PART I -- METHODS OF CARBON SEQUESTRATION

CHAPTER 1 -- AGRICULTURAL SINKS

When the Kyoto Protocol refers to carbon sequestration, it is always in the context of forestry. However, as shown in Table 1.1, agricultural sinks may in fact have greater potential than forestry—at least in the United States—to contribute to carbon sequestration. Changes in agricultural practices—including land restoration, reclamation, intensification of prime farmland, conservation tillage, residue management, water management, and improved cropping systems—could sequester an additional 82 to 232 million metric tons of carbon (MMTC) per year.

Table 1.1 U.S. Soil Sequestration Potential and Land Requirements

Techniques	*Carbon Sequestered (MMTC/yr)*	*Land Required (Megahectares)*
1. Reduced Erosion of C	12-22	*6*
2. Increased C Sequestration		
Conservation Tillage	32	*16.2*
Incorporated Manure/Residue	5.8	*100 Mt mixture*
Crop-Rotation	10.2	*51*
Converted Summer Fallow	1.9	*9.4*
CRP	0.3-1	*13.8*
Wetlands	30	*40*
Other Soil Sequestration	0-127.1	
3. Savings in Fuel Consumption	1-2	
Total	**88-232**	

*source: (Adapted from Lal 1998a)

This sequestration would offset almost 50 percent of the target greenhouse gas (GHG) reduction set for the United States by the Kyoto Protocol for the year 2010. Table 1.1 shows the most important techniques for carbon sequestration in agricultural lands and the amount of carbon per year that each technique could remove from the atmosphere.

Agriculture holds particular promise as a method of carbon sequestration because it may involve low or zero costs. Furthermore, unlike some forms of carbon sequestration, agricultural sinks pose few environmental problems. Indeed, in some cases there may be substantial environmental gains. The widespread adoption of conservation tillage practices would not only increase the levels of carbon sequestered in farm soils but would do much to reduce farm pollutant runoff—currently the main source of water pollution in U.S. lakes and streams.

These practices may prove most useful as a short-term greenhouse gas mitigation strategy. As additional carbon is sequestered in soils, the potential for further sequestration declines. Hence, agricultural sinks may make their greatest contribution to overall carbon sequestration over the next 25-50 years.

The Role of Carbon in Agricultural Soils -- During photosynthesis, plants synthesize CO_2 through the use of solar energy. They then combine water and nutrients contained in the soil in order to grow. The carbon engaged in the plant material is then either transferred to animals that eat the vegetation or released during the respiration process or during microbial decomposition of litter (dead plants and animals). All of this action occurs in the uppermost layer of the earth's land crust known as the pedosphere, where the atmosphere is linked to the rest of earth's ecosystem.

Carbon is sequestered in the part of the soil called humus, which provides more stable storage of carbon than biomass. Humus is made up of a collection of organic matter that results from decomposition of animal and vegetative litter. It composes a relatively stable carbon pool (Brady, 1996). Some of the more stable compounds found in the humus may not turn over for hundreds to thousands of years (DOE, 1999). Most importantly, scientists can encourage increases in humus carbon content by stimulating natural processes that bond carbon chemically to other elements in the soil or increase resistance to microbial decomposition. Soil scientists also hope to increase sequestration by adopting agricultural processes that reduce soil erosion by wind and water and oxidation of soil from frequent turnover.

Terrestrial ecosystems and soils can be a source of carbon as well as a sink. Tillage practices involve significant soil turnover, which exposes the soil to air and generates soil releases of carbon through CO_2 as a result of oxidation. Wind and water erosion lead to further releases of carbon. The amount of carbon "lost" due to cultivation is illustrated below in Table 1.2. On average, for the U.S. uncultivated land would contain about 1329 MMTC more than cultivated land. Worldwide, poor agricultural practices now account for five percent of the yearly increase in the greenhouse carbon dioxide. Schlesinger estimates the annual global net release of carbon from agriculture activities at 800 MMTC/yr (Lal, 1998a). The 90-230 MMTC emitted annually from arable land and pastures in the tropics accounts for the largest portion of that global amount (Crookshank, 1999). The basic premise behind the reduction of emissions through the sequestration of carbon in soils relies on the restoration of original carbon levels.

Table 1.2 Soil Carbon Loss Estimates From Cultivation in U.S.

Status	**Mean**	**Minimum**	**Maximum**
Precultivation	8298 MMTC	6297 MMTC	10324 MMTC
Current	6969 MMTC	5304 MMTC	8654 MMTC
Losses	1329 MMTC	993 MMTC	1670 MMTC

*source: (Kern, 1994)

Although agriculture has thus been an important net contributor to higher atmospheric carbon levels in the past, it is the earlier removal of carbon from soils that in part creates the possibility of soils serving as a sink in the future. Soils previously depleted of carbon can be restored to their historic higher levels. Thus, the manipulation of soils through changes in farming practices is one viable way to sequester carbon and remove it from the atmosphere.

Scientists believe carbon levels have decreased by 61 percent from natural sequestration levels and that this equilibrium could be restored through improved agricultural practices (see

Appendix 1A). When native vegetation was converted into agricultural production in the United States, 20-50% of the original carbon soil content was lost within the first 40 to 50 years of the Agricultural Revolution through poor agricultural practices. It is expected that in the next 50 years, Best Management Practices (BMPs) in agriculture could restore 5000 MMTC to the soil (Lal, 1998b). It is also possible that, in addition to reversing the carbon loss due to land use changes in the past, manipulation of the soil through agricultural processes may increase carbon sequestration beyond earlier natural levels.

The worldwide carbon sequestration potential of agricultural sinks is substantial. Farm soils in many nations have been severely depleted, and improving the quality of these soils would provide the dual benefits of more fertile soil and create a large increase in the amount of carbon sequestered in these soils. As shown in Table 1.3, global estimates vary widely. At the higher end, one estimate suggests that agricultural lands have a worldwide potential to sequester up to at least 1000 MMTC per year globally. This level of sequestration could offset up to 14 percent of the 7100 (+/- 1100) MMTC per year of total global carbon emissions (Batjes, 1998).

Table 1.3 Global Agricultural Estimates

Author/Technique	**Estimate (MMTC/yr)**	**Source**	**Implications[1] (Percent of Global Emissions)**
Cumulative Agricultural Practices			
R.N. Sampson	140	Batjes 234	2
R.T. Watson	400-800	Batjes 233	6-11
V. Cole	400-600	Batjes 234	6-8.5
U.S. Department of Energy	850-900	DOE 4-6	12-13
R. Lal	100-1000	Batjes 234	1.7-14
Europe	142	Lal 150	2
United States	88-232	Lal2 84	1.2-3
Specific Practices			
96 Mha Set Aside[2]	20-40	IPCC 51	0.3-0.56
Global CT	29.6-98	Lal 1	0.4-1.4
Ending Tropical/Sub-tropical Deforestation[3]	154	Lal 150	2

[1] Assuming 7100 MMTC global emissions.
[2] 15% of 640Mha cropland permanently reserved in United States, Canada, former Soviet Union, Europe, Australia, and Argentina
[3] Averaged over 50 years.

I. Carbon Sequestration And Farm Management

There are a variety of methods by which the levels of carbon sequestered in soils in the United States could be increased by changes in farm management practices:

Soil Erosion Management -- Cropland generates the most soil erosion in the United States at present. Wind- and water-induced agriculture erosion contributes to a loss of 1871 MMTC per year. Much of the most carbon-rich soil lies in the very top layer of the ground. This top layer is highly erodible and vulnerable to oxidation. Wind and water erosion displaces 115.2 MMTC per year, and 20% of that amount ends up in the air. This 12 to 22.8 MMTC per year increase could be prevented if erosion control measures, such as residue management and vegetative buffer development, were adopted on the remaining 6 Mha of highly erodible land in the United States (Lal, 1998b). Land restoration of wetlands and highly erodible lands may also decrease the effects of erosion.

Land Restoration and Reclamation -- Wetlands and marshlands provide a very important carbon sink. These areas require protection and restoration, because the loss of these wetlands has led to flooding, water pollution, runoff, and poor groundwater recharge. Although most of the carbon removed through runoff is retained in pools of water as sediment, during a dry season the existing wetland storage systems that hold carbon from runoff may be drained, allowing for oxidation of the soil carbon. Wetlands account for 14.5% of the soil carbon in the world, yet only six percent of the land around the globe is made up of wetlands.

The United States has already lost 50% of its wetlands. From 1954 to 1992, 237 Mha of wetlands were lost to agricultural expansion (Lal, 1998b). Lal estimates that two hectares of restored wetlands can sequester 0.5 MMTC/yr, so restoration of 50% of the degraded wetlands could sequester 30 MMTC/yr (Lal, 1998b). This would require 40 Mha or 15% of the world's total wetland area. Increased carbon content in the soil has been shown to reduce run-off and pollution. This side benefit of increased carbon sequestration will help farmers meet the water pollution restrictions set by the EPA.

Provisions included in the 1985 and 1990 Farm Bill, the Conservation Reserve Program (CRP), and the Wetland Restoration Program (WRP) reduced water and wind erosion in the United States by one billion tons of soil per year between 1982 and 1992. The CRP allows for the purchase of ten-year easements on highly erodible land, committing the farmland to ten years of permanent vegetative cover, usually perennial grasses or trees. In some cases the CRP is used to improve stream buffers to reduce water pollution or create windbreaks to stop wind erosion. It is estimated that if all cropland currently eligible for the CRP program was enrolled, 8.1 MMTC per year of carbon could be sequestered (Lal, 1998b). Over a ten-year period, 13.8 Mha in the CRP would sequester 3-10 MMTC. The WRP works in a similar way and also halts farming on sensitive lands. It promotes the purchase of thirty-year easements on wetland areas drained by agriculture in order to return them to their original state and function.

Conservation Tillage -- Tillage is defined as a mechanical manipulation of soil to control weeds, present suitable seedbed, and incorporate organic residues (Brady, 1996). Conventional tillage usually involves a moldboard plow, which twists into the soil and loosens very large chunks. The farmer must trace his fields with his tractor to plow, disk, cultivate, plant, and cultivate again. This labor-intensive system also consumes a considerable amount of fossil fuel. Furthermore, because of the active cultivation of the soil, the practice of conventional tillage prevents root growth. During decomposition, root growth distributes carbon deeper into the humus where the carbon is more stable. Even more importantly, conventional tillage exposes more soil carbon to the air to be oxidized and released as CO_2. Conventional tillage practices lead to a 30-50% decrease in soil carbon when taken cumulatively.

By contrast, conservation tillage practices leave more residue on the surface and experience 31% less CO_2 loss than moldboard plowing (Reicosky, 1999). Formally, conservation tillage is defined as any tillage and planting system that leaves at least 30% of the soil surface covered by residue after planting to reduce water erosion, or where wind erosion is a primary concern, and maintains at least 1000 kg/ha of flat, small grain/residue equivalent on the surface during critical wind erosion period (Lal, 1998b). Ridge-till, no-till, and mulch-till are common types of conservation tillage. Figure 1.1 below explains in detail these conservation tillage methods, as well as methods of conventional and reduced tillage.

Figure 1.1 Types of Tillage Systems

No-till: From planting to harvest, the soil is left undisturbed with the exception of nutrient injection. In most systems, planter-mounted coulters till a narrow seedbed assisting in the placement of fertilizer and seed. Herbicides are the primary use for weed control.

Ridge tillage: Similar to no-till, the soil is not tilled between the harvest of one crop and planting of the next. The ridge till system involves planting crops on raised ridges with sweeps, disk openers, coulters, or row cleaners. Residue remains on the soil surface between the ridges.

Mulch tillage: Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used prior to planting, but at least 30 percent of the soil surface is covered with residues after planting.

Reduced-till: Tillage systems that leave 15-30% of crop residue on the soil surface after planting are considered reduced-till systems.

Conventional-till: Tillage systems that leave less than 15% of crop residue on the soil surface after planting are considered conventional-till systems. These systems generally involve plowing or intensive tillage.
(CTIC, 1998g)

Conservation tillage involves much less plowing, and the plant materials are left in the field following the crop harvest. Conservation tillage attempts to reduce the amount of overturned soil by reducing soil disturbance from tillage and increasing residue in the soil by sowing over crop-cover and leaving residue on the surface. As a result of these practices, carbon sequestration increases (see Appendix 1B). Leaving crop residues on the soil allows for the residue to become organic carbon that is eventually incorporated into the humus.

Another benefit from conservation tillage is that it uses one-fifth the fossil fuel of conventional tillage. This reduction alone, from the decreased use of tractors, can mitigate 1-2 MMTC per year. In particular, no-till requires only one trip over the land to plant and spray herbicide.

Conservation tillage usually incorporates crop rotation, which encourages the farmer to grow a winter cover crop. A winter crop is sown over the summer crop so that the nutrients taken up by one crop are replenished through the growth of another. The residues from the previous crop are not cleared, but incorporated into the soil to increase productivity and carbon sequestration. This system results in a need for less irrigation, fuel, chemical herbicides, and chemical fertilizers. It also increases soil quality. A change to crop-rotation in the maize/soybean producing states alone could lead to a one to two percent offset in United States CO_2 emissions (Drinkwater, 1998).

In the United States, 37 percent of croplands are currently under a conservation tillage system of one sort or another. The further widespread adoption of conservation tillage could lead to a sequestration of 32 MMTC/yr over the next 25 years (Lal, 1998b). To reach this amount would require 16.2 Mha of cropland. President Clinton has set a national goal that 50% of U.S. cropland should be under conservation tillage by 2002.

Residue Management -- Intensification of agricultural land requires a move in farming practices away from extensification, which is the use of marginal lands that leads to decreases in soil quality, towards improved soil management practices that result in increased land productivity. Conservation tillage and residue management serve as tools for intensification.

Residue management is one agricultural practice that increases carbon sequestration through the incorporation of manure/residue into the soil. It is well known that applying nutrients (fertilizer) to the soil increases cropland productivity. It has also been demonstrated that adding nitrogen in an inorganic form or an organic form, such as manure, may increase carbon sequestration. The process is like laying down a layer of carbon over the farm fields. One thousand Mt of organic and inorganic agriculture by-products are generated every year in the United States, and integration of ten percent of this manure and residue into cropland could mitigate 5.8 MMTC/yr (Lal 1998b).

Crop Rotation -- Crop rotation has also proven effective in sequestering carbon. Table 1.4 below shows how conservation tillage combined with different combinations of crop rotation increases the amount of carbon sequestration over regular plowing with or without crop rotation. It also shows that combining conservation tillage and residue management with crop rotation of wheat and peas might sequester more carbon than a plowing system that does not incorporate mulch.

Table 1.4 Organic carbon change in the 0- to 20-cm soil zone, as affected by cropping systems, 1931-1990, Pendleton, Oregon

				Organic Carbon ton/ha		
Cropping	**Date**	**Years in**	**Initiation**	**1990**	**Change**	**Change /year**

System	Started	Place				
Virgin grassland			56.83			
Grass pasture	1931	60	35.4	45.09	+9.69	0.162
W/F plow	1931	60	35.4	28.49	-6.91	-0.115
W/F plow	1951	40	33.73	30.39	-3.34	-0.084
W/F mulch	1951	40	33.73	30.55	-3.18	-0.08
W/P plow	1963	28	31.62	30.68	-0.94	-0.034
W/P mulch	1963	28	31.62	33.66	+2.04	**0.073**
W/W plow	1931	60	36.16	35.48	-0.68	-0.011
W/W no-till	1981	10	31.45	32.29	+.84	**0.093**
W/F=wheat/summer fallow, W/P=wheat/pea, W/W=winter/wheat, plow=moldboard plowed 20 cm deep, mulch=non-inversion tillage<10 cm deep; All cropping systems were fertilized and all crop residues except for pea vines in the W/P were returned to the soil.						

*source: (Lal, 1998a)

In the United States, 51 Mha are suitable for winter crop cover. If all of that cropland incorporated winter crop cover, 10.2 MMTCE per year could be sequestered (Lal, 1998b). In addition, another 1.9 MMTCE/yr could be sequestered if the 9.4 Mha of summer fallow croplands were cropped (Lal, 1998b). The use of crop rotation in this manner also helps balance the nitrogen/carbon ratio, which furthers the sequestration of carbon, similar to the effect of manure.

There is some scientific debate as to whether conservation tillage programs can actually manipulate cropland to sequester more carbon than if the land is allowed to return to its native vegetative state. Further research should help clarify this issue, but for now it is best to recognize that both methods increase carbon sequestration significantly.

II. Economics Of Agricultural Sequestration

The likelihood of realizing the potential for sequestration of greater carbon in agricultural soils depends in part on the financial feasibility of conservation tillage and other farming methods that promote this goal. Conservation tillage is a profitable farming practice in most cases due to its lower operating costs, which result from fewer plowing and other cultivation activities. This tillage practice also reduces soil erosion, improves the quality of soil, and reduces pollutant runoffs.

However, as noted above, only 37 percent of the U.S. cropland at present is under conservation tillage. Because of the risks and costs associated with changing tillage practices, the federal government must be the catalyst to provide farmers with incentives to change tillage practices.

Profitability of Conservation Tillage -- Although conservation tillage practices can result in lower crop yields than conventional plowing, reduced till or no-till practices are usually more profitable due to reduced operating costs. Research from the Conservation Technology Information Center (CTIC) shows that a no-till conservation tillage system can save as much as 225 hours and 1,750 gallons of fuel per year on 500 acres. No-till systems require approximately one trip for planting as opposed to conventional systems requiring two or three tillage operations plus planting. The decreased number of trips also results in savings of approximately $2,500 per year on machinery wear (CTIC, 1998e).

While fertilizer and seed costs are similar, herbicide costs are usually higher in the initial years of conservation tillage. Since tilling the soil helps control weeds, less tillage increases the dependence on herbicides. However, after the initial years, the herbicide costs appear to decrease (Weil, 1999).

For corn, soybeans, and winter wheat, fuel costs of conservation tillage are less than 50% of those in conventional tillage systems, while labor is reduced by 40%. In general, conservation tillage systems decrease total costs per acre by 15%. Most of this decrease can be attributed to the reduced costs of seedbed preparation.

Studies in Indiana and Iowa -- According to the CTIC study shown in Appendix 1A, ridge-till soybeans in Indiana have been more profitable than all other systems from 1991-1996 at $74.31 per acre followed closely by no-till at $71.48 per acre. While plow soybeans have a slightly higher yield than ridge-till or no-till, the plow soybeans costs were significantly higher, resulting in much lower average profits of $58.91 per acre (Walter, 1997).

According to Dan Towery of CTIC, the mulch-till in Indiana and ridge-tillage in Iowa have been the most profitable systems for corn, as no-till corn has had problems during cold wet springs. John Matocha of Texas A&M University, in a twelve-year tillage study at the Corpus Christi research center, has shown similar results, indicating that reduced tillage boosts corn yields during dry years (Walter, 1997).

Appendix 1B shows that the yields for all five tillage systems are within five percent of the average for all fields in Iowa. However, the profitability figures shown below in Table 1.5 favored no-till or reduced tillage systems. Table 1.5 shows comparatively high profitability for conservation tillage practices. For corn, the ridge-till system had the greatest profitability at $72.03 per acre followed closely by no-till at $70.01 per acre. The main economic advantage of the no-till systems is the lower field operations cost. Ridge-till systems gain an edge typically with lower pesticide costs (Walter, 1996).

For Iowa soybeans, mulch-till and ridge-till showed the greatest profits at $70.73 and $70.02 per acre, respectively. The advantage of mulch-till soybeans was both the lower pesticide and low machine operations costs. Due to slightly higher pesticide costs offsetting its lower machine operations costs, no-till soybeans fell close behind at $67.97 per acre. According to Jim Lake of Purdue University, the pesticide cost difference between no-till and reduced tillage was $5.65 per acre for soybeans and $4.40 for corn. Plow soybeans were the least profitable at $40.79 per acre (Walter, 1996).

Table 1.5 Profits ($/A) in Iowa from 1992-1995:

CORN					
	1992	**1993**	**1994**	**1995**	***Average***

No-till	49.36	20.71	68.96	141.01	*70.01*
Ridge-till	47.16	22.95	78.41	139.60	*72.03*
Mulch-till	4.74	10.16	57.06	97.79	*42.44*
Reduced-till	35.48	6.24	55.30	122.84	*54.97*
Plow	36.96	-25.90	28.21	84.52	*30.95*
SOYBEANS					
	1992	**1993**	**1994**	**1995**	***Average***
No-till	35.48	61.60	77.95	96.85	*67.97*
Ridge-till	40.78	58.17	76.10	105.03	*70.02*
Mulch-till	31.76	53.30	89.58	108.29	*70.73*
Reduced-till	39.02	43.97	74.86	87.21	*61.27*
Plow	7.81	36.76	43.76	74.88	*40.79*

*source: Conservation Technology Information Center Study (Walter, 1996)

Soybeans and Conservation Tillage -- As shown in Appendix 1C, soybeans have the greatest promise for increases in the use of conservation tillage. Full season soybeans account for 28.66% of the 66,641,227 cropped acres while double cropped soybeans account for 66.32% of the 6,162,951 cropped acres. On average, no-till systems were used on 32% of soybean acres in 1998, rising from 29% in 1997 (CTIC, 1998c).

To achieve the national goal of 50 percent of cropland under conservation tillage, no-till will need to be on approximately 60 percent of soybean acres by 2002. No-till accounted for 58% of soybeans planted in Ohio and 55% of those planted in Indiana in 1998. Other midwestern states are likely to follow this trend. Economics will thus provide the momentum to switch to no-till soybeans.

Soybeans are well-suited to no-till methods in almost every region of the country. They adapt to a wide variety of weather conditions, planting dates, and soils. The bean seed germinates and emerges well even in less-than-ideal spring conditions (CTIC, 1998d).

Corn and Conservation Tillage -- While no-till soybeans show the greatest opportunities for conservation tillage, new conservation methods are being developed so that corn growers can capitalize on the reduction of costs from conservation tillage without the problems associated with cold wet springs. Strip-till, a hybrid of no-till and ridge-till systems, shows great promise for corn farmers.

Under strip-till, corn growers use ammonia injection knives to till and raise the seedbed in the fall, then plant seed into the tilled area the following spring. Two-thirds or more of the row's width remains covered in residue, increasing the soil's microbial activity and building organic matter. Over time as the soil's condition improves, the soil is able to retain more moisture in drought conditions later in the summer. Strip-till yields are similar to conventional tillage but have lower costs (CTIC, 1998f).

III. Environmental Benefits Of Agricultural Sinks

While conservation tillage can reduce some crop yields, it has proven to be more profitable than conventional tillage in most cases. As opposed to other methods of carbon sequestration, converting to conservation tillage is a win-win situation. The farming industry has an economic and an environmental incentive to change tillage practices.

Conservation tillage practices, along with the use of winter crop cover, allow soil to increase carbon sequestration and mitigate the greenhouse effect. These practices reduce the soil's exposure to air; therefore, less soil carbon is oxidized and released into the air as carbon dioxide. As the soil is able to sequester more carbon, it becomes more productive for agricultural use.

Reduced tillage also decreases the pollutant runoff in addition to improving the quality of the soil. Soil erosion from water and wind can be reduced up to 90% by crop residues as compared to an intensively tilled, unprotected field. The reduction of soil erosion improves the quality of both the soil and water by reducing non-point source pollution. Conservation tillage can improve conditions for aquatic life. Excess phosphorus in lake water causes algae to multiply rapidly, often resulting in algal blooms, which deplete oxygen supplies for fish (CTIC, 1998e).

Crop residues can cut herbicide runoff in half on some sites by helping to hold soil particles and associated nutrients on the fields. These residues help reduce or eliminate water runoff from a field by acting as tiny dams to allow water more time to soak into the soil. Earthworms and intact old plant roots increase the soaking effect by creating channels (CTIC, 1998e).

IV. Obstacles To Agricultural Sequestration

While research shows that conservation tillage is cost-effective and provides external benefits such as less soil erosion, less pollutant runoff and increases in carbon sequestration, the use of conservation tillage is not increasing. Appendix 1D shows that while conservation tillage practices increased gradually during the 1990's, there was a slight decrease from 1997 to 1998 (CTIC, 1998b).

In 1998, approximately 37 percent of crops were planted with conservation tillage, compared to 35 percent in 1993. President Clinton set a national goal that 50 percent of cropland should be under conservation tillage by 2002. CTIC data shows that this goal will be difficult to achieve without changes in national farming policies.

While conservation tillage presents a win-win situation in terms of profitability and the environment, there are several reasons why conservation tillage has not been readily adopted by all farmers. Farmers already know how to farm under conventional tillage systems, and machinery is widely used, familiar, and accessible. When switching to conservation tillage, farmers do not have the benefit of over 100 years of research, learning and "trial-and-error" experiences (Dakota Lakes Research Farm, 1998).

While conventional tillage equipment is more costly than conservation tillage system equipment, to change systems requires new equipment. The initial cost of a newly designed planter is approximately $50,000. Even though conservation tillage is more profitable than conventional tillage in the long run, these capital costs can discourage farmers from making a large investment in new machinery (Weil, 1999).

Conventional tillage systems are flexible and can be adapted to a wide range of soil and crop conditions. The adoption of a conservation tillage system can add costs in the form of mistakes or precautionary measures. However, these costs are reduced with time and experience. Conventional plowing systems allow a grower to cover up mistakes easier through tillage. While a ridge-till conservation system will allow a farmer to correct some of these mistakes early, a mistake with a no-till system can devastate a harvest (Hood, 1998).

When crop residues are incorporated into the soil through conventional tillage instead of remaining on the soil surface, the soil warms faster, helping the crops to grow earlier. Conservation tillage systems leave crop residues on the surface, creating a disadvantage during cold temperatures. Conventional systems can have a greater yield advantage during cold wet springs due to the incorporation of crop residues in the soil.

Some farmers dislike conservation tillage methods for aesthetic reasons, due to the residue on the soil surface, which many growers find distasteful. While the residue provides benefits to the soil, it can also harbor disease and make the farmland look untidy. Some farmers prefer to see the black dirt they grew up with when they look at their farms (Hood, 1998). Many farmers like Aaron Chappell of Arkansas refer to the use of crop residues as “ugly farming” (Richards, 1997).

The recent trend toward organic farming is also a barrier to conservation tillage. No-till systems are heavily dependent on the use of herbicides to kill weeds. Since there is no practical alternative to herbicides in conservation tillage, many organic farmers continue to use conventional tillage methods to control weeds throughout the growing season.

Issues in Soil Sequestration -- There are a few concerns with respect to the widespread adoption of these practices. One prescription for conservation tillage will not fit all regions. For example, farmers in colder climates may need to adjust their conservation tillage practices towards strip-till instead of no-till because the growing season is shorter. Kentucky, Maryland, and Virginia adopted conservation tillage practices early on and have almost reached their carbon equilibrium levels.

Conservation tillage can lead farmers to be more dependent upon herbicides. They do not necessarily use more chemicals, but without the use of a plow to break up weeds they must rely more on herbicides. Many scientists suggest that future genetic engineering will mitigate this problem by producing seeds that are resistant to pests and weeds and that sequester more carbon.

Not all agricultural lands are suitable for conservation tillage. For example, rice paddies should not be drained and returned to native lands. Instead, agroforestry projects should be used in these areas to mitigate carbon emissions. Arid lands have less potential to sequester carbon and require different practices than temperate and tropical lands. Arid and even degraded soils could sequester more carbon with proper management. Worldwide, a recent DOE analysis suggests 800 to 1300 MMTC/yr could be sequestered on these poor quality farmlands, as found in Africa and some parts of Asia (DOE, 1999).

If appropriate policies are adopted, the rate of carbon sequestration could be expected to increase dramatically during the first decade of implementation. However, such rapid increases would not continue indefinitely. The level of increase in carbon sequestration will begin to flatten out as the system reaches a new carbon equilibrium. Within 25-50 years the equilibrium will have been reached if the proper techniques are developed. Because of this practical upper limit, carbon sequestration in agriculture is not a long-term solution to carbon sequestration.

For the longer term, a number of questions remain unanswered. If climate change alters growth patterns of vegetation by raising the levels of CO_2 in the atmosphere, current carbon sequestration models of respiration and decomposition equilibrium for CO_2 may no longer apply. In future research, special attention should be paid to the long-run models and the effects of sequestering carbon so that carbon sinks do not become new carbon sources.

Conventional tillage has several disadvantages. Labor, fuel and equipment costs associated with seedbed preparation are higher. The risk of soil compaction and weeds spreading increases with the additional field traffic. The risk of soil erosion from water and wind and soil crusting are also greater due to the lack of soil surface residue. Tillage also reduces organic matter levels. However, the risks and costs involved in changing tillage systems have kept farmers from changing to conservation tillage even in cases where it has proven to be more profitable in the long run.

V. Federal Disincentives

The federal government attempted to remove economic disincentives for farmers to implement conservation tillage systems and crop rotation through the 1996 farm bill. Before 1996, the farm bill's commodity program provisions stabilized prices of commodities such as corn, sorghum, cotton, rice, small grains and wheat to maintain an adequate domestic supply. The supports enabled farmers to remain in business during times of surplus by providing a guaranteed price for crops.

If the market price of the protected commodity fell below the guaranteed price, the government paid the farmer the difference through a deficiency payment. This guarantee applied only to a proportion of the grower's base acres set by the government. The base acres included the land on which the supported commodity was grown. Farmers enrolled in this program had to agree to keep a portion of their base acres out of production in years when the commodity surplus was most likely to drive down prices.

This program gave farmers an incentive to maximize base acreage to increase deficiency payment income before 1996. Farmers grew the same commodity crop on as many acres as possible every year. If the farmer planted a different crop, it was subtracted from his or her base acreage. This practice increased the need to rely more heavily on pesticides to control pests that feed on a particular crop. The lack of crop rotation also depleted the nutrients in the soil, increasing the need for chemical fertilizers (Smith, 1995).

The commodity program also gave growers the incentive to farm their land more intensively. Since farmers were periodically required to abstain from farming a proportion of their acreage, they tried to increase the harvest from the remaining land. They also tried to maximize their return on the commodity program land because the crops grown on that land earned a guaranteed price. In order to maximize the returns, they were likely to apply more chemicals and uproot trees or hedgerows. Trees and hedgerows reduce erosion and provide shelter to birds and animals that prey on crop pests (Smith, 1995).

The 1996 farm bill, entitled the Federal Agricultural Improvement and Reform (FAIR) Act of 1996, replaced the commodity program of price supports with a seven-year system of direct, declining payments ending in 2002. The FAIR Act allowed farmers greater planting flexibility. Any commodity or crop may be planted on contracted acreage with some limited exceptions.

The FAIR contract payments were based on a farmer's historical crop acreage and production. Congress authorized contract payments to farmers of $5.57 billion for 1996, but payments declined to $4.008 billion by 2002. These payments represented a substantial decrease from the record high level of $26 billion in support payments in 1986. However, farmers have received additional subsidies through supplemental legislation since the 1996 farm bill was enacted.

In March 1999, farm-state senators proposed federal crop insurance reforms to help farmers mitigate risk increased from the lack of price supports. Currently crop insurance is useless for areas that have had several years in row of disasters because policies are based on past yields. If a producer planted a new crop based on the flexibility of the 1996 farm bill, insurers will not cover the new crop until a few years later when the crop is established. Therefore, the current crop insurance structure discourages the farmer from switching crops. A current bill before the Senate proposes to address these problems by creating an average production history credit program for new farmers and those farmers that added or rotated crops (Quaid, 1999).

In the absence of commodity programs, farmers have had additional incentives to make more economically and environmentally beneficial decisions. Farmers can focus more on market-driven decisions based on profitability that can also improve the environment. However, President Clinton's goal of having 50% of U.S. cropland under conservation tillage by 2002 does not seem to be within reach. The amount of land under conservation tillage has only increased two percent since 1993. The introduction of the FAIR Act of 1996 has not had a great influence on promoting more environmentally sound tillage practices and crop rotation.

VI. Policy Options

Farmer incentives for carbon sequestration -- While the market provides an incentive for environmentally sound farm practices, including increasing carbon sequestration, farmers are not changing their tillage practices. To address this problem, a new federal incentive program based on environmental benefits should be created.

The current system does not provide the farmer with incentives. Instead it provides direct declining payments intended to wean farmers off of government subsidies. However, due to the interest of the public in maintaining a healthy farm economy and a reasonably priced food supply, these subsidies are not likely to disappear quickly. Payments should become an incentive system to improve both the farmer's profits and the environment. The federal government would be the likely catalyst for this incentive program.

The current Conservation Reserve Program (CRP) is an expensive way to reduce soil erosion and improve water quality. The CRP allows the government to purchase ten-year easements of highly erodible land to remove from productive use. If farmers use sound farming practices such as conservation tillage, crop rotation, and winter crop cover, they could still achieve adequate environmental results without the expense of putting land out of production (Smith, 1995).

The use of crop residues through conservation tillage reduces soil erosion and pollutant runoffs. The purpose of CRP is to achieve these same benefits. By creating new incentives for conservation tillage, the farm bill could be modified to pay for good environmental practices or direct environmental results while keeping land in production. Funds for CRP programs could be diverted to programs to promote the use of conservation tillage.

Carbon Tax Credits -- Illinois farmer Jim Kinsella proposed that farmers receive a payment or tax credit of one cent per pound (or $20 per ton) of carbon sequestered in the soil. Based on estimates of 1997 yields, he states that a 127 bushel-per-acre of corn crop would receive a $30 per acre credit while a 40 bushel-per-acre wheat crop would earn roughly $17.50 per acre. A 39-bushel-per acre soybean crop would only earn about $8 per acre due to its lower ability to sequester carbon (Kinsella, 1998).

Rattan Lal of Ohio State University estimates that total carbon residue sequestered in U.S. crop residues for corn in 1996 was approximately 10.8 to 21.6 MMTC per year, compared to 3.7 to 7.4 MMTC per year for soybeans (Lal, 1998b). The actual amount of soil carbon levels can be verified by soil core tests performed for a 10-20 acre area for approximately six dollars per sample (Weil, 1999).

Kinsella suggested offsetting the cost of the program through the creation of a carbon tax on carbon emitters. Carbon emitters such as utility companies would have to pay a tax on the amount of carbon they emit. Farmers would receive additional subsidies to sequester carbon at no cost to the government through Kinsella's proposed program.

During the first few years of a carbon tax credit program, farmers may have the greatest incentive to grow more high carbon-sequestering crops such as corn, resulting in a surplus to the market and a shortage of other crops. Carbon sequestration in the soil, however, is front-loaded. The economic benefits to the farmer will be greatest in the first few years and will level off over the remaining 25-50 years. This would result in a short-term incentive (Weil, 1999). However, this short-term strategy could buy time for the United States to develop long-term carbon sequestration strategies.

Carbon Credit Trading Program -- Another way to induce farmers to increase the ability of soil to sequester carbon is to set up a carbon credit trading system. Under this system, the government could determine a carbon target for a region and allot carbon emitting rights to businesses and carbon credits to farmers. Farmers could sell their carbon credits to electric utility companies and other carbon emitters. The farmers and carbon emitters would then trade credits among themselves in order to remain within the carbon target set for the region. This system could help a region to reduce overall carbon emissions and allocate carbon emissions among producers.

Payments for Carbon Farming -- Similar to the carbon tax system, the federal government could also provide farmers with direct payments for carbon sequestered in their soil. Crops such as corn sequester large amounts of carbon. While soybean farmers have a very large incentive to use conservation tillage due to its overwhelming profitability, corn farmers do not have a large financial incentive. However, growing corn allows more carbon to be sequestered in the soil than growing soybeans. If farmers of high carbon-sequestering crops had additional incentives to sequester carbon, these farmers might be more inclined to change tilling practices.

While the carbon sequestration incentives may be largest during the first few years of conservation tillage, start-up costs and learning costs are the biggest barriers to conservation tillage. Once farmers switch tillage systems, they will have more of an incentive to continue farming under conservation tillage since on average it is more profitable.

Currently, the government is not paying for results. The government is providing subsidies to farmers without receiving benefits in return. If the government provided payments for carbon farming, the use of conservation tillage practices would increase. Farmers could help reduce erosion, improve water quality, and sequester carbon, while increasing the productivity of their own farms.

Federal Start-Up Subsidies, Loans and Programs -- Another option is to pay farmers to start using conservation tillage. The government could create an incentive by defraying the start-up costs and providing additional subsidies for conservation tillage. These farmers would initially receive a financial incentive in the form of short-term subsidies or loans for changing tillage practices, rotating crops, and using winter crop cover. Over time, conservation tillage methods usually prove to be more profitable due to reduced costs; therefore, this incentive would only need to be a short-term startup strategy.

The largest barriers for farmers are the costs and risks associated with changing tillage practices. Financial incentives could reduce these costs. Federal programs could also educate farmers in conservation tillage practices and thereby reduce risks. While over 100 years of research, data, and lessons are available for conventional tillage systems, the data on conservation tillage is not as widely disseminated among farmers.

Water Quality Law Enforcement -- The government could also enact laws in accordance with the Clean Water Act or other environmental policies to encourage the use of conservation tillage. However, the government should at the same time provide growers with some additional financial subsidies to reduce the risk of farmers going out of business.

The increase in crop residues from conservation tillage decreases soil erosion from wind and water and results in reduced pollutant runoff. As more phosphorus bonds to the soil, phosphorus movement to lake water is reduced, resulting in less algae and increasing oxygen available to fish. The increased use of crop residues therefore protects aquatic animals and results in cleaner lakes (CTIC, 1998a). Reduced erosion also prevents increased sedimentation and nutrient pollution of rivers and streams.

Carbon Sequestering Soil Additives -- After 25-50 years of conservation tillage, the soil will eventually return to its organic native levels and cease sequestering additional carbon. However, emerging technologies could increase the ability of soil to sequester carbon. The Department of Energy (DOE) report on carbon sequestration speaks of "the possible use of byproducts created by advanced chemical methods as soil additions to increase organic content, water retention, and protection of organic matter, and to improve the texture of the soil so it can hold more carbon." The DOE reports that it could lead to the creation of "smart fertilizers" to increase the natural ability of soil to sequester carbon (DOE, 1999).

While increasing the soil's natural ability to sequester carbon, the use of "smart fertilizers" could help farmers mitigate the greenhouse effect and increase the productivity of their soil. The increase in the soil's natural ability to sequester carbon could make agriculture a strategy to sequester carbon beyond 25-50 years.

VII. Conclusions

Conservation tillage has proven to be more profitable, in most cases, and more environmentally sound than conventional tillage. However, since only 37% of the U.S. cropland is under conservation tillage, the case can be made that further incentives are needed to reduce the risks and costs associated with switching tillage practices.

The government can play an important role in promoting the use of conservation tillage by changing its subsidy system and enforcing laws to promote farming practices that would benefit the environment. By reforming the current farm bill to provide payments for environmental benefits instead of direct subsidy payments, farmers could help mitigate global climate change.

Because there is more carbon stored in the soil than in the atmosphere, forests, and all vegetation combined, agricultural sinks could prove to be an important aspect of mitigating global climate change. Conservation tillage practices combined with crop rotation and winter crop cover, could drastically increase the amount of carbon sequestered over the next 25-50 years. With only 37% of U.S. crops planted with conservation tillage in 1998, there is great potential for additional increases in carbon sequestration to 88-232 MMTC per year (Lal, 1998a). This reduction would make a significant contribution to achieving the cumulative 577 MMTC per year reduction from predicted baseline outcomes, as required by the Kyoto Protocol over the next ten years. With appropriate government policies, this goal might be accomplished at little or no cost to taxpayers and with significant environmental benefits as a bonus.

REFERENCES

Batjes, N.H. (1998). “Mitigation of atmospheric CO_2 concentration by increased carbon sequestration in the soil.” Biology and Fertility of Soils. 27: 230-235.

Brady, Nyle C. and Ray R. Weil. (1996). The Nature and Properties of Soils. New Jersey: Prentice Hall.

Cocheo, Steve. (February 1997). “How Ag’s New Age is Playing in the Hinterland.” ABA Banking Journal, 89: 7-10.

Conservation Tillage Information Center (CTIC). (4 November 1998a). “Conservation Tillage Report ‘Troubling’ for U.S. Agriculture.” Retrieved from www.ctic.purdue.edu/Survey/AgTroubling.html.

Conservation Tillage Information Center (CTIC). (1998b). “Conservation Tillage Trends.” Retrieved from www.ctic.purdue.edu/CRM/TillageTypes.html.

Conservation Tillage Information Center (CTIC). (1998c). “Crop Residue Management.” Retrieved from www.ctic.purdue.edu/cgi-bin/CRMMap…od.

Conservation Tillage Information Center (CTIC). (1998d). “Expect No-Till Soybean Acres to Almost Double by 2002.” Retrieved from www.ctic.purdue.edu/Survey/SideSoy.html.

Conservation Tillage Information Center (CTIC). (1998e). “14 Benefits for U.S. Farmers and the Environment through Conservation Tillage.” Retrieved from www.ctic.purdue.edu/CRM/Benefits.html.

Conservation Tillage Information Center (CTIC). (1998f). “Strip-Till – A Practical Solution for Conservation Tillage Corn.” Retrieved from www.ctic.purdue.edu/Survey/SideCorn.html.

Conservation Tillage Information Center (CTIC). (1998g). “Tillage System Definitions.” Retrieved from www.ctic.purdue.edu/CRM/TillDefine.html.

Crookshank, Steven L. (March 1999). “Carbon Sinks and the Kyoto Protocol.” Discussion Paper #109. American Petroleum Institute.

Dakota Lakes Research Farm. (1998). “No-Till Guidelines for the Arid and Semi-Arid Prairies.” Retrieved from http://dakotalakes.com/Guidelines.htm.

Department of Energy. (February 1999). “Carbon Sequestration.” Draft. February 1999: 4-1 to 4 29. Retrieved from www.fe.doe.gov/sequestration.

Drinkwater, L.E., Wagoner, P., and M. Sarrantonio. (19 November 1998). “Legume-based Cropping Systems Have Reduced Carbon and Nitrogen Losses.” Nature, 396: 262-265.

Hood, Mike. (April 1998). "Ridge-Till is a System for Lonely Connoisseurs." Successful Farming, 96: 38-40.

IPCC. (4 May 1999). "Technologies, Policies and Measures for Mitigating Climate Change." Retrieved from http://www.ipcc.ch.

Kern, JS. (1994). "Spatial patterns of soil organic carbon in the contiguous United States." Soil Science Soc. Am J., 58: 439-455.

Kinsella, Jim. (March 1998). "We Can Help Fix Global Warming, Farmers." Successful Farming,96: 50.

Lal, Rattan, Kimble, John, Follet, Ronald, and Bobby Stewart. (1998a). Management of Carbon Sequestration in Soil. New York: CRC Press.

Lal, Rattan, J.L. Kimble, R.F. Follett, and C.V Cole. (1998b). The Potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Ann Arbor: Ann Arbor Press.

Quaid, Libby. (4 March 1999). "Senators Propose Crop Insurance Overhaul." Business News.

Reicosky, Donald. (29 March 1999). "Tillage Intensity and CO_2 Emission from Soils." Retrieved from http://www.nal.usda.gov.tektran.data.000008/07/0000080751.html.

Richards, Keith. (Summer 1997). "'Ugly Farming' Saves Trips, Reduces Runoff." Southern Sustainable Farming, 15. Retrieved from http://ekolserv.vo.slu.se/Docs/www/Periodicals/SouthSustAgWorkGr/SSAWG_97_06.

Smith, Katherine. (Spring 1995). "Time to 'Green' U.S. Farm Policy." Issues in Science and Technology, 11: 71-78.

Walter, John. (April 1996). "Four Years Running: Four Years of Numbers Crunching Shows Profitability of Conservation Tillage." Successful Farming, 94: 46-48.

Walter, John. (April 1997). "MAX Monitors Profit." Successful Farming. Retrieved from www.agriculture.com/sfonline/sf/1997/april/max/index.html.

Weil, Raymond. Personal interview. 8 April 1999.

Appendix 1A: Costs, Yields, and Profits in Indiana from 1991-1996

Tillage System	Pesticides ($/A)	Field Operations ($/A)	Yield (bu/A)	Cost ($/A)	Profit ($/A)
CORN					
No-till	28.35	49.06	144.6	1.99	64.71
Ridge-till	19.13	56.70	148.8	1.94	56.24
Mulch-till	26.36	59.50	152.5	1.97	76.63
Plow	23.27	66.31	147.8	2.08	68.69
Reduced-till	24.05	60.50	146.2	2.05	60.66
Average	*26.48*	*53.68*	*146.4*	*2.00*	*66.34*
SOYBEANS					
No-till	33.26	44.00	49.0	4.68	71.48
Ridge-till	32.04	47.33	49.6	4.72	74.31
Mulch-till	29.74	53.84	50.3	4.63	70.00
Plow	25.41	60.44	50.0	4.77	58.91
Reduced-till	26.92	58.22	48.9	4.87	54.59
Average	*31.51*	*47.74*	*49.1*	*4.71*	*69.35*

*source: Conservation Technology Information Center (Walter, 1997)

Appendix 1B: Study of Yields (bu/A) in Iowa from 1992-1995

CORN					
	1992	**1993**	**1994**	**1995**	***Average***
No-till	171.4	110.3	174.1	148.3	*151.0*
Ridge-till	168.9	112.8	180.2	156.2	*154.5*
Mulch-till	160.7	108.2	177.7	149.3	*149.0*
Reduced-till	171.6	106.4	174.2	147.9	*150.0*
Plow	178.7	110.4	172.4	144.2	*151.4*
SOYBEANS					
	1992	**1993**	**1994**	**1995**	***Average***
No-till	50.6	44.3	58.5	53.2	*51.7*
Ridge-till	49.7	42.3	57.5	54.9	*51.2*
Mulch-till	50.4	42.4	61.5	55.4	*52.4*
Reduced-till	51.8	42.7	60.3	51.8	*51.7*
Plow	47.0	42.1	56.7	51.0	*49.2*

*source: (Conservation Technology Information Center)

Appendix 1C: CTIC Study of U.S. Tillage Systems by Type of Crop 1998

	Total Planted Acres	No-Till	Ridge-Till	Mulch-Till	Reduced Till	Conventional Till
Corn (FS)	80,530,888	16.41%	2.92%	19.57%	25.08%	36.03%
Corn (DC)	1,127,790	28.34%	0.16%	16.88%	19.91%	34.70%
Small Grain (SpSd)	33,504,935	8.30%	0.02%	22.58%	35.89%	33.21%
Small Grain (FISd)	47,774,791	9.31%	0.09%	24.21%	33.81%	32.58%
Soybeans (FS)	66,641,227	28.66%	0.92%	22.58%	22.17%	25.67%
Soybeans (DC)	6,162,951	66.32%	0.12%	7.80%	12.78%	12.98%
Cotton	13,627,167	4.89%	2.19%	5.31%	13.14%	74.47%
Grain Sorghum (FS)	9,336,745	11.11%	1.46%	21.06%	33.66%	32.72%
Grain Sorghum (DC)	574,204	31.72%	0.82%	16.16%	26.69%	24.61%
Forage Crops	7,062,600	10.23%	xxxx	13.85%	25.82%	50.10%
Other Crops	26,989,880	4.64%	0.26%	12.94%	25.92%	56.24%
Total	**293,333,178**	**16.30%**	**1.20%**	**19.73%**	**26.61%**	**36.16%**

*source: (CTIC, 1998c)

Appendix 1D: Conservation Tillage Trends 1989-1998 (percent of planted acres)

	No-Till	Ridge-Till	Mulch-Till	Conservation Tillage Subtotal	Total Planted Acres
1989	14,148,144 *5.06%*	2,716,275 *0.97%*	54,868,667 *19.62%*	71,733,086 *25.65%*	279,654,989
1990	16,861,810 *6.00%*	3,037,899 *1.08%*	53,344,132 *18.98%*	73,243,841 *26.07%*	280,985,927
1991	20,610,658 *7.33%*	3,234,786 *1.15%*	55,306,285 *19.66%*	79,151,729 *28.14%*	281,249,680
1992	28,078,484 *9.92%*	3,359,054 *1.19%*	57,267,155 *20.24%*	88,704,693 *31.35%*	282,909,079
1993	34,824,650 *12.52%*	3,453,789 *1.24%*	58,871,296 *21.16%*	97,149,735 *34.92%*	278,173,865
1994	38,985,494 *13.73%*	3,564,789 *1.26%*	56,776,723 *20.00%*	99,327,006 *34.98%*	283,916,794
1995	40,913,787 *14.68%*	3,400,055 *1.22%*	54,550,797 *19.57%*	98,864,639 *35.47%*	278,696,109
1996	42,889,487 *14.78%*	3,400,228 *1.17%*	57,525,484 *19.82%*	103,815,199 *35.77%*	290,203,415
1997	46,019,351 *15.62%*	3,782,820 *1.28%*	60,039,262 *20.37%*	109,841,433 *37.27%*	294,697,094
1998	47,807,513 *16.30%*	3,532,613 *1.20%*	57,860,673 *19.73%*	109,200,799 *37.23%*	293,333,178

*source: (CTIC, 1998a)