop residues on the soil surface all contribute to improve crop water-use efficiency.

Reduced tillage and crop residue management systems were initially developed to protect the surface from wind and water erosion, but they also increased soil water storage under a wide range of climates and cropping systems. Unger (1978) showed that high wheat residue levels resulted in increased storage of fallow season precipitation, which subsequently produced higher sorghum grain yields in the field studies in the Southern Great Plains of the USA. High residue levels of 8 to12 Mg ha^{-1} resulted in about 80 to 90 mm more stored soil water at planting and about 2.0 Mg ha^{-1} more of sorghum grain yield than a no residue treatment. Similarly, Smika (1976) showed pronounced tillage affects on soil water profiles following 34 days of drying in field experiments where no tillage treatment that maintain surface residue cover resulted in more water storage in the soil profile below a depth of 5 cm. Excellent reviews of the effects of reduced tillage and increased resides on water conservation are given by Smika and Unger (1986) and Unger, et al., (1988). Emphasis on improved residue management and less intensive tillage systems in conservation agriculture combines the beneficial effects of water conservation and soil C enhancement important in water limited areas.

Ion adsorption or exchange is one of the most significant nutrient cycling functions of soils. Cation exchange capacity (CEC) is the amount of exchange sites that can absorb and release nutrient cations. Soil organic matter can increase CEC of the soil from 20 to 70% over that of clay minerals and metal oxides present. In fact, Crovetto (1996) showed that the contribution of organic matter to cation exchange capacity exceeded that of the kaolinite clay mineral in the surface 5 cm of his soils. Robert (1996 & 2001) showed a strong linear relationship between organic C and CEC of his experimental soil. The CEC increased four-fold with an organic C increase from 1 to 4%. Water quality can deteriorate when less SOC is available for natural filtering. Organic matter helps hold nutrients in place so they do not leach into ground water or run off into surface waters. It also helps hold certain pesticides in place longer so they can decompose naturally. The toxicity of other elements can be inhibited by SOM, which has the ability to adsorb soluble chemicals. The adsorption by clay minerals and SOM is an important means by which plant nutrients are retained in crop rooting zones and out of surface waters.

Soils relatively high in C, particularly with crop residues on the soil surface, are very effective in increasing SOM and in reducing soil erosion. Reducing or eliminating runoff that carries sediment from fields to rivers and streams will enhance environmental quality. Under these situations, the crop residue acts as tiny dams that slow down the water runoff from the field allowing the water more time to soak into the soil. Worm channels, macropores and plant root holes left intact increase infiltration (Edwards, et al., 1988). Water infiltration is two to ten times faster in soils with earthworms than in soils without earthworms (Lee, 1985). Soil organic matter contributes to soil particle aggregation that makes it easier for the water to move through the soil and enables the plants to use less energy to establish to root systems (Chaney & Swift, 1984). Intensive tillage breaks up soil aggregates and results in a dense soil making it more difficult for the plants to get nutrients and water required for their growth and production.

Soil erosion leads to degraded surface and ground water quality. Another secondary benefit of higher SOM is decreased water and wind erosion (Uri, 1999). Crop residues on the surface help hold soil particles in place and keep associated nutrients and pesticides on the field. The surface layer of organic matter minimizes herbicide runoff, and with conservation tillage, herbicide leaching can be reduced as much as half (Braverman *et al.*, 1990). The enhancements of surface and ground water quality are accrued through the use of conservation tillage and by increasing SOM. Increasing SOM and maintaining crop residues on the surface reduces wind erosion (Skidmore, Kumar & Larson, 1979). Depending on the amount of crop residues left on the soil surface, soil erosion can be reduced to nearly nothing as compared to the unprotected, intensively tilled field.

Soil organic matter can decrease soil compaction (Angers & Simard 1986; Avnimelech & Cohen, 1988). Soane (1990) presented different mechanisms where soil "compactibility" can be decreased by increased SOM content: 1) improved internal and external binding of soil aggregates; 2) increased soil elasticity and rebounding capabilities; 3) diluted effect of reduced bulk density due to mixing organic residues with the soil matrix; 4) increased temporary or permanent existence of root networks; 5) localized change electrical charge of soil particles surfaces, and 6) changed soil internal friction. While most soil compaction occurs during the first vehicle trip over the tilled field, reduced weight and horsepower requirements associated with forms of conservation tillage can also help minimize compaction. Additional field traffic required by intensive tillage compounds the problem by breaking down soil structure. The combined physical and biological benefits of SOM can minimize the affect of traffic compaction and result in improved soil tilth.

Maintenance of SOM contributes to the formation and stabilization of soil structure. Another spoke in the wagon wheel of environmental quality is improved soil tilth, structure and aggregate stability that enhance the gas exchange properties and aeration required for nutrient cycling (Chaney & Swift, 1975). Critical management of soil airflow with improved soil tilth and structure is required for optimum plant function and nutrient cycling. It is the combination of many little factors rather than one single factor that results in comprehensive environmental benefits from SOM management. The many attributes suggest new concepts on how we should manage the soil for the long-term aggregate stability and sustainability.

A secondary benefit of less tillage and increasing SOM is reduced air pollution. Carbon dioxide is the final decomposition product of SOM and is released to the atmosphere. Research has shown that intensive tillage, particularly the moldboard plow, releases large amounts of CO_2 as a result of physical release and enhanced biological oxidation (Reicosky, *et al.*, 1995). With conservation tillage, crop residues are left more naturally on the surface to protect the soil and minimize evaporation with more controlled conversion of plant C to SOM and humus. Intensive tillage releases soil C to the atmosphere as CO_2 where it can combine with other gases to contribute to the greenhouse effect. Thus, a combination of the economic benefits of conservation tillage through reduced labor requirements, time saved and reduced machinery costs and conserved fuel combined with the water conservation benefits listed above appeals universally. Indirect measures of social benefits as society enjoys a higher quality of life from environmental quality enhancement will be difficult to quantify. Conservation agriculture, using direct seeding techniques, can benefit society and can be viewed as both "feeding and greening the world" for global sustainability.

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

No till 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. Carbon sequestration alone can not solve the climate change dilemma, but as we search for technological advancements 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. 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. 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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