

**A Comparative Examination of the Efficiency of Sequestering Carbon  
in U.S. Agricultural Soils**

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## **A Comparative Examination of the Efficiency of Sequestering Carbon in U.S. Agricultural Soils**

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(Senior authorship is shared)

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*Abstract. This paper demonstrates the need to integrate bio-physical and economic data to assess the competitiveness of U.S. agriculture to provide soil C and participate in a market for C credits. We discuss alternative methods of calculating the costs of soil C sequestration and compare the cost of sequestering soil C in Iowa and Montana. Our analysis shows that the opportunity cost per Mg of C varies in response to regional resource endowments and net returns. Economic models show that Montana could sequester a relatively small amount of soil C annually at a lower opportunity cost per Mg than Iowa, but Iowa can sequester larger quantities more efficiently. We compare these results to estimates of the cost of C sequestration from other domestic and international studies, and find that U.S. agriculture could be competitive in a domestic or international market for C reduction credits.*

Key words: carbon reduction credits, carbon sequestration, economics of carbon sequestration, efficiency, U.S. agriculture

## **Introduction and Background**

The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC, 1998) aims to reduce atmospheric concentrations of anthropogenic greenhouse gases (GHGs) to minimize the potential for global climate change. Under the protocol, the U.S. is required to reduce net emissions of GHGs to 93% of 1990 levels between the years 2008 and 2012 (UNFCCC, 1998). This target could be met by reducing emissions of important GHGs, principally N<sub>2</sub>O (nitrous oxide), CH<sub>4</sub> (methane) and CO<sub>2</sub> (carbon dioxide), as well as removing CO<sub>2</sub> from the atmosphere and sequestering carbon (C) in agricultural or forest sinks. To facilitate these reductions the Kyoto protocol allows for the development of a trading scheme in emissions reductions credits. If C can be sequestered in agricultural soils at a lower cost than emissions reductions or sequestration efforts by other sectors, agricultural producers will be in a position to benefit from this new market opportunity.

Total U.S. emissions of GHGs are estimated at between 1,485 and 1,709 million Mg of C equivalent per year (MMgCE yr<sup>-1</sup>), of which emissions from agriculture are thought to be between 109 and 123 MMgCE yr<sup>-1</sup> (Lal et al., 1998). With appropriate management practices, agricultural soils can sequester additional C. Estimates suggest that up to 8% of U.S. emissions can be reduced by sequestering C in cropland soils (Lal et al., 1998). Alternatively, U.S. cropland has the potential to sequester between 4,000 to 6,000 MMg C if soil C can be returned to pre-cultivation levels (Lal et al., 1998; IPCC, 1996).

In addition to domestic reductions in GHGs, the Kyoto protocol (Article 12) allows developed countries (those listed in Annex 1 of the Convention) to purchase emissions reduction credits from projects in developing countries and use these credits to offset their obligations to reduce GHGs (UNFCCC, 1998). Developed countries can also trade emissions reduction credits between themselves. If U.S. agriculture wishes to be a participant in a global market for C credits it must sequester C at a cost that is competitive both nationally and internationally with other sources of C.

This paper demonstrates how bio-physical and economic data can be integrated to examine the costs of supplying soil C. Studies by Antle et al. (2001a) and Pautsch et al. (2001) are used to compare the relative economic efficiency of states within the Northern Great Plains

and Cornbelt regions at supplying soil C within a market for C credits. This is the first detailed comparison of the relative costs of soil C sequestration across different agro-ecozones of the U.S. We show that given the range of practices considered within each study, these agro-ecozones are not equally efficient at sequestering soil C since the opportunity cost per Mg of C sequestered varies spatially in response to economic and resource variability. Finally, we compare these estimates to the costs of C sequestration in other domestic and international projects to examine whether agricultural producers in these agro-ecozones could be competitive in a domestic or international market for C reduction credits.

### **Bio-physical Potential to Sequester C within U.S. Cropland Soils**

As land is converted from native vegetation to modern agriculture, C stored within the soil is oxidized and released into the atmosphere; in some cases, biomass production also decreases, reducing inputs of C into the soil (IPCC, 1996; Lal et al., 1998). Tiessen et al. (1982), Mann (1986), and Rasmussen and Parton (1994), estimate that 20% to 50% of soil C is lost during the initial 20 to 50 years of cultivation. Because of this past depletion of soil C levels, cultivated soils in many areas have the capacity to store more C than they do at present (Lal et al., 1998).

Soil C can be increased by adopting practices that reduce soil disturbance and thus C oxidation; and/or by increasing the amount of biomass produced on an area. As plants photosynthesize, they take CO<sub>2</sub> from the atmosphere and deposit it in the soil in the form of C stored in roots and other vegetative material. The inherent potential of a site to sequester soil C is influenced by bio-physical factors such as soil type, climate, topography and vegetation. Factors that influence soil C emissions and sequestration are discussed in Lal et al. (1998 p. 22).

Historic and current land use and management can influence the C sequestration potential of cultivated sites. There are several land use and management practices that can be adopted to increase soil C (Lal et al., 1998; CAST, 1992). For example, a switch from conventional to conservation tillage reduces C oxidation and thus emissions of CO<sub>2</sub>. Switching from a crop-fallow system to continuous cropping increases biomass production and inputs of C into the soil (Lal et al., 1998). The potential for these practices to sequester additional C varies spatially, as

shown in this paper, and is further influenced by the accompanying cropping intensity or tillage practice. Soil C is expected to increase relatively slowly during the first 2–5 years of management modifications with larger changes between 5–10 years and flattening off thereafter until reaching a finite limit over a period of 50–100 years (Franzluebbers and Arshad, 1996; IPCC, 1996). If producers subsequently revert to their original practices the stored C may be returned to the atmosphere.

To date there are few estimates of the potential for different agro-ecozones within the U.S. to sequester additional soil C. The presence of spatially heterogeneous bio-physical and economic conditions suggest that a single land use or management practice will not be equally efficient at sequestering C at different sites.

The majority of cropland in Iowa (one of the Cornbelt states), is continuously cropped (Mitchell et al., 1997) and consequently has little potential to sequester additional soil C through an increase in biomass production. In these areas, research has focused upon reducing tillage intensity to increase the rate of soil C accumulation. In contrast, Montana (in the Northern Great Plains) is mostly in a crop-fallow rotation and research has concentrated upon intensifying crop production to sequester additional soil C. An increase in biomass production coupled with a decrease in tillage intensity could further increase the rate of C accumulation. An exhaustive list of potential management practices has not yet been examined in every area.

The potential annual increase in soil C per ha attributable to changes in tillage practices within Iowa and increased cropping intensity within Montana are presented in Table 1. These estimates are generated by Century, a C dynamics model (Parton et al., 1987; Paustian et al., 1992; Paustian et al., 1996). Table 1 shows that a change from conventional tillage to no-till can sequester an additional  $0.52 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$  in Iowa, exceeding the potential to sequester additional C by increasing cropping intensity in Montana by  $0.08 \text{ Mg C ha}^{-1} \text{ yr}^{-1}$  (approximately 19%). The 1997 census of agriculture reports that there are 11 million ha of cropland in Iowa and 7 million ha of cropland in Montana (USDA, 1997). The combination of census figures and C rates from the Century model suggests that if Iowa producers switched to conservation tillage they would sequester C at a faster rate per ha as well as sequester a greater total C amount when compared to the potential to sequester C by increasing biomass production in Montana.

However, simply considering the bio-physical potential of an area to sequester soil C ignore economic, social and technical constraints. These factors will influence the costs of placing land in activities that sequester soil C and the willingness of producers to change their production practices. The role of economic constraints is discussed in the next section.

## **Economic Considerations**

### **Incentive payments to producers**

In this section we show that if farmers are making land use and management decisions to maximize their current net returns, they will obtain lower net returns when they change practices to sequester additional C. This reduction in returns is the opportunity cost to the producer of sequestering soil C. The opportunity cost per Mg C will vary spatially with land productivity and production choices (Antle et al., 2001a).

