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Economic and Environmental Co-benefits of Carbon Sequestration in Agricultural Soils: Retiring Agricultural Land in the Upper Mississippi River Basin

Hongli Feng, Lyubov A. Kurkalova, Catherine L. Kling,
and Philip W. Gassman

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Center for Agricultural and Rural Development
Iowa State University
Ames, Iowa 50011-1070
www.card.iastate.edu

Hongli Feng and Lyubov Kurkalova are associate scientists and Philip Gassman is an assistant scientist, all in the Resource and Environmental Policy Division (REP) in the Center for Agricultural and Rural Development (CARD) at Iowa State University; Catherine Kling is a professor of economics and head of the REP Division at CARD.

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For questions or comments about the contents of this paper, please contact Hongli Feng, 560D Heady Hall, Iowa State University, Ames, IA 50011-1070; Ph: 515-294-6307; Fax: 515-294-6336; E-mail: hfeng@iastate.edu.

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Abstract

This study investigates the carbon sequestration potential and co-benefits from policies aimed at retiring agricultural land in the Upper Mississippi River Basin, a large, heavily agricultural area. We extend the empirical measurement of co-benefits from the previous focus on environmental benefits to include economic transfers. These transfers have often been mentioned as a co-benefit, but little empirical work measuring the potential magnitude of these transfers has previously been undertaken. We compare and contrast five targeting schemes, each based on maximizing different physical environmental measures, including carbon sequestration, soil erosion, nitrogen runoff, nitrogen leaching, as well as the area enrolled in the program. In each case, the other environmental benefits and economic transfers are computed. We find that the geographic distribution of co-benefits (including economic transfers) varies significantly with the benefit targeted, implying that policy design related to targeting can have very important implications for both environmental conditions and income distributions in sub-regions.

Keywords: carbon sequestration, co-benefits, co-effects, economic transfers, environmental benefits targeting, Upper Mississippi River Basin.

ECONOMIC AND ENVIRONMENTAL CO-BENEFITS OF CARBON SEQUESTRATION IN AGRICULTURAL SOILS: RETIRING AGRICULTURAL LAND IN THE UPPER MISSISSIPPI RIVER BASIN

1. Introduction

In the past decade, carbon sequestration in the agricultural and forest sectors has attracted intense interest both in the scientific community and among policymakers. With the Kyoto Protocol becoming a binding treaty, many participating countries will be seeking efficient ways to meet the targets to which they have committed. Even countries that are not obligated by the agreement to reduce their greenhouse emissions (a notable example is the United States) are considering policies that will cut carbon emissions. Most of the literature on carbon sequestration has focused on its cost-effectiveness, and it has been shown that the agricultural and forest sectors have the potential to abate a significant amount of carbon emissions at moderate prices (McCarl and Schneider 2001). However, there are many critical issues that have to be addressed in designing an implementation plan for carbon sequestration, including the measuring and monitoring of carbon stored in soil, the non-permanence of sequestered carbon, and co-benefits (co-costs) that are generated simultaneously with carbon sequestration. In this paper, we empirically examine the co-benefits issue related to carbon sequestration.

Agricultural management practices that sequester carbon may simultaneously have other effects, often referred to as “co-effects” or more illustriously as “co-benefits.” The latter term is consistent with the view that the co-effects are likely to be beneficial for most agricultural carbon sequestration activities, although this will not always be the case. There are several reasons why a thorough understanding of the co-benefits associated with carbon sequestration is critical for designing policies to sequester carbon. First, the magnitude of co-benefits will determine whether program design needs to explicitly address co-benefits. For example, if carbon permit markets become highly developed wherein carbon sequestration credits can be purchased to offset carbon emissions, the co-benefits are externalities associated with the transactions. Whether government intervention is needed to correct for the resulting inefficiencies depends upon the magnitude of the externalities; if the externalities are relatively small, then it may be socially optimal for policymakers not to intervene since there are always transaction costs associated with designing and implementing a policy. On the other hand, if co-benefits (or co-costs) are important, it may be necessary to regulate or adapt carbon markets to appropriately integrate the effects. In the extreme, if co-costs are very important, possibly even outweighing the significance of the carbon benefits, then it may make more sense to consider fundamentally different policy instruments, (e.g., green payments in lieu of carbon markets).

In addition to their magnitude, it is also important to understand the heterogeneity of co-benefits from different sequestering practices and the location of those benefits. For example, while both land retirement and conservation tillage are likely to improve water quality, land retirement has the additional benefit of reduced fertilizer and pesticide use while the latter does not. For locations with particularly poor water quality, this mix of co-benefits is likely to be quite important. For other locations, it will be less important.

A third reason to consider co-benefits is that political support for a carbon sequestration policy may be strongly linked with co-benefits, particularly economic co-benefits. Farmers' income is an important policy issue, especially in developed countries where income support for farmers has had a long history and where farm lobbies have strong power in promoting or blocking programs. In this context, it is imperative to know the size and geographical distribution of net transfers, not just gross payments, to farmers/landowners to assess the likelihood of a carbon sequestration program's acceptability. In general, areas that will potentially benefit the most from a program are likely to bring strong political support, which may or may not coincide with income distribution goals of federal policymakers.

2. Co-benefits from Carbon Sequestration Policies

Two distinct types of co-benefits have been attributed to carbon sequestration in agricultural soils: effects on other environmental goods and income support. For example, a program like the Conservation Reserve Program (CRP), in which retired cropland could earn carbon credits in an expanded carbon market, would likely reduce erosion and nutrient runoff, as well as sequester carbon. Since erosion and nutrient runoff are implicated in water quality problems in many areas of the country, these reductions are co-benefits of the program or carbon market.

The co-benefits related to income support or economic vitality are a bit murkier to define and measure but are clearly dependent upon the details of the program or market that induces carbon sequestration. One way to define this co-benefit is the amount of revenue received by the farmer or landowner in excess of the full opportunity cost of a new practice or land use. Continuing with the land retirement example, if a farmer receives just enough compensation to cover his/her cost of taking land out of production, his/her net income will not be affected and therefore there will be no economic co-benefit from the program. However, if the compensation is greater than the opportunity cost of keeping the land in production, then the farmer has a higher net income and is better off because of the market/program. This is the measure of economic co-benefit we adopt for the remainder of this paper.

In addition to these two categories of co-benefits, there are other categories of co-effects of a carbon market or sequestration program that are not as direct but they may be sizable and are thus worth noting. First, if a practice affects the overall supply of agricultural outputs or demand for agricultural inputs, there will be effects on prices and this will affect society at large, resulting in overall welfare increases for some groups of people (e.g., consumers or producers) but decreases for others. These market effects are particularly important for assessing the impacts of climate mitigation strategies at the national level. McCarl and Schneider (2001) provided an excellent analysis of such impacts for greenhouse gas mitigation in U.S. agriculture and forestry. According to their results, farmers could benefit overall from mitigation policies because of higher prices of their outputs, although consumers of agricultural commodities would lose substantially. Other examples of market effect analyses include Alig et al. 1997 and Alig, Adams, and McCarl 1998.

Another co-effect arises from the potential substitution of carbon sequestration for outright reductions in carbon emission. It is well known that carbon emissions often generate co-costs in the form of other air polluting compounds such as NO_x. A large literature has been devoted to the estimation of the magnitudes of these co-costs, which can be sizable

(Burtraw et al. 2003). If carbon sequestration is used to reduce the amount of carbon in the atmosphere in lieu of directly reducing carbon emissions, then the reduced co-costs associated with the reduced carbon emissions will not be realized. The relative magnitudes of co-costs from carbon emissions and co-benefits from carbon sequestration will affect overall social welfare, as discussed in Elbakidze and McCarl 2004.

As noted earlier, few estimates of the economic co-benefits to farmers have been developed; however, there are some important studies that have assessed the size of environmental co-benefits from sequestration activities. Plantinga and Wu (2003) estimated the reductions in agricultural externalities from an afforestation program encouraging the conversion of agricultural land to forest in Wisconsin. Using existing benefit estimates, they show that the value of reduced soil erosion and benefits from enhanced wildlife habitat are on the same order of magnitude as the costs of the carbon sequestration policy. Matthews, O'Connor, and Plantinga (2002) also found that carbon sequestration through afforestation has significant impacts on biodiversity and that impacts can differ by region. McCarl and Schneider (2001) demonstrated that reduced levels of erosion, phosphorous, and nitrogen pollution from traditional cropland are likely as carbon prices increase. Greenhalgh and Sauer (2003) and Pattanayak et al. (2002) both found that the water quality co-benefit of carbon sequestration is very significant. Finally, by reviewing the estimates in the literature, Elbakidze and McCarl (2004) concluded that the magnitude of co-benefits from sequestration is comparable to the magnitude of co-costs from carbon emissions.

In the remainder of this paper, we assess the co-benefits from a carbon sequestration policy in a large agricultural region in the United States. In contrast with most previous studies of multiple benefits, this study not only estimates the relative efficiency of alternative benefit targeting schemes for improving various measures of environmental quality but also specifically investigates farmers' profitability from participating in the policies. We estimate the overall magnitude of the farmers' revenues and identify the spatial distribution of these revenues within our study region under alternative policy targeting schemes.

In the next two sections we describe the basic model, policies evaluated, study region, and simulation models. Section 5 introduces the aggregate co-benefit results.

Section 6 discusses the spatial distribution of the economic and environmental co-benefits under alternative targeting of the policies, and section 7 gives the conclusions.

3. Conceptual Model and Policy Design

To model alternative subsidy policies, assume there are N crop producers (farms) indexed by i that can potentially retire land from production, and there are K environmental improvements (benefits) such as carbon sequestered, reduced soil erosion, and reduced nitrogen runoff, indexed by j. Let $\overline{x}_i$ be the farm size in acres and c_i the per acre opportunity cost of retiring land. We assume that the retirement of acres from farm i generates b_i^j units of the j th benefit per acre, $i = 1,...,N$, $j = 1,...,K$.

We consider a policy in which producers are offered a uniform payment based on per unit of the j th benefit, s^j, to retire land from active production. Although every farm enrolled in the program is paid the same payment per unit of the benefit, the payments differ across acres. The per acre profit the i th farm gets from participating in the program is $s^j b_i^j - c_i$. We assume that as long as the farmer does not lose money from participating, he/she enrolls in the program on all the acres for which the subsidy is offered. In fact, such a policy pays some farmers more than the absolute minimum necessary to retire land from active production, thus creating a transfer of program funds to the farmers.

Consider the policy that targets the j th benefit, that is, the policy that maximizes the amount of the j th benefit generated by the program subject to the budget constraint, C, by deciding on the magnitude of the payment s^j as well as on the number of acres x_i, $0 \le x_i \le \overline{x}_i$, on which to offer the payment. Thus, the policymaker's problem can be written as

$$\max_{x_1,...,x_N,s^j} \sum_{i=1}^{N} b_i^j x_i \tag{1}$$

subject to $C - s^j \sum_{i=1}^{N} b_i^j x_i = 0$ (the budget constraint), $\bar{x}_i - x_i \geq 0$, $i = 1,...,N$ (land constraints), $s^j b_i^j x_i - c_i x_i \geq 0$, $i = 1,...,N$ (farmer rationality constraints), and $x_i \geq 0$, $i = 1,...,N$, $s^j > 0$ (non-negativity constraints).[1]

If the farms are heterogeneous in the environmental benefits from land retirement and the benefits are not perfectly correlated across j, the solution to problem (1) differs depending on which of the benefits is targeted. In this study, we simulate the alternative subsidy policy designs in problem (1) under varying budget levels and under alternative choices of the environmental benefit. For completeness of the picture, we also consider the policy that targets the area retired, that is, the policy that maximizes the area enrolled in the program subject to the budget constraint.

4. Study Region and the Simulation Models

The study region is the Upper Mississippi River Basin (UMRB), which extends from the source of the Mississippi River at Lake Itasca in Minnesota to a point just north of Cairo, Illinois. The region covers nearly 492,000 km^2, primarily in parts of Minnesota, Wisconsin, Iowa, Illinois, and Missouri (Figure 1). At present, cropland and pasture are the dominant land uses in the UMRB, which together are estimated to account for over 60 percent of the total area (NAS 2000). Dramatic alteration in the native vegetation from perennial prairie grasses to extensive cropland has generated serious water quality problems; the region has more than 1,200 stream segments and lakes that appear on the U.S. Environmental Protection Agency listing of impaired waterways, and the area is estimated to contribute significantly to the nitrate load discharged into the Mississippi River, which has been implicated in the cause of the extensive Gulf of Mexico hypoxic zone (Goolsby et al. 1999).

Because of the water quality problems, the area is a natural target for conservation efforts. Likewise, the highly productive agricultural lands, with their potential for carbon sequestration, make the region a good candidate for policies that target carbon. We consider a green payment type policy for carbon sequestration under which farmers with the highest benefit per dollar are enrolled. The payment is uniform across the study region and is equal to the highest cost per ton of carbon among enrolled farmers. This

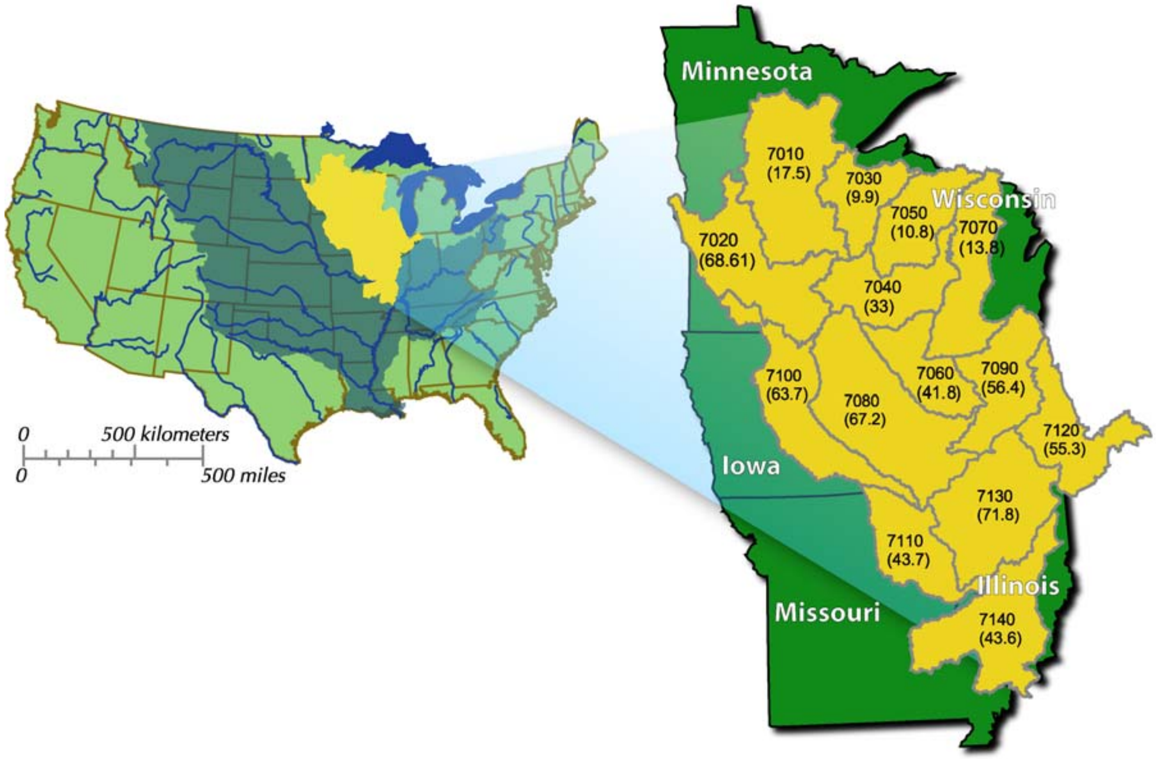

FIGURE 1. Upper Mississippi River Basin: 4-digit HUC and percentage of area under cropland

payment rate exactly equals the carbon price that would result from a competitive carbon market. Thus, while the study is motivated primarily with the design of conservation programs in mind, the findings, particularly with respect to income transfer, apply equally to a carbon market. We also consider programs that target other environmental benefits, treating carbon effectively as a co-benefit of these policies.

The simulations are carried out on $N = 40,249$ National Resource Inventory (NRI) (Nusser and Goebel 1997) cropland points, each representing a farm, with the total area represented being nearly 26 million hectares (ha). The costs of adoption, c_i, $i = 1,...,N$, are obtained using the approach of Smith (1995), who measured the opportunity cost of land retirement by means of the cropland cash rental rate. The methodology and empirical estimates of the cropland cash rental rates for the points considered in the analysis are provided in Kurkalova, Burkart, and Secchi 2004.

We consider $K = 4$ environmental benefits from land retirement, including carbon sequestration, reduction in erosion, nitrogen runoff reduction, and nitrogen leaching reduction. The farm-specific environmental benefits, b_i^j , are estimated at each of the data points using the Environmental Policy Integrated Climate (EPIC) model, version 3060 (Izaurralde et al. 2005),[2] which has been extensively tested and validated for predicting the environmental benefits from agricultural land retirement under a wide range of conditions. At each data point, two 30-year simulations were run, one assuming land retirement and the other assuming intensive tillage practices. Carbon sequestration is measured as the annual average of the difference between the total soil carbon under land retirement and that under intensive tillage at the end of the simulation period. The other benefits are measured as the difference in the average annual discharge under tillage and that under land retirement. The average carbon sequestration benefits of retiring land in the sample, 680 kg C ha^{-1} yr^{-1}, compares favorably with those reported by Follett et al. (2001).

5. Results: Aggregate Co-Benefit Estimates

We investigate a maximum program budget of $500 million, which was estimated to be enough to enroll about 10 percent of the region's cropland in the program. The total environmental benefits of the policies are provided in Table 1. The first column presents the results from a policy that targets carbon, that is, enrolls acreage into the program based on the highest carbon benefits per cost of enrollment. Such a program is predicted to enroll 1.5 million ha and to sequester 3.2 million metric tons (mt) of carbon and to have sizable erosion, nitrogen runoff, and nitrogen leaching benefits. The program would pay $158 million more to farmers than their opportunity cost, resulting from a per mt payment of just under $155.

TABLE 1. Area, environmental benefits, income transfer, and the uniform subsidy of a $500 million land retirement policy under alternative targeting

	Benefit Targeted				
	Carbon	Erosion	N Runoff	Leaching	Area
Area (mha)	1.5	1.7	1.3	1.6	3.1
Carbon (mmt)	3.2	0.8	0.6	1.0	1.3
Erosion (mmt)	7.4	40.5	14.1	9.7	27.1
N Runoff (tmt)	2.8	5.1	11.7	2.8	6.1
N Leaching (tmt)	10.0	6.4	5.6	30.6	15.3
Transfer (mill. $)	158.1	209.9	256.2	216.9	147.7
Payment	154.8	12.3	42.6	16.4	163.3
	($/mt)	($/mt)	($/kg)	($/kg)	($/ha)

In contrast, the second column of the table indicates that if erosion gains are targeted, over 4 million acres would be enrolled. While only about one-fourth of the carbon would be sequestered as under the carbon-targeting program, more than five times as much erosion would be controlled. Sizable, but less dramatic differences in N runoff and leaching would also be realized. The total amount of transfer payments would increase by about one-third.

The results for programs that would target N runoff, leaching, and land area are similar. In all cases it is evident that targeting significantly increases the amount of the targeted benefit obtainable relative to the policies that target other environmental benefits or maximize the amount of land enrolled.

An intuitively appealing way to depict the consequences of alternative targeting schemes is through Lorenz curves (Kurkalova, Kling, and Zhao 2004; Zhao, Kurkalova, and Kling 2004). The Lorenz curves depict the proportion of the benefit obtained under a targeting scheme relative to the benefit obtainable when the indicator itself is targeted, for varying levels of budget. We simulate the policies at 25 varying budget levels and report the Lorenz curves in Figures 2 and 3.

For example, when carbon is targeted (Figure 2), at a budget of $100 million, only about 10 percent of the maximum potential erosion or nitrogen runoff is achieved relative to if those benefits had been targeted. A higher percentage can be achieved as the budget increases (as expected), but even at the fairly high level of $500 million, only about 20 percent of the maximum benefit can be achieved. While the percentages are higher for nitrogen leaching and the total land area, there is still a much smaller amount of the total benefits achieved relative to if those benefits had been targeted.

Figure 3 depicts the situation for carbon when one of the other four environmental indicators is targeted. Again, the curves demonstrate that there is a significant trade-off between the carbon sequestered and environmental co-benefits and that that trade-off occurs even at fairly high budget levels.

These results for the UMRB are similar to those reported in Kurkalova, Kling, and Zhao 2004 for alternate targeting strategies for the policies that offer payments for adopting conservation tillage in Iowa. Both studies find that targeting land in conservation policy provides the highest proportion of carbon benefits obtainable among the other

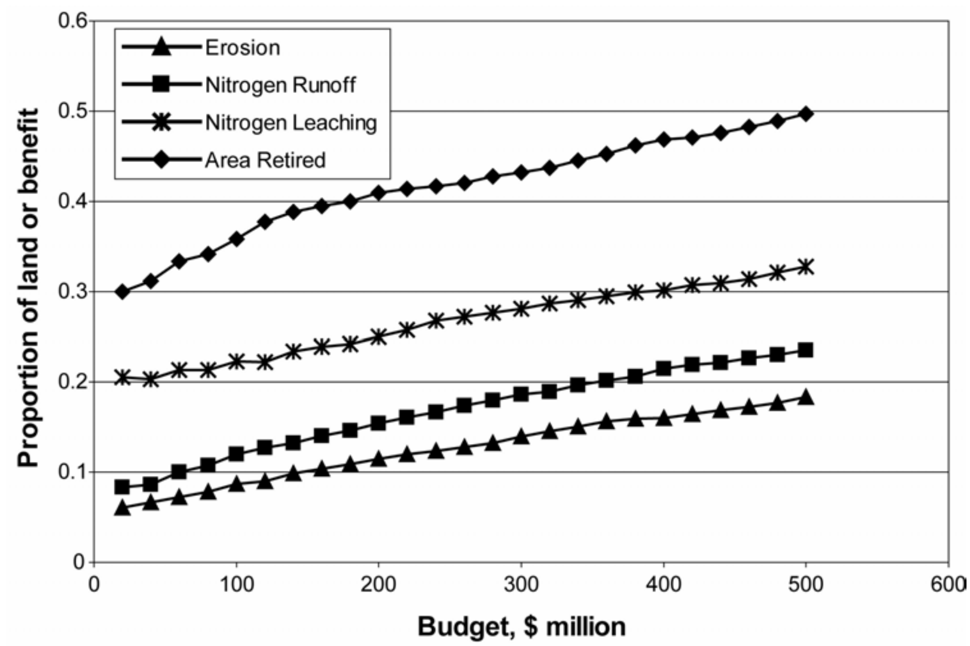

FIGURE 2. Area retired from production and benefits under the carbon-targeting policy as compared with those if land and/or the benefits were targeted

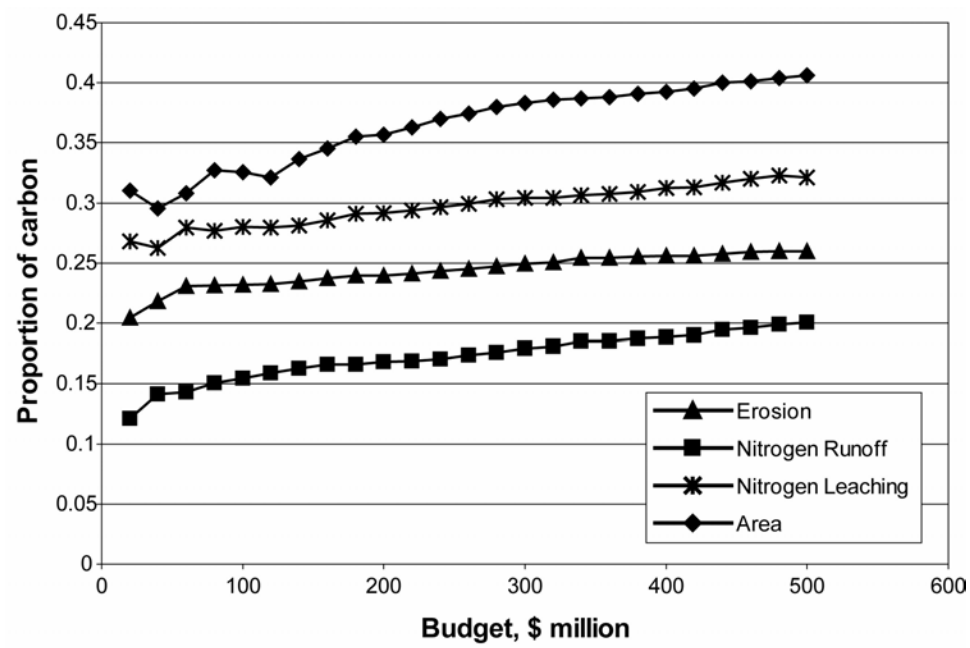

FIGURE 3. Carbon sequestered under alternative targeting

targeting alternatives considered. However, the scale of the policies considered is different in our study; while Kurkalova, Kling, and Zhao (2004) investigate the budget levels sufficient to enroll almost the entire study area in the conservation program, we do not deem retiring large proportions of prime agricultural land realistic. In consequence, the Lorenz curves reported in Figures 2 and 3 do not achieve the much higher fraction of the maximum potential co-benefits reported in Kurkalova, Kling, and Zhao.

To obtain some sense of the magnitude of co-benefits provided in Table 1, we refer to the estimates available in the literature. Ribaudo (1989) estimated that the benefits from reduced soil erosion are about \$5 per mt for our study region. For a policy that targets carbon, the benefits from erosion reduction alone would be about \$35 million, which is about 7 percent of the program cost (or about 10 percent of the program cost minus transfer). However, for a policy that targets erosion, the benefits from erosion reduction would account for about 70 percent of program cost excluding transfer. In addition, if the carbon price turns out to be lower than \$5 per mt, then the combined benefits from carbon and erosion would be higher under any policy considered than under the policy targeting carbon. It is difficult to estimate the benefits from nutrient reductions because it is a complex process to transform these nutrient reductions into water quality improvement. Even if we know the water quality improvement, its evaluation can also be a daunting task. According to one estimate (Feather, Hellerstein, and Hansen 1999), the benefits of CRP from fresh-water based recreation can be higher than \$10 per acre for our study region. Using this estimate, Table 1 implies that the carbon price would have to be higher than \$10 per mt just for the carbon benefit to be as high as its recreational co-benefits. These rough estimates indicate that co-benefits from carbon sequestration can be significant.

6. Results: Heterogeneity across Co-benefits and Geographical Areas

We now consider the spatial distribution of these co-benefits, with a particular focus on the distribution of economic co-benefits. Since we consider five targeting criteria (the environmental indicators) and seven indicators for outcomes (program costs, transfers, acres enrolled, carbon sequestration, erosion, nitrogen runoff, and nitrogen leaching), the results are too numerous to illustrate in their entirety here. Thus, we select a few sets of results, which highlight some of the most interesting spatial consequences of these policies. In Figure 4, we present maps indicating the share of land area, program cost, transfer payments, and carbon sequestration going to sub-watersheds in the UMRB as a result of a $500 million policy that targets the total amount of land area enrolled in the program. In Figure 5, the same set of information is presented for a program that targets carbon. We present the distribution of the per acre average values of some indicators when erosion is being targeted in Figure 6, and the distribution when runoff is being targeted in Figure 7.

In contrast with Figures 4 and 5, Figures 6 and 7 present the distribution of the ratio of the region-average per acre indicator to that for the whole UMRB. To illustrate the difference, consider, for example, carbon indicators. Let $\{UMRB\}^*$ and $\{HUC7080\}^*$ denote the sets of the farms selected in the program that are located in the UMRB and in the sub-watershed (HUC 7080), respectively. Then, for the HUC 7080, Figure 4D and Figure 6D report

$$\sum_{i \in I^* \cap \{HUC7080\}^*} b_i^{carbon} x_i \Big/ \sum_{i \in I^*} b_i^{carbon} x_i$$

and

$$\frac{\sum_{i \in I^* \cap \{HUC7080\}^*} b_i^{carbon} x_i}{\sum_{i \in I^* \cap \{HUC7080\}^*} c_i x_i} \Bigg/ \frac{\sum_{i \in I^*} b_i^{carbon} x_i}{\sum_{i \in I^*} c_i x_i},$$

respectively. That means that the magnitudes of the indicator depicted in Figure 4D are normalized so that the sum of the proportions of carbon across all the 14 sub-watersheds is equal to one. In contrast, the magnitudes of the indicator in Figure 6D are normalized so that the values above (below) one imply that the sub-watershed contributes higher (lower) amounts of carbon per acre enrolled than does the average acreage enrolled in the program.

One immediate and striking observation from the maps is that the distribution of benefits is very uneven across geographical areas, regardless of which indicator and criterion is used. Thus, in addition to significant trade-offs between the total amounts of environmental co-benefits as seen from the Lorenz curves, there is also the potential for

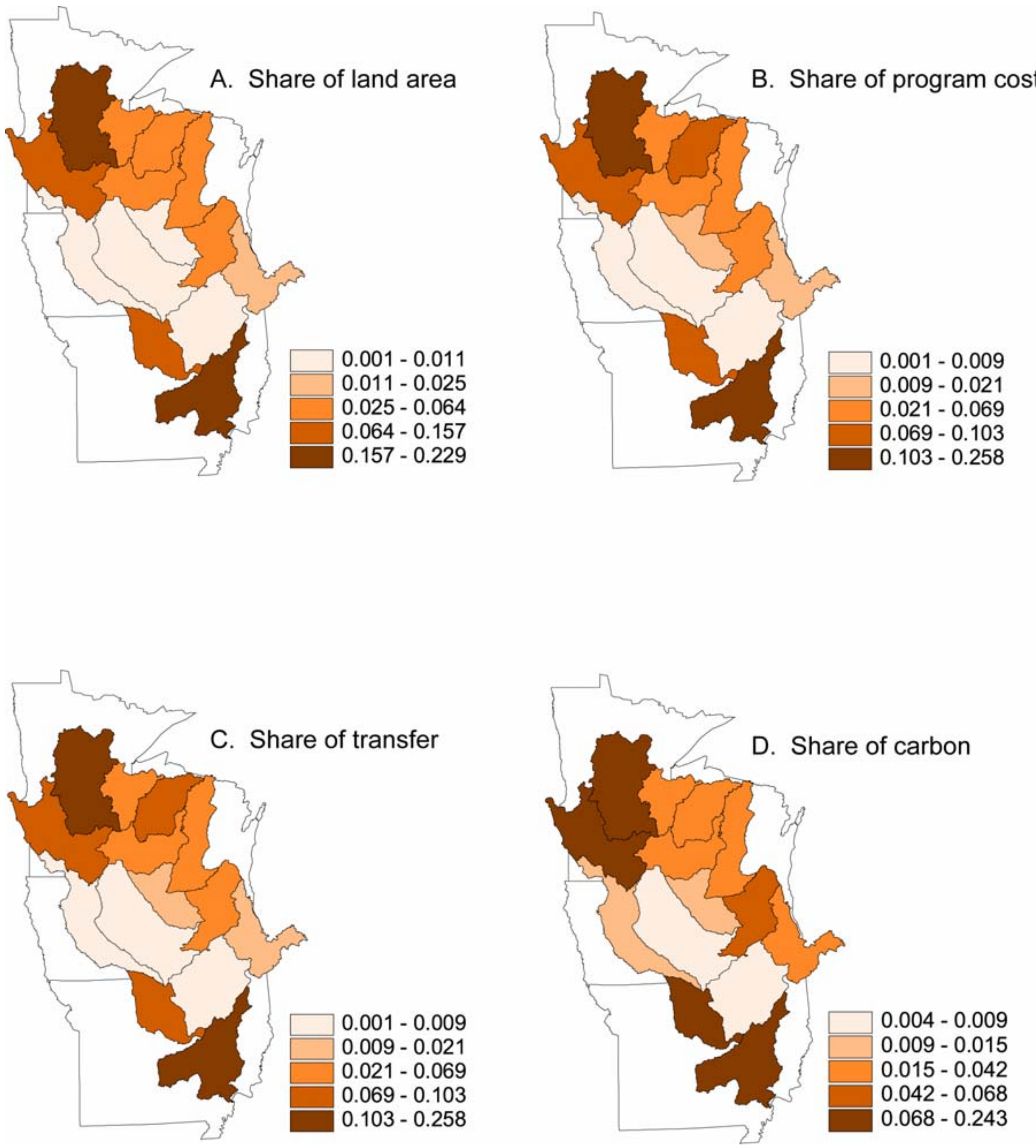

FIGURE 4. Regional shares under area targeting

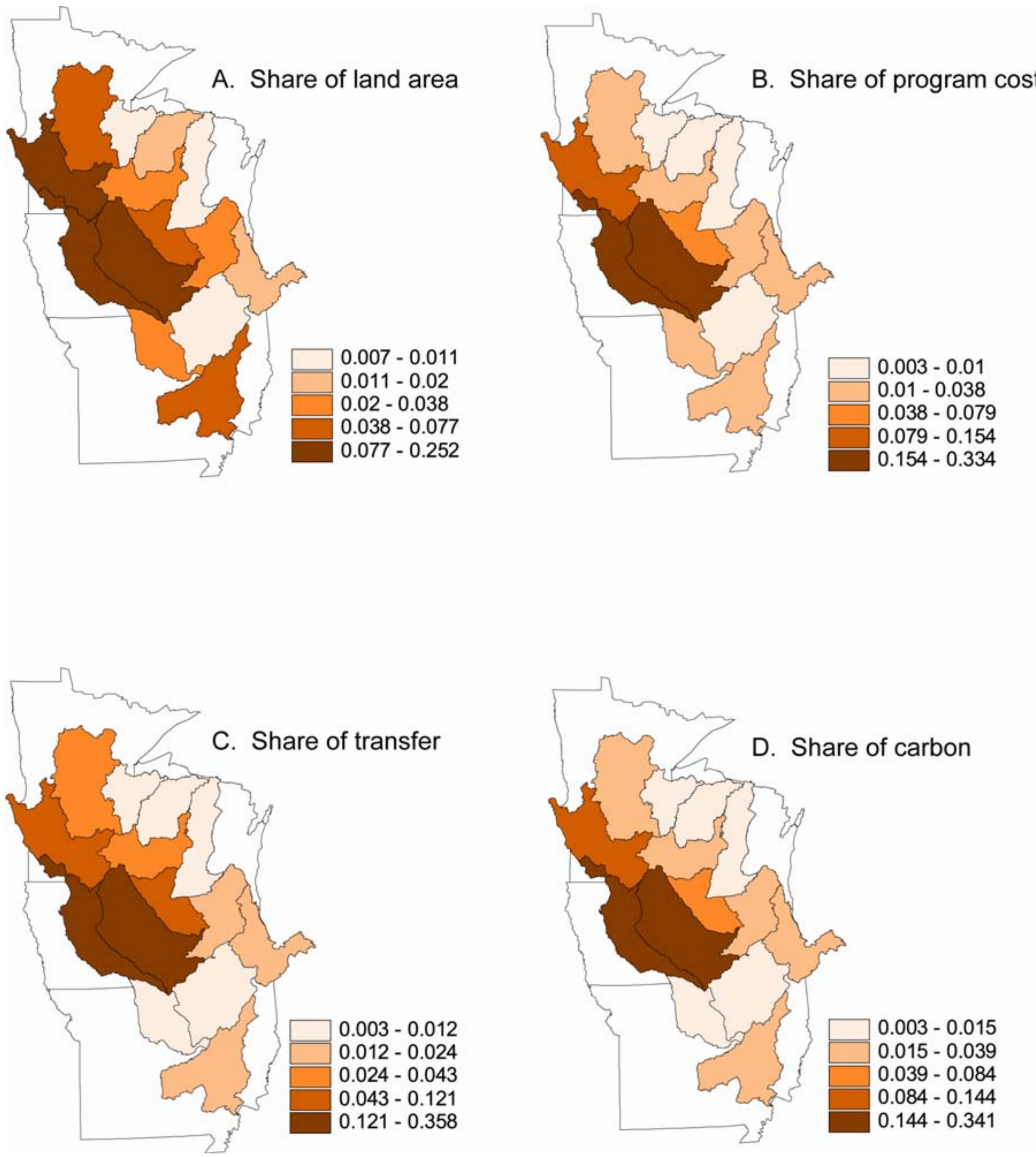

FIGURE 5. Regional shares under carbon targeting

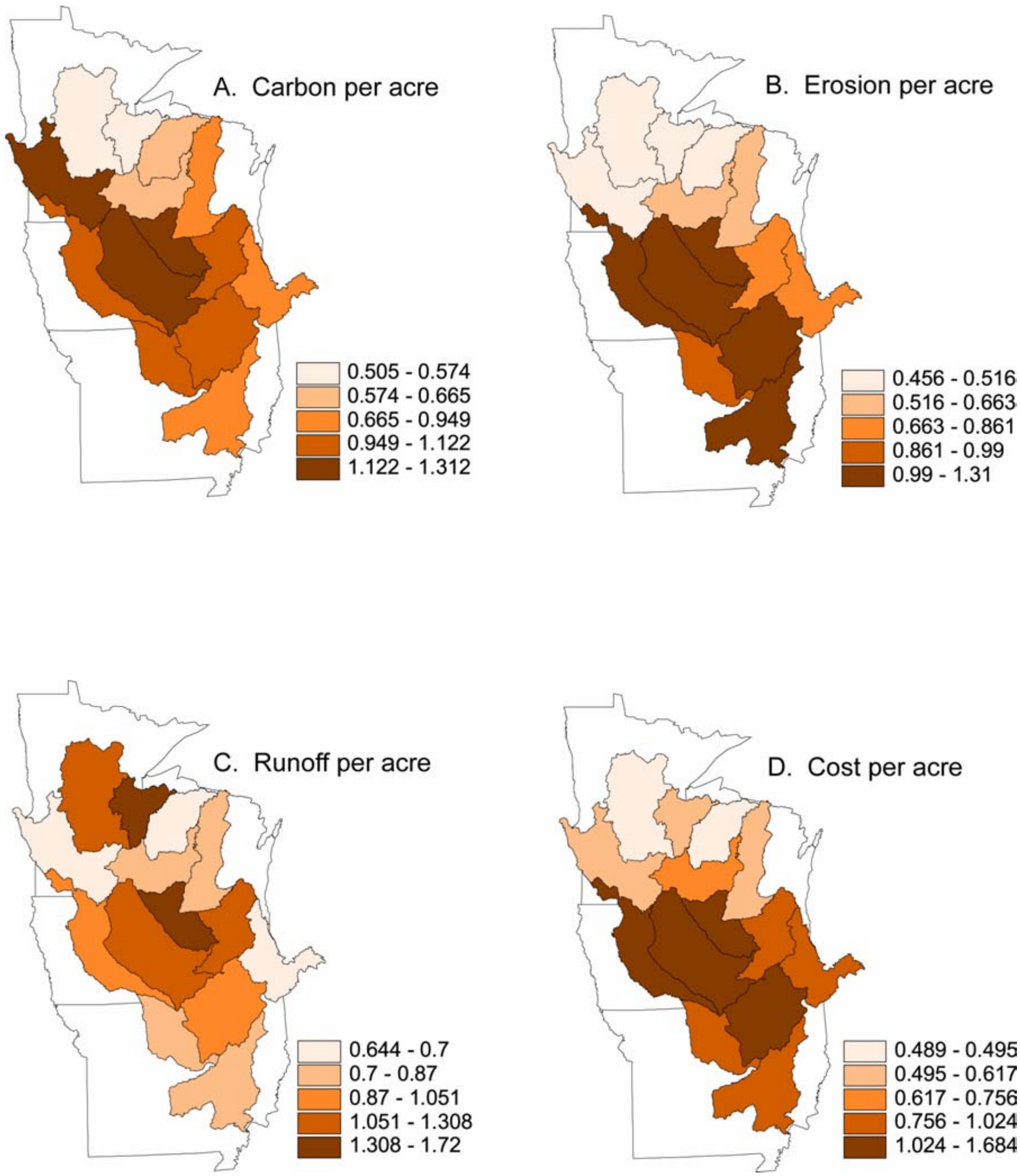

FIGURE 6. Per acre of selected indicators under erosion targeting

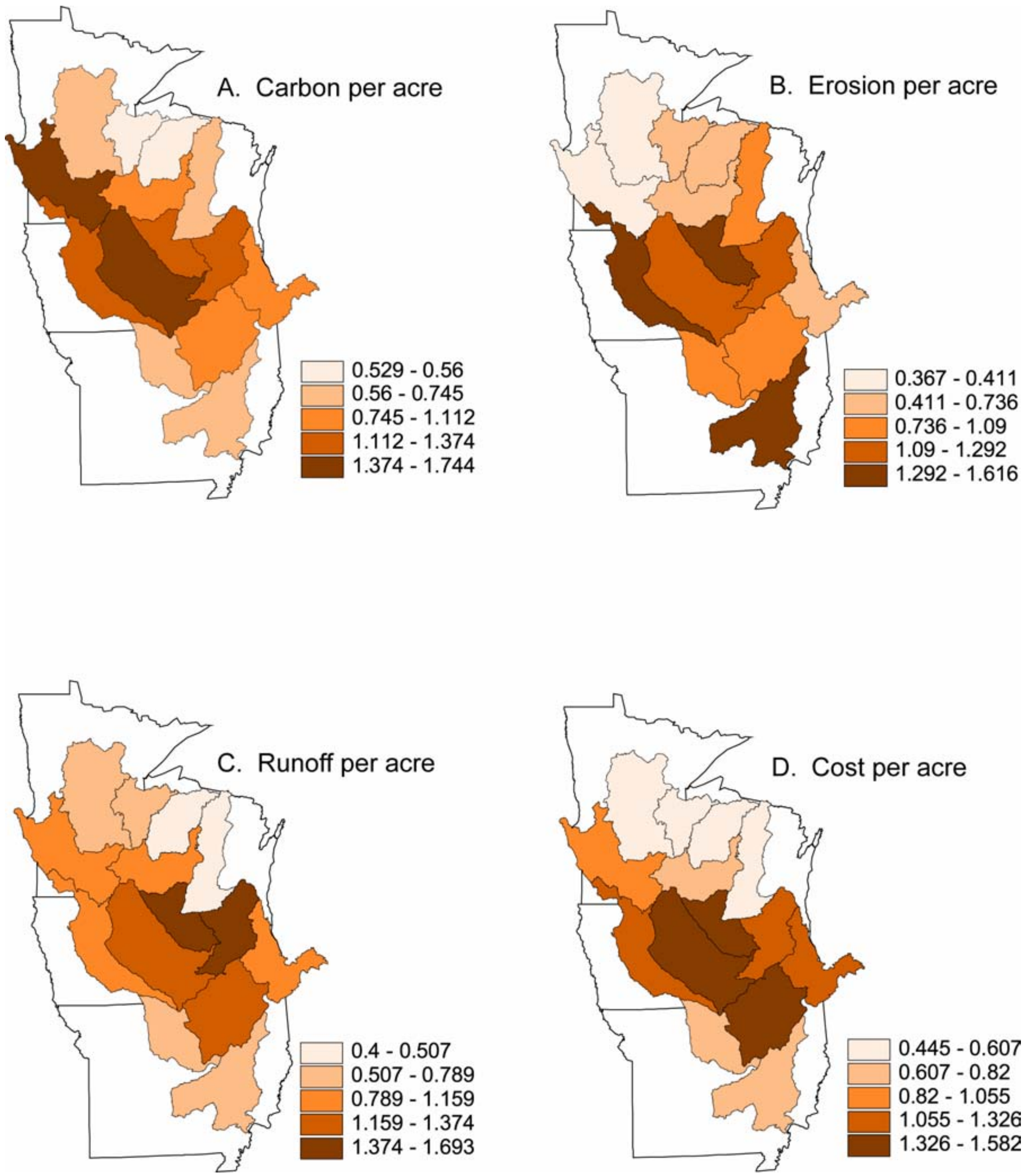

FIGURE 7. Per acre of selected indicators under runoff targeting

sizable trade-offs across geographic regions. This point is especially important for transfers (economic co-benefits) because, unlike environmental benefits, monetary transfers generate direct and immediate benefits to farmers. Thus, there may be strong pressure from different sub-regions to adopt a policy design that will generate the largest net transfer for them. And, not surprisingly, different land will be enrolled under different criteria. In general, benefit targeting enrolls more land with higher costs than does area targeting, which, by definition, enrolls land with the lowest costs (as illustrated by Figures 4A and 5A).

Despite the clear heterogeneity in indicators across the sub-watersheds, there is a surprisingly high degree of correlation between benefits (both environmental and economic) and costs in the sense that areas with high cost shares also tend to have high benefit shares. This correlation clearly exists for the area targeting and carbon targeting criteria (as shown by a comparison between Figures 4B and 4D and between Figures 5B and 5D). It is also generally the case under runoff targeting and erosion targeting (maps not shown). However, there are some important exceptions to this generalization when costs and benefits are measured in terms of per acre values, as demonstrated by Figures 6A-6D and Figures 7A-7D, where for example southwest Minnesota (HUC 7020) has a high carbon benefit per acre (Figure 6A) but a relatively low cost per acre (Figure 6D).

A third observation from the maps is that under area targeting (Figure 4), areas with the highest transfer share include Minnesota and Wisconsin and the southern tip of the UMRB. This excludes Iowa, which has a high transfer share under all other benefit-targeting criteria. It is also interesting to consider which areas have the highest potential transfer per acre. This question has different implications than the overall share accruing to a region because the former better measures benefits to individual enrolled farmers while the latter may indicate more about the overall transfer and economic vitality to a geographical region. Specifically, an individual farmer will have a higher incentive to participate the higher the per acre transfer, even though the overall benefit to a region may be low because only a few farmers participate. One way this can happen is if an area is on average a high cost area but has a few low-cost farmers. In this case, there will be a relatively low rate of participation, but those who participate may receive very high economic co-benefits (transfers).

The areas with high economic co-benefits per acre appear to be the areas with high cost per acre (i.e., Iowa and Illinois) under the targeting criteria of erosion and carbon (maps not shown). However, for other targeting criteria, this is not the case. For example, for central Iowa (HUC 7080), the cost per acre is high but transfer is low under area targeting policy. However, for the neighboring sub-regions (7100 and 7060), the opposite is true under the same policy.

Finally, despite the heterogeneity across sub-regions just discussed, the maps for the three environmental indicators are largely similar, which is consistent with the Lorenz curves in Figures 2 and 3, indicating that there is a positive correlation among carbon and its co-benefits. Note that the maps show spatial heterogeneity under a single budget. From the parallel nature of the Lorenz curves in Figures 2 and 3, we may expect that the heterogeneity pattern would also stay about the same as the budget varies. However, this kind of extrapolation can be risky since our preliminary analysis shows that this is not necessarily the case.

7. Conclusions

As noted in the introduction, the efficient policy response to the presence of co-benefits (both economic and environmental) resulting from land retirement to sequester carbon depends largely on the magnitude and distribution of the co-benefits across sub-regions. The empirical findings presented here strongly suggest that for the region of the UMRB, the co-benefits are likely to be sizable in absolute magnitudes, with those magnitudes in turn being highly dependent upon the design of the policy (i.e., the choice of indicator to target). Further, the co-benefits are likely to be highly variable across the sub-regions of the Basin.

These findings have important policy implications. They suggest that if society values these co-benefits, then a carbon market or conservation policy that solely focuses on carbon sequestration will not be efficient.[3] Simultaneous implementation of conservation policies and the expansion of carbon markets is one possible direction for such a socially efficient policy. However, this raises a number of challenging implementation questions, such as how to handle potential double payment for co-benefits (is a farmer who gets paid for land retirement from a federal program allowed to also sell the carbon credits in the carbon market?) and baseline questions (if a farmer would have put that land into CRP anyway, is it legitimate to count the carbon gains as additional carbon?).

Endnotes

1. For cases in which the solution to (1) is not unique, we chose the one that first enrolls the farms with the smallest cost per unit of benefit. This solution is also the one that provides the greatest total profit to participating farmers. Our simulation results are not particularly sensitive to this assumption.
2. Earlier versions of EPIC were called Erosion Productivity Impact Calculator (Williams 1990).
3. This of course assumes that the indicators we employ in this analysis correlate reasonably well with the true environmental services of interest.

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