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Conservation agriculture, CO_2 mitigation, and Enonmental Benefits: GlobalPolicies and Perspectives

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Introduction:

China's Loess Plateau is characterized by some of the most extensive soil erosion in the world. The ecological devastation present in this region is influenced by many factors in addition to the very nature of the soil. The silt-like nature is noted as being among the most erosion prone soils known in the world. Of all the factors contributing to soil erosion in the Loess Plateau Region, including the desertification, wind erosion, violent rain storms, and earthquakes, the most significant overall has been irrational land use (Bojie et al., 1999). Conservation agriculture is proposed as a change from traditional agriculture as one way of managing the agricultural land and enhancing environmental quality in a sustainable way. The main pillars of conservation agriculture are minimum soil disturbance, continuous crop residue cover, and the use of cover crops and/or diverse crop rotations. The purpose of this document is to review current knowledge of two of the three main conference topics, combating soil erosion and rebuilding vegetation, as related to Conservation Agriculture. This work will emphasize the critical role of soil carbon (C) in conservation agriculture for decreasing soil erosion and maintaining environmental quality and will stress the need for field research using these techniques. While many examples will be from other parts of the world, the principles and concepts will apply equally well to the Loess Plateau Region in developing land use policy.

Agriculture and the Carbon Cycle

Agriculture has contributed to water contamination from sedimentation and the greenhouse effect with tillage-induced carbon dioxide (CO_2) losses. Improved tillage management techniques have shown that scientific agriculture can also be a solution to these environmental issues in general and specifically to mitigating the greenhouse effect (Lal et. al., 1998). Improved agricultural practices such as direct seeding or conservation tillage have the potential to sequester more carbon (C) in the soil than farming emits through land use and fossil fuel combustion. Thus, a combination of the economic benefits of enhanced soil management through reduced labor requirements, time savings, reduced machinery and fuel savings with direct seeding, combined with the environmental benefits listed above has universal appeal. Indirect measures of social benefits as society enjoys a higher quality of life from environmental quality enhancement will be difficult to quantify. Conservation agriculture, working in harmony with nature using direct seeding techniques that increase soil C, can be of benefit to society and can be viewed as both "feeding and greening the world" for global sustainability.

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. Preliminary assessments indicate that soil C sequestration can be a 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. The drive to survive in the Loess Plateau Region of China has created environmental problems directly attributed to conventional agriculture that can be partially solved with conservation agriculture.

High levels of fossil fuel combustion and deforestation have transformed large pools of fossil C from coal and oil into atmospheric CO_2. Conservation and increased fuel efficiency are important players in reducing CO_2 emissions from the use of fossil fuels. International strategies aimed at reducing CO_2 in the atmosphere include soil C sequestration, tree planting, and ocean sequestration of C. Other technological strategies to reduce C inputs include developing energy efficient fuels, and efforts to develop and implement non-C energy sources, such as hydrogen fuel cells. All of these efforts combined can reduce CO_2 concentrations in the atmosphere and help to alleviate global warming.

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, especially in the Loess Plateau region of China.

Soil carbon management in conservation agriculture

Based on the soil C losses with intensive agriculture, reversing the decreasing soil C trend with less tillage intensity should be beneficial to sustainable agriculture and the global population by gaining better control of the global C balance. The literature holds considerable evidence that intensive tillage decreases soil C and supports increased adoption of new and improved forms of conservation tillage or no-till (direct seeding) to preserve or increase storage of soil organic matter (Lal et al., 1998). Better control of the C balance will lead to better harmony between man and nature. The environmental and economic benefits of conservation agriculture and direct seeding demand their consideration in the development of improved soil C storage practices for sustainable production.

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. Dynamic soil quality encompasses those properties that can change over relatively short time periods (e.g. soil organic matter, labile soil organic matter fractions, soil structure components, and macro porosity) in response to human use and management and that are strongly influenced by agronomic practices. Soil organic matter is both inherent, as total soil organic matter is related particle size distribution, and dynamic, as it is related to ongoing inputs organic matter to the soil. A dynamic part of soil C cycling is directly related to the "biological C" cycle.

The "biological C" cycle is of the utmost importance in conservation agriculture and is differentiated from the "fossil C" cycle. Fossil C sequestration entails the capture and engineered storage of C content of fossil fuels prior to its release to the atmosphere. Biological C sequestration entails removal of C from the atmosphere by plants. Fossil fuels (fossil C) are very old geologically, as much as 2 million years. Biofuels (bio-C) are very young geologically and can very from 1 to 10 years in age and as a result can be effectively managed for improved C cycling. One example of biological C cycling is the agricultural production of biomass for fuel. The major strength of biofuels is the potential to reduce net CO_2 emissions to the atmosphere. Enhanced C management in conservation agriculture, may make it possible to take CO_2 released from the fossil C cycle and transfer it to the biological C cycle to enhance food, fiber and bio-fuel production as well as enhancing environmental quality.

Environmental benefits of soil C sequestration

The main benefit of conservation agriculture or direct seeding is the immediate impact on soil organic matter and soil C interactions (Reicosky, 2001). Soil organic matter is so valuable for what it does in the 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 also will lead to enhanced air quality, water quality and increased productivity as well as mitigating the greenhouse effect. Soil C is one of our most valuable resources and may serve as a "second crop" if global C trading systems becomes a reality. 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. In agricultural production systems, many decisions are made based on farmer experience and economic considerations. However, the recent emphasis on environmental concerns requires a balance between economic and environmental factors that have caused soil organic matter management decisions to rise to a high-level priority.

Agricultural soils typically contain 1 to 4 % C on mass basis. The relatively small amounts of C could be considered analogous to a catalyst or to the tip of the iceberg where a small amount visible has a big impact. Soil C performs many important beneficial functions with respect to environmental enhancement. Farmers are the primary soil managers who each have a tremendous responsibility to maintain soil organic matter for environmental benefit of the global population. Thus, farmers who use conservation agriculture or direct seeding techniques are helping to maintain environmental quality for all of society. Quality food production and economic and environmentally-friendly management practices that are socially acceptable will lead to sustainable production and be mutually beneficial to farmers and all of society. Enhanced soil C management is a win-win strategy (Lal et al., 1998). Agriculture wins with improved food and fiber production systems and sustainability. Society wins because of the enhanced environmental quality.

Removing CO_2 from the atmosphere is only one significant benefit of enhanced C storage in soils. Soil organic C represents a key indicator for soil quality, both for agricultural functions (production and economy) and for environmental functions (C sequestration and air and water quality). Soil organic matter is the main determinant of biological activity because it is the primary energy source. The amount, diversity and activity of soil fauna and microorganisms are directly related to SOM content and quality. Organic matter and the biological activity that it generates, have a major influence on the physical, chemical and biological properties of the soils. Soil aggregation and stability of soil structure increases with increasing organic C.

The main contribution of conservation agricultural management techniques,which are successful in providing a net C sink in soils, includes conservation agriculture or no till (direct seeding) that minimizes or eliminates manipulation of the soil for crop production. It also includes the practice of conservation or mulch tillage, which leaves most crop residues on the soil surface. These procedures generally protect the soil, increase infiltration, reduce soil erosion, improve water use efficiency, and increase C concentrations in the topsoil. Conservation tillage can also reduce the amount of fossil fuel consumed in intensive tillage and by other farm operations and thus decrease the rate of CO_2 buildup in the atmosphere. Cover crops, such as clover for nitrogen accumulation and small grains, capture CO_2 through photosynthesis for soil protection and improvement between periods of regular crop production. Cover crops improve C sequestration by enhancing soil structure, adding nitrogen to the soil, and adding organic matter to the soil. Diverse crop rotation is a sequence of several different crops grown in regularly recurring succession on the same area of land. The more diverse crop rotations provide long-term stability in crop production systems by minimizing pest and disease problems. Diverse rotations mimic the diversity of natural ecosystems more closely than intensive mono-cropping practices. Varying the type of crops grown can increase the quality and level of soil C. However, effectiveness of crop rotation depends on the type of crops grown, rotation duration, intensity of tillage, soil type and climate conditions.

Ecosystem services provided by soil carbon

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 in the Loess Plateau of China as well as other places around the world. 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 animals and plants interacting with one another and with their physical environmer Ecosystems include physical, chemical and biological components such as soils, wate and nutrients that support the biological organisms living within them. People are pa of these ecosystems. Agricultural ecosystem services include production of food, fib and biofuels, provisions of clean air and water, natural fertilization, nutrient cycling i soils, mitigation of climate, pollination, genetic resources, recreational, cultural an social benefits and many other fundamental life support services required for ou existence. These services may be enhanced by increasing the amount of C stored i soils. Our agricultural ecosystems help moderate weather extremes and their impact mitigate natural droughts and floods, protect stream and river channels and coasta shores from erosion, control agricultural pests, maintained biodiversity, generate an preserve soils and renew their fertility, detoxify and decompose wastes, contribute t climate stability, 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 cause damage or loss of 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 necessary for our survival.

Increased soil organic matter is known to increase the water holding capacity along with increasing infiltration so that it has a tremendous effect on soil water management. Soils relatively high in C, particularly with crop residues on the soil surface, are very effective in increasing soil organic matter and reducing soil erosion loss. 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. 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. 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. Reducing or eliminating runoff that carries sediment from fields to rivers and streams will enhance environmental quality. It is important, therefore, that C loss from the soil system through historical land use of farming practices be restored to its natural potential using direct seeding and conservation tillage methods for sustainable production.

Conservation agriculture or no-till (direct seeding) saves time, saves money, and with the environmental benefits can be useful in saving the planet. Eco-efficient farming is economically competitive and environmentally friendly that maintains the sustainability of food and fiber production. This requires a certain level of environmental consciousness and a normal part of doing business in modern agriculture. We must reduce pollution and use our resources in line with the earth's carrying capacity for sustainable production of food and fiber. The responsibility lies on the shoulders of the farmer to maintain a delicate balance between the economic implications of farming practices and the environmental consequences of using the wrong practices. This responsibility entails producing food and fiber to meet the increasing population while maintaining the environment for a high quality of life. The social value of an agricultural community is not just in food and fiber production, but producing in harmony with nature for better quality soil, water, air and biological diversity where C cycling is fundamental.

Conservation agriculture and tillage erosion

Tillage has been an integral component of global crop production for centuries. The short-term impact of moldboard plow and various tillage methods on CO_2 loss from the soil has been evaluated using a portable dynamic chamber. Recent studies that measured short-term C loss from various tillage methods indicated major C loss immediately following intensive tillage (Reicosky and Lindstrom, 1993). They found that 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 related to the depth of soil disturbance that resulted in a rougher surface and larger voids than to residue incorporation. Lower CO_2 fluxes resulted from tillage systems associated with low soil disturbance and small soil pores. No-till had the least amount of CO_2 loss during the 19-day period. Reicosky and Lindstrom (1993) and Reicosky (1998) concluded that intensive tillage methods, especially moldboard plowing to 0.25 m deep, affected this initial soil flux differently and suggest improved soil management techniques such as strip tillage or forms of conservation tillage can minimize agricultural impact on global CO_2 increase.

One aspect of conventional agriculture is its ability to change the landscape. The study of tillage has evolved into a science built on an understanding of the relationships between tillage and soil physical properties, crop growth, pests, soil erosion, and, most recently, C sequestration. The recognition of two processes associated with tillage has the potential to dramatically change future tillage research (Lobb et al., 2000). These processes are tillage translocation and tillage erosion (Lindstrom et al., 1992; Govers et al., 1994; Lobb et al., 1995; Poesen et al., 1997). Tillage translocation is the resultant displacement of soil by tillage tools expressed as a mass of soil moved forward or laterally relative to the direction of tillage. The translocation of soil by tillage varies greatly within landscapes as a result of several factors; these include the design and operation of tillage implements and the topographic and soil properties of landscapes. The consequence of this variation in translocation is net soil redistribution or "leveling" within landscapes resulting in tillage erosion. Typically, tillage results in the progressive down-slope movement of soil, causing severe soil loss on upper slope positions and accumulation in lower slope positions. Visual evidence of tillage erosion includes: loss of organic rich topsoil and exposure of subsoil at the summit of ridges and knolls, and undercutting of field boundaries (fencelines, hedgerows, terraces, etc.) on the down-slope side and burial on the up-slope side.

Although intensive tillage on steep slopes in the China Loess Plateau for the last 50 years has been considered as the major reason for the accelerated soil erosion, its effect on soil quality has never been directly measured. Li and Lindstrom (2001) found a significant positive relationship between soil nutrients and soil accumulation from tillage on the steep slopes and terraces. Soil redistribution by tillage might provide some short-term soil quality benefits in the lower slope positions as evidenced by small increases in soil organic matter and available nutrients within the plow layer. However the continuous accumulation of soil materials above the initial soil surface by long-term intensive tillage will eventually result in the degradation of soil quality in the lower portions of the slope. These results are supported in a follow-up study by Li et al., (2004). They conducted 50 plowing operations over a five day period using a donkey-drawn moldboard plow on a steep back slope in the Loess Plateau Region. They measured topographic changes, soil organic matter changes, and nutrient content changes along a downslope transect after each 10 tillage events. They concluded soil redistribution by intensive tillage resulted in immediate deterioration in soil quality within the tilled layer in the upper slope and temporary improvement in the lower slope. However, the continuous accumulation of soil materials above the initial soil surface by long-term intensive tillage will eventually result in the degradation of soil quality in the lower portions of the slope. Intensive tillage resulted in changes in landscape variability that were attributed to soil movement and resulted in physical and fertility degradation on the slope as well as creating conditions for severe erosion and soil loss. This type of extreme landscape would be an ideal location for testing conservation agriculture techniques and their suitability for maintaining food and fiber production and environmental quality.

In other parts of the world, the moldboard plow was identified as the major contributor to tillage erosion, but all tillage implements will contribute to this problem (Govers et al., 1994; Lobb and Kachanoski, 1999). Soil translocation from moldboard plow tillage operations has been identified as a cause of soil movement from specific landscape positions that can be greater than currently accepted 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 ^{137}Cesium, accounted for at least 70% of the total soil loss. Tillage speed increases nonlinearly the rate of tillage erosion.

The relationship between soil productivity and tillage erosion is complex. Soils are not the sole factors controlling crop yields. The degree to which crop yield losses are related to soils is a function of several interacting factors including soil physical, chemical and biological properties, landscape position, crop grown, management practices, and weather conditions before and during the growing season. Schumacher et al. (1999) used modeling procedures to show that tillage erosion caused soil loss from the shoulder position while soil loss from water erosion occurred primarily in the mid to lower backslope position. The decline in overall soil productivity was greater when both processes were combined compared to either process acting alone. Water erosion contributed to nearly all the decline in soil productivity in the backslope position when both tillage and water erosion processes were combined. While there are many other reasons for intensive tillage, tillage sets up the soil to be loose, open and very susceptible to high intensity rainfall and subsequent erosion. The net effect of soil translocation from the combined effects of tillage and water erosion was an increase in spatial variability of crop yield and a likely decline in overall soil productivity (Schumacher et al., 1999). A similar analysis is desperately needed for the Loess Plateau Region of China.

Carbon sequestration policies and perspectives

The increase in greenhouse gas concentrations in the atmosphere is a global problem that requires a global solution (Kimble et al., 2002; Lal, 2002). Concern about negative effects of climate warming resulting from increased levels of greenhouse gases in the atmosphere has led nations to establish goals and policies for reductions of these emissions. Initial targets for reductions are stated in the Kyoto protocol to the United Nations framework convention on climate change, which allows trading credits that represent verified emission reductions and removal of greenhouse gases from the atmospheres (United Nations framework convention on climate change secretariat, 1997). The emissions trading may make it possible to achieve reductions in net greenhouse gas emissions for far less cost than without trading (Dudek et al., 1997). Storing C in soils using conservation agriculture techniques can help offset greenhouse gas emissions while providing numerous environmental benefits such as increasing site productivity, increasing water infiltration, and maintaining soil flora and fauna diversity (Lal et al., 1998; Lal, 2002). Storing C in forests may also provide environmental benefits resulting from increased numbers of mature trees contributing to C sequestration (Row et al., 1996).

As interest in soil C sequestration grows globally and C trading markets are developed, it is important that appropriate policies be developed that will prevent the exploitation of soil organic C and at the same time replace the lost C and establish its value (Walsh, 2002). International policies are needed that will encourage the sequestration of C for all environmental benefits that will evolve (Kimble et al., 2002). Making C a commodity necessitates determining its market value and doing so with rational criteria. Both farmers and society will benefit from sequestering C. Enhanced soil quality benefits farmers, but farmers in China and society in general, benefit from erosion control, reduced siltation of reservoirs and waterways, improved air and water quality, and biodegradation of pollutants and chemicals. Farmers need to be compensated for the societal benefits of C sequestration and the mechanisms that develop will allow for C trading and maintaining property rights. One important criterion in developing the system is the measurement and verification of the C options for sequestration that must be developed and the importance of making policymakers aware of these procedures and the technical difficulties. The use of the C credit market mechanisms is intended to help meet the challenge of climate change and future C constraints that enable sustainable development and at the lowest social cost. Carbon credit accounting systems must be transparent, consistent, comparable, complete, accurate, and verifiable (IPCC, 2000). Other attributes for a successful system include global participation and market liquidity, linking of different trading schemes, low transaction costs, and rewards for early actions to voluntarily reduce emissions before regulatory mandates are put in place. Characterizing the relationships between soil C and water quality, air quality and all the other environmental benefits should be an easy sell to get social acceptance of this type of agriculture. The largest impediment is the educational processes directed at the policymakers and food consuming public that require further enhancement within China.

A growing number of organizations around the world are implementing voluntary projects that are climate-beneficial as a means to improve efficiency and reduce operating costs and risk. Businesses and institutions throughout the world are realizing that the benefits of good environmental management far outweigh the cost, both now and in the future, of good corporate management that include strategies to reduce greenhouse gas emissions, risk exposure, costs and enhance overall competitive operations. Multinational organizations are participating in C energy credit trading markets in order to avoid future compliance costs and to protect their global franchise in the face of increasing concern over global warming (Walsh, 2002). In the evolution toward a global economy and as concerns over global environmental impacts increase, CO_2 emissions management will become a factor in the planning and operations of industrial and government entities all over the world, creating challenges and opportunities for those who are able to recognize and capitalize on them.

Trade in C credits has potential to make conservation agriculture more profitable and enhance the environment at the same time. The potential for C credits has attracted considerable attention of farmers and likely buyers of the C credits. However, it is difficult to stay fully informed about developing C credits because of their technical complexity and the pace of development on this subject. Rules for trading in C credits are not yet agreed upon but international dialogue is underway to develop a workable system and rules for trading. The number of organizations working on developing a C trading systems suggests that some type of international mechanism will evolve and that C credit trading will become a reality. Information is rapidly becoming available on publicly traded C credits, however, little information is available on privately traded contracts. A great deal of uncertainty exists at this time as to what companies will emerge as reliable sources of high-quality information and has entities that can handle trading in a fair and reliable manner. Potential suppliers and buyers of C credits are urged to proceed with caution because many of the issues central to C credit markets and trade are yet to be clarified. We must convince policy makers, environmentalists and industrialists that soil C sequestration is an additional important benefit of adopting improved and recommended conservation agricultural production systems. This option stands on its own, regardless of the threat of global climate change from fossil fuels.

Conservation agricultural practices can help mitigate global warming by reducing C emissions from agricultural land and by sequestering C in the soil through regulatory, market incentive, and voluntary or educational means (Lal, 2002). Public policy can encourage adoption of these practices. 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. Ir and potential investors in C sinks need to be aware that there is uncertainty international level. Administration and transaction costs could play a key determining the success of any C credit trading system. Cost of these ar expected to be minimized through improved techniques and services for measuri reporting sequestered C, private sector consultants, economies of scale, a emergence of market mechanisms and strategies such as C pooling or aggre There are risks involved in selling C credits in advance of any formalized intern trading system and those participating in early trading need to clarify responsil and obligations. However, care should be taken in the design of these policies to their success and to avoid unintended adverse economic and environ consequences and to provide maximum social benefit.

Summary

While we learn more about soil C storage and its central role in environmental ber we must understand the secondary environmental benefits of conservation agric (no-till) and what they mean to sustainable production agriculture in the Loess Pl of China. Understanding these environmental benefits and getting the conserv practices implemented on the land will hasten the development of harmony bet man and nature while increasing production of food and fiber. Increasing sc storage can increase infiltration, increase fertility, decrease wind and water ero minimize compaction, enhance water quality, decrease C emissions, impede pesti movement and enhance environmental quality. Increased levels of greenhouse gas the atmosphere require nations to establish international and national goals and poli for reductions. Accepting the challenges of maintaining food security by incorpora C storage in conservation planning demonstrates concern for our global resources our willingness to work in harmony with nature. This concern presents a positive for conservation agriculture in China that will have a major impact on glc sustainability and our future quality of life.

Science and technology play an important role in creating sound scientific knowle for sustainable use of our land resources. The integration and diffusion of the scient knowledge into the respective social and policy framework is just as critical for planning and implementation of sustainable land use. The following speci recommendations are aimed at implementing socially acceptable and environmenta friendly production systems within the soil and climate constraints employing t principles and concepts of conservation agriculture.

1.Develop integrated participatory educational programs on the importance of soil carbon and carbon and nitrogen cycling in agricultural systems and the direct impact on environmental quality.

2.Encourage the development of participatory farmer-lead regional conservation organizations with emphasis on zero tillage and direct seeding for both large and small scale farms.

3.Develop improved soil management plans that decrease tillage intensity and the volume of soil disturbed and enhance the soil physical, chemical and biological properties.

4.Develop improved crop residue management practices that yield continuous residue cover to protect the soil surface.

5.Encourage cropping systems that maintain vegetation cover during the heavy rainfall periods.

6.Utilize diverse crop rotations and cover crops to maximize soil carbon and nitrogen input in combination with agroforestry and perennial species with dense root systems to protect the soil from erosive forces.

7.Develop the concept of comprehensive crop production systems that simultaneously encompasses management aspects for optimum grain yield and environmental protection.

8.Develop regional on farm research programs and demonstrations for farmers and the public to illustrate the potential economic and environmental benefits with conservation agriculture.

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