If we assume that the goal of each individual producer is to maximize their profits from production, they will be engaged currently in land use and management practices that yield the highest net returns. Producers will change these management practices to those that sequester additional C only if they are provided with an incentive that compensates them for any economic losses. There are many ways to structure economic incentives that encourage producers to participate in activities that sequester soil C (Antle and Mooney, 2001). The following example is based on a market scheme that pays producers for each Mg of additional C (see Antle et al., 2001a for more detail). This scheme is analogous to a per ha payment that varies spatially in response the ability of each site to sequester soil C (discussed in the next section). We assume that: production decisions on each ha are independent; participation is voluntary in any program designed to sequester additional C; and measuring, monitoring and transactions costs are zero and that there are no social or technical constraints that limit the adoption of management practices that sequester soil C. Let  $\pi_0$  represent profits per ha from current activities, and  $\pi_a$  profits from a management change that sequesters additional C, such that  $\pi_0 > \pi_a$  and  $\pi_0 - \pi_a$  is the opportunity cost per ha of sequestering additional C. Further let  $p$  represent the market price per Mg C paid to producers and let  $\Delta C$  represent the additional C sequestered on that ha annually as a result of adopting the new management practice. Under the assumptions of this

model, a producer will adopt a practice that sequesters additional soil C if  $\pi_0 - \pi_a \leq p\Delta C$ , that is if the total payment received per ha ( $p\Delta C$ ) compensates the producer for the opportunity cost per ha incurred by changing their management practice. Rearranging the previous expression we obtain  $\frac{\pi_0 - \pi_a}{\Delta C} \leq p$  that indicates the price per Mg must be large enough to compensate the producer for the opportunity cost of sequestering each Mg of C before a producer will change management practices. The opportunity cost per Mg,  $\frac{\pi_0 - \pi_a}{\Delta C}$  is determined by the quantity of C sequestered per ha as a result of changing management practices and the opportunity cost per ha of changing management practices. This expression supports the earlier assertion that the absolute quantity of C that can be sequestered on each ha annually,  $\Delta C$ , does not reflect producer willingness to engage in activities that sequester additional soil C. Thus the bio-physical potential of an area to sequester C and the economic costs of changing land management practices must be considered jointly.

## **Efficiency of Soil C Sequestration within Different Agricultural Regions of the U.S.**

### **Comparison of Montana and Iowa costs under a per Mg scheme**

The previous sections demonstrate that bio-physical factors determine the ability of an area to sequester C and economic factors determine the opportunity costs of changing management practices to sequester additional C. Antle et al. (2001a) and Pautsch et al. (2001) are two studies that have integrated bio-physical and economic data to examine the efficiency of soil C sequestration for different regions of the U.S. Both studies can be compared to show how the cost per Mg C varies over space.

Pautsch et al. (2001) use a discrete choice econometric logit model to examine producer decision-making in response to payments offered to sequester soil C. Producers are offered variable per acre payments (analogous to constant per Mg payments) for additional Mg C produced by a change in tillage from conventional to conservation till.

Fourteen major rotations were examined based on production of corn, soybeans, wheat, sorghum and hay. Corn and soybeans were the prevalent crops, planted on 90% of the land area.

Producers make a decision to switch tillage practices if the expected net returns under the new tillage system, plus payments for the additional C sequestered maximize their expected net returns. The probability of adopting a conservation tillage practice varies across production sites in response to bio-physical and economic conditions. Annual site-specific changes in C are estimated using a meta-model developed by Mitchell et al. (1997) based on EPIC (Erosion Productivity Impact Calculator). Carbon changes are estimated over 30 years (Mitchell et al., 1997) and converted to an annual basis assuming a linear accumulation over time for approximately 9 million ha of cropland soils. Site-specific annual changes in soil C are aggregated across sites to obtain the aggregate C supply function for Iowa corresponding to a per Mg payment scheme for C produced by a change in tillage practices.

Antle et al. (2001a) examine the economic potential for C sequestration on approximately 3 million ha of cropland soils within six agro-ecozones in Montana. A site-specific econometric-simulation process model (Antle and Capalbo, 2001) is used to predict changes in cropping systems in response to payments offered for each Mg of C produced as a result of intensifying biomass production. Analogous to Pautsch et al. (2001), producers are offered payments for each additional Mg of C that they can sequester by changing their cropping systems from either a crop-fallow system to grass or continuous cropping. Seven systems are considered by the model, spring wheat-fallow, barley-fallow, winter wheat-fallow, grass and spring wheat, barley and winter wheat continuous cropping. The additional soil C expected from a change in crop systems is estimated by Century, an ecosystem model of soil C dynamics (Parton et al., 1987; Paustian et al., 1992; Paustian et al., 1996). Carbon is assumed to accumulate over 20 years at a linear rate, as is typically done in the soil science literature (Watson et al., 2000; Mitchell et al., 1997). If the returns from the new system plus payments for the additional C produced exceed the returns from the original system the producer will change cropping systems (consistent with the theoretical framework presented earlier within this paper).

In these two studies the costs of sequestering soil C are considered from different viewpoints. Antle et al. (2001a) report the marginal costs of supplying soil C within six agro-ecozones over a period of 20 years. Marginal cost (MC) is the increase in total producer opportunity cost as a result of sequestering one additional unit of C. In contrast, Pautsch et al.

(2001) provide an estimate of the average annual cost of purchasing soil C. This is the cost incurred by a government or private agent when they purchase C, i.e., the price per Mg multiplied by the number of Mg purchased, and will exceed the opportunity costs incurred by producers generating C in most cases. The cost estimates per Mg C from Antle et al. (2001a) and Pautsch et al. (2001) can be compared directly by converting them to a common metric. We show below that the marginal cost of sequestering a given quantity of C is approximately equal to the average cost of purchasing that same quantity and thus can be compared directly.

The total producer opportunity cost of supplying a given quantity of C is the area under the marginal cost curve; for example, the opportunity cost of supplying  $C_1$  Mg of C is area A (Fig. 1). The marginal cost of sequestering one more Mg for a total of  $C_2$  Mg of C is area B.  $P_2$  is the price paid for each Mg of C at quantity  $C_2$ , area B can be approximated as  $MC_2 = P_2(C_2 - C_1) = P_2$  (where  $C_2 - C_1 = 1$ ). The total cost of purchasing  $C_2$  Mg of C by the government or other purchasing agent is  $P_2 * C_2$  and the average cost per unit is equal to  $(P_2 * C_2) / C_2 = P_2$  or the MC of the last Mg of C. Figure 1 and the previous discussion demonstrate that the marginal cost of supplying the last unit of a given quantity of C is approximately equal to the average cost per unit of purchasing that same quantity. Thus, the estimated costs of C sequestration generated by Pautsch et al. (2001) can be compared directly to Antle et al. (2001a) after the latter estimates have been converted to an annual basis.

The linear increase in C over 20 years used by Antle et al. (2001a) is converted to an annual basis by dividing through by 20. The annual quantity of C supplied at each price level within each of the six agro-ecozones was then summed to create an annual supply curve for Montana. Both the costs and C quantities are comparable to Pautsch et al. (2001) in that they represent the cost per Mg C from changes in consumer decision-making and management practices in response to an annual per Mg C payment.

One remaining difference between the two studies is the model used to estimate changes in soil C. Antle et al. (2001a) use Century while Pautsch et al. (2001) use a meta-model (Mitchell et al., 1997) derived from EPIC. Mitchell et al. (1997) show that an additional 0.2 MT/ha/yr C can be sequestered Iowa soils by changing from conventional to conservation tillage.<sup>1</sup> This figure

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<sup>1</sup> This figure was calculated from Tables 1, 3 and 4 and associated discussions in Mitchell et al. (1997).

is similar to the estimate from Century (Table 1) for a switch from conventional to moderate tillage but much less than that predicted by Century for a switch from conventional tillage to no-till. These figures suggest that if Pautsch et al. (2001) had used estimates from Century, the potential for soil C accumulation on each ha in Iowa might be greater than reported and demonstrates the potential for different outcomes under alternative modeling combinations.

Figure 2 compares the MC per Mg C within Montana ( $MC_M$ ) and Iowa ( $MC_I$ ) under payments that range between \$10 and \$700  $Mg^{-1}$  C. The relative placement of these curves is a function of both the spatial differences in the MC of soil C sequestration and the size of each study area. Both curves are inelastic throughout the price range considered, meaning that an increase in the price offered for each Mg of C will result in a less than proportional increase in the quantity of C supplied in both areas. At prices greater than \$340  $Mg^{-1}$ ,  $MC_M$  is almost vertical (or perfectly inelastic) implying that further price increases will generate negligible increases in C. This occurs because most of the cropland has already switched to management practices that sequester soil C. Iowa producers can sequester a greater total amount of C, in part reflecting the larger area of cropland suitable for soil C sequestration.

Figure 2 also shows that the two regions are not equally efficient at sequestering soil C. At prices less than \$155  $Mg^{-1}$ , C can be sequestered more efficiently within the cropland soils of Montana because a given quantity of C can be supplied at a lower marginal cost. For example, 0.5  $MMgC\ yr^{-1}$  can be supplied at \$30  $Mg^{-1}$  in Montana and \$80  $Mg^{-1}$  in Iowa. The total cost to producers is represented by the area under the marginal cost curves to the left of this quantity.  $MC_I$  lies above  $MC_M$  at prices less than \$155  $Mg^{-1}$  encompassing a larger area at any given C level. Montana producers would supply more C at prices less than \$155  $Mg^{-1}$  because the total producer costs of supplying C over this price range are higher for producers in Iowa than those in Montana. However at higher prices, Montana's available land becomes a limiting factor so the opportunity cost per Mg rises rapidly and Iowa producers become more efficient at sequestering soil C. Sandor and Skees (1999) estimate that the market price of C credits could range between \$15 to \$348  $Mg^{-1}$ . Figure 2 demonstrates that C can be sequestered in both regions within this range and thus, these areas of the U.S. agricultural sector are potential participants in a market for C credits.

### **Influence of program design on costs of C sequestration**

The design of policies to sequester soil C will influence the cost of producing or purchasing a given quantity. Abstracting from measurement and monitoring costs, Antle and Mooney (2001); Antle et al. (2001a) and Pautsch et al. (2001) have shown that a per Mg scheme is more efficient than a per ha scheme because this design accounts for the spatially heterogeneous ability of land units to sequester soil C and the spatial variation in the opportunity cost of switching production practices. Existing farm support programs such as the Conservation Reserve Program (CRP) or Environmental Quality Incentive Program (EQUIP) provide payments for each ha converted to a recommended land management practice. Similarly structured per ha payments will sequester C less efficiently than a per Mg scheme since producers are paid a fee that is not directly correlated with the benefits (in terms of the quantity of sequestered C) provided at each location (Antle and Mooney, 2001; Antle et al., 2001a). Stavins (1998, 1999) and Pautsch et al. (2001) suggest that the costs of measurement and monitoring under a per Mg scheme could be prohibitively costly and thus a per ha payment scheme might be preferred because compliance could be confirmed at a lower cost. However, recent results by Antle et al. (2001a) suggest that the efficiency gains offered by a per Mg program could be large, even accounting for the additional costs of measurement and monitoring.

### **Costs of Soil C Sequestration in Agriculture versus Alternatives for Mitigating GHGs**

Antle et al. (2001b) have calculated the marginal costs of supplying C under a range of per ha payment policies for the Northern Great Plains. The first is a policy under which producers are given a payment if they switch from a crop-fallow system to grass. The second provides producers with a payment if they switch from a crop-fallow system or grass to continuous cropping. Pautsch et al. (2001) also examine a policy that pays producers on an area basis for changing their tillage practices from conventional to no-till.

Table 2 compares the per Mg payment schemes of Antle et al. (2001a) and Pautsch et al. (2001) with the per-area payments described above. Results show that some C can be

sequestered in U.S. cropland soils for as little as \$10 Mg<sup>-1</sup> C. At close to \$100 Mg<sup>-1</sup> C, between 0.3862 and 0.5371 MMgC yr<sup>-1</sup> can be sequestered in Iowa and between 0.1142 and 0.8536 MMgC yr<sup>-1</sup> within Montana. Under a per Mg payment scheme both states combined could sequester approximately 1.4 MMgC yr<sup>-1</sup> at a marginal cost close to \$100 Mg<sup>-1</sup>.

However, the agricultural sector must also compete with the costs of C sequestered by forest practices and other means. Stavins (1999) and Parks and Hardie (1995) show that C can be sequestered domestically at between \$26 and \$150 Mg<sup>-1</sup> (Table 3) by changing marginal agricultural lands to forested use. International pilot projects have suggested that C can be sequestered in forest biomass at between \$3 to 28 Mg<sup>-1</sup> (Table 3). A comparison of the costs reported in Tables 2 and 3 indicates that soil C sequestration in U.S. cropland is competitive with domestic and international projects however the degree of participation and quantity of C supplied (as a proportion of the total traded) will be dependent on the equilibrium market price for C credits.

## **Discussion and Conclusions**

This paper demonstrates that firstly, economic and bio-physical factors need to be considered jointly to assess the efficiency of sequestering soil C and calculate the size of incentives that will encourage producers to participate in a market for C credits. Secondly, the studies compared in this paper demonstrate that the efficiency of soil C sequestration varies spatially in response to the bio-physical potential of an area to sequester soil C, and the opportunity cost of management changes. Those areas with the lowest opportunity costs per Mg C will participate in a market for C credits. Under alternative policies, for example a per-ha payment scheme, the spatial distribution of producer participation will differ and favor areas with the lowest opportunity cost per ha. However, Antle et al. (2001a) show that in the Northern Great Plains, the marginal costs per Mg of soil C sequestered under a per ha payment mechanism are as much as four times higher than the costs under the per Mg payment mechanism. Policies based on economic or bio-physical information alone will result in an inefficient allocation of resources. U.S. policies to encourage C sequestration are likely to be influenced by political as well as economic considerations.

Thirdly, evidence shows that the agricultural sectors within the Northern Great Plains and the Cornbelt could benefit from participation in a market for C credits both domestically and internationally. There are large areas of the U.S. that are not suited to afforestation and through soil C sequestration may be able to participate in a C market. An additional benefit, unlike the conversion of agriculture to forestry uses, is that these land areas will be maintained in production, supporting rural communities.

Fourthly, other important greenhouse gases are omitted from this study but need to be considered in a full accounting of the global warming potential associated with changes in management and production practices. Efficient policies will provide incentives to reduce the total global warming potential of the net changes in emissions and sequestration as a result of changing management practices.

Finally, these results are based on point estimates from each model and as such should be treated as only one of a range of possible outcomes. Confidence intervals are not available for either study but are the subject of current research. In addition, these results only consider a subset of potential management changes, and although these are considered to be the most promising at present an expanded set may change the opportunities available to producers.

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Table 1. Annual increase in soil C from management changes: Iowa and Montana.

Change in management	Additional carbon <sup>1</sup> (Mg ha <sup>-1</sup> yr <sup>-1</sup> )
Iowa – Change in tillage practice	
Intensive tillage to moderate tillage	0.19
Intensive tillage to no-till	0.52
Montana – Change in cropping system	
Spring wheat <sup>2</sup> fallow to continuous spring wheat	0.38
Spring wheat fallow to continuous winter wheat	0.44
Permanent grass to continuous spring wheat	0.06
Permanent grass to continuous winter wheat	0.13

<sup>1</sup>Estimates were calculated using Century (Parton et al., 1987; Paustian et al., 1992 and 1996) and provided by the Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins.

<sup>2</sup>*Triticum aestivum* L.

Table 2. Total annual soil C sequestration over a marginal cost range of \$0 to approximately \$100 per Mg.

Source	Policy Type <sup>1</sup>	Marginal cost (\$/Mg)	Annual carbon increase (million Mg)	Location
Per Mg payment				
Pautsch et al. (2001)	A	\$13 to \$92	0.0777 to 0.5371	Iowa
Antle et al. (2001)	B	\$10 to \$100	0.3597 to 0.8086	Montana
Per ha payment				
Pautsch et al. (2001)	C	\$20 to \$102	0.0777 to 0.3862	Iowa
Antle et al. (2000b)	D	\$32 to \$102	0.0197 to 0.1142	Montana
Antle et al. (2000b)	E	\$12 to \$98	0.0298 to 0.8198	Montana

<sup>1</sup>A - producers are paid for each Mg of additional C produced as a result of switching from conventional tillage to no-till.

B - producers are paid for each Mg of additional C produced by a change in cropping system.

C - producers are paid for each ha that is switched from conventional tillage to no-till.

D - producers are paid for each ha that is switched from a crop-fallow system to permanent grass.

E - producers are paid for each ha that is switched from a crop-fallow system or permanent grass to a continuous cropping system.

Table 3. Estimates of greenhouse gas (GHG) emissions reduction costs from U.S. and non U.S. sources.

Source	Marginal cost (\$/Mg)	Annual carbon increase (million Mg)	Location	Reduction source
Stavins (1999) <sup>1</sup>	\$0 to \$150	470	U.S.	Marginal agricultural land changed to forestry use
	\$0 to \$73	6.35	Delta States	
Parks and Hardie (1995) <sup>1</sup>	\$0 to \$26	19.96	U.S. cropland	Marginal agricultural land changed to forestry use
IPCC (2000)	\$14.25 <sup>2</sup>	0.0448	Czech Republic	Forestry
IPCC (2000)	\$27.80 <sup>2</sup>	0.0243	Uganda	Forestry
IPCC (2000)	\$3.00 <sup>2</sup>	0.0114	Belize	Forestry
IPCC (2000)	\$21 <sup>2</sup>	0.0225	Malaysia	Forestry

<sup>1</sup>See Stavins (1999, Table 3) for detailed notes on calculation of annual carbon amount and marginal cost estimates for both studies.

<sup>2</sup>Reported figures are point estimates of the average cost per Mg C to a purchasing agent. This is equivalent to the marginal cost to the producer of producing the last Mg at that quantity.

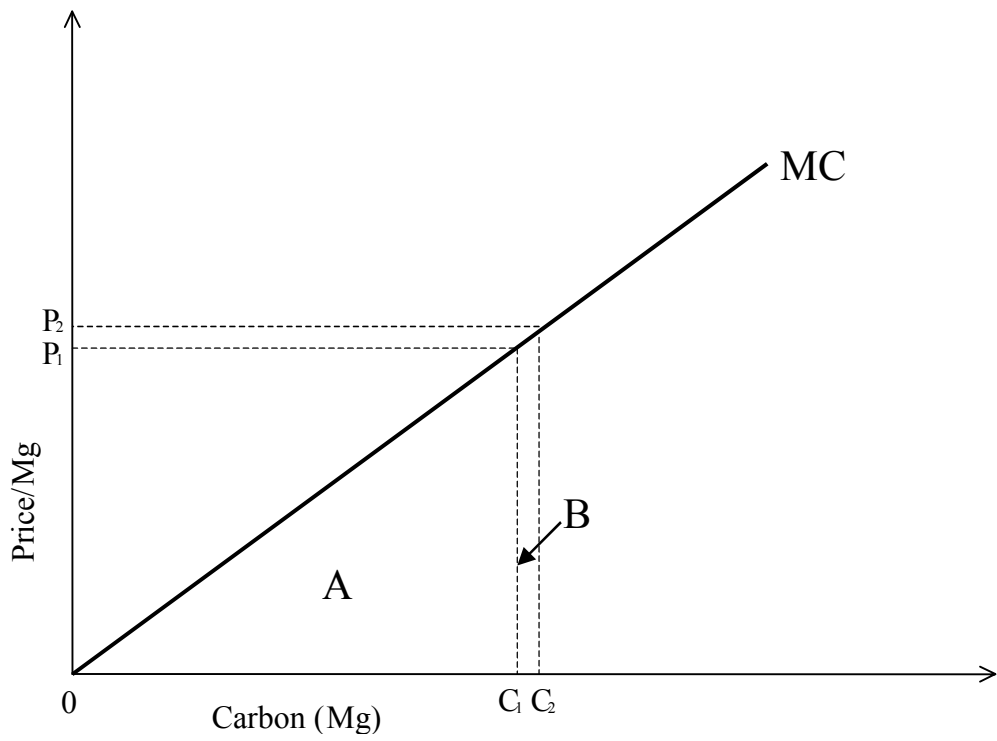


Figure 1. Marginal cost (MC) of carbon production.

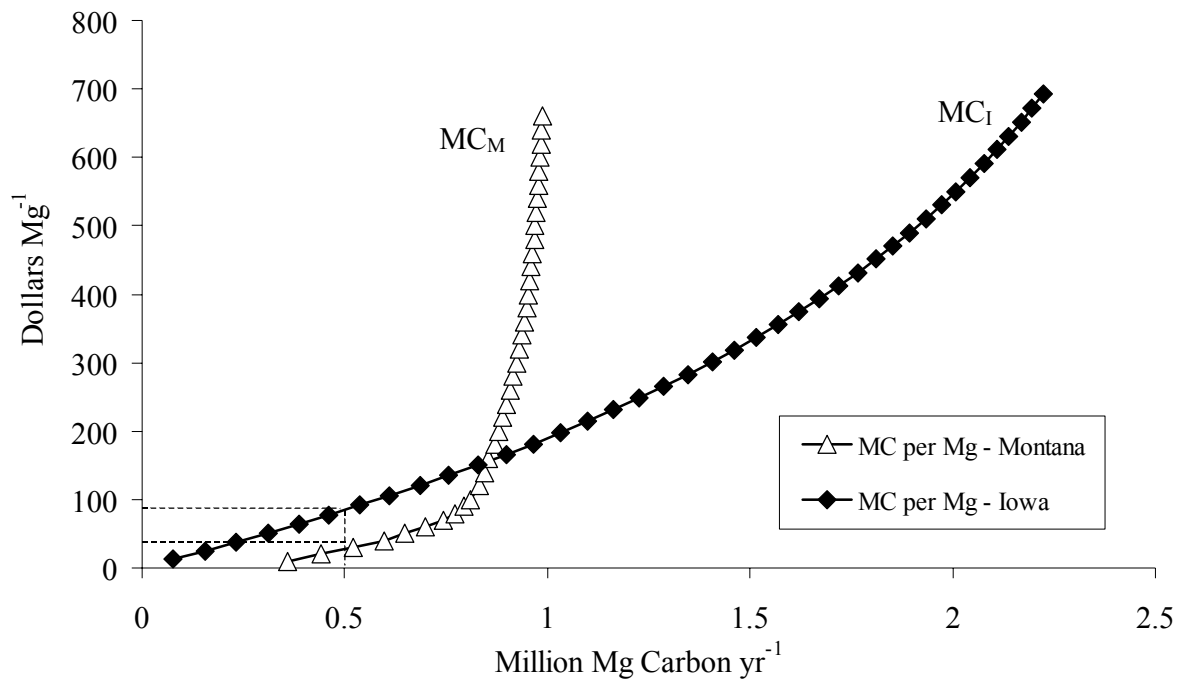


Figure 2. Marginal cost (MC) of soil C sequestration under a per Mg payment scheme implemented in Iowa and Montana.