RANGELAND CO_2 FLUXES: IMPLICATIONS OF RESULTS FROM THE USDA-ARS FLUX NETWORK

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1. INTRODUCTION

Atmospheric concentrations of carbon dioxide (CO_2) have doubled since the end of the last Ice Age and increased over 30% since the beginning of the Industrial Age, almost 200 years ago. Concern that increasing levels of CO_2 and other greenhouse gases may alter the intensity of Earth's greenhouse effect and alter the climate has led to efforts to reduce greenhouse gas levels, both by reduction of emissions and by biotic removal and storage of CO_2-C in plant biomass and soils as organic carbon by agriculture and forest management. Long-term measurements of CO_2 fluxes in major terrestrial ecosystems are required to define the magnitude of C exchange between the biosphere and the atmosphere, and to determine which ecosystems account for the "missing C." The large C sink thought to exist in North America likely consists of smaller sources and sinks of unknown magnitudes. Considerable information has accumulated regarding C storage in soils used for crop production, and networks such as AmeriFlux are measuring net C accumulation in forests and other ecosystems. Little information is available regarding the role of grasslands and shrublands in the global C balance, despite their extensive distribution. Less information exists relative to their potential for sequestering C.

The objective here is assess C storage by managed terrestrial ecosystems in light of the findings of a coordinated effort to measure CO_2 fluxes and net ecosystem productivity (NEP) over the major grassland ecosystems of the western and central U.S.

2. METHODS

Scientists at 10 locations participating in the Agricultural Research Service Rangeland CO_2 Flux Network have recorded net fluxes above native grasslands and shrublands almost continuously for several years, beginning as early as 1995, using the Bowen ratio/energy balance approach and, at some locations, acrylic chambers. The Bowen ratio/energy balance approach was selected over the micrometeorological alternative, eddy covariance, because the instrumentation was simpler and less expensive, it seemed more appropriate for short vegetation with relatively little roughness, and because evapotranspiration rates are also calculated by the method. Network participants also monitor vegetation productivity, meteorological conditions, and organic carbon (C) stocks in soils and vegetation. These measurements are made at each location on undisturbed sites typical of the region. However, at certain sites, measurements are made on paired sites to assess the effects of management practices such as grazing and burning.

3. RESULTS AND DISCUSSION

Measurements of CO_2 fluxes at the ARS CO_2 Flux Network locations indicate that all but the most arid are functioning as sinks, in un-managed states. That is, NEP is positive in most years in the absence of any herbivory, fire, or other influence which might alter productivity and thus C assimilation. Net annual ecosystem C exchange at these ungrazed and relatively undisturbed sites varies widely with precipitation and other variables, but rates averaged over years range from 200 g CO_2 m^{-2} yr^{-1} at an arid sagebrush site to about 1,100 g CO_2 m^{-2} yr^{-1} at a mesic tallgrass prairie site (Svejcar et al., and Dugas, this session). Annual fluxes are consistently negative in respect to the terrestrial surface at only one site, an arid grassland/shrubland near Tucson, Arizona, where respirational losses of CO_2 may be over-estimated due to evolution from highly calcareous soil surfaces.

4. CONCLUSIONS

An average NEP on U.S. rangelands of 200 g CO_2 m^{-2} yr^{-1}, or 0.54 metric tons (MT) C ha^{-1} yr^{-1}, represents about 168 million metric tons (MMT) of C sequestered annually over the 312 million ha of U.S. rangelands (extent of U.S. rangelands according to U.S.D.A., 1989). Total C sequestration would be 87 MMTC yr^{-1} if the smaller areal extent of grasslands, 161 Mha, used in estimates of potential storage rates discussed below (Schuman et al., 2001), is accepted. At a relatively mesic sagebrush site in Idaho, NEP averaged about 0.6 MTC ha^{-1} yr^{-1}. Soil C storage rates were on the order of 1 MTC ha^{-1} yr^{-1} after perennial grasses were established on C-depleted crop land and left undisturbed under the Conservation Reserve Program at five locations in the southern Great Plains (Gebhart et al., 1994). Measurements of CO_2 fluxes at the ARS CO_2 Flux Network locations indicate that C storage rates on mesic rangelands can approach the relatively high rates observed on CRP lands. This

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implies that C storage rates may be higher than expected on rangelands, especially where perennial grasses are grown under intensive management and harvested to maintain high NPP.

Recent estimates of potential C storage rates in the U.S. include 177 annually (MMTC yr^{-1}) in forests, an average of 142 MMTC yr^{-1} on crop lands, and 70 MMTC yr^{-1} on all grazinglands (Follett et al., 2001), which includes rangelands, pastures, and lands enrolled in the Conservation Reserve Program. The 70 MMTC yr^{-1} represents about 5% of current U.S. emission of C as CO_2. Up to 16 of the 70 MMTC yr^{-1} were attributed to potential improvements in management of rangelands; "nonintensively managed" rangelands were assumed to be small sinks or sources of CO_2. Another estimate of U.S. rangelands' potential to store C, 41 MMTC yr^{-1}, includes accumulation due to actions taken to increase storage rates and avoiding losses by maintaining existing soil C stocks (Schuman et al., 2001). For instance, maintaining rather than terminating grazing would avoid a loss of 16 MMTC yr^{-1}.

Annual C storage rates on rangelands based on CO_2 flux measurements imply that rangelands are currently functioning as C sinks, and are doing so to an extent that exceeds their predicted "potential." Productivity may be enhanced by environmental changes such as nitrogen deposition, rising atmospheric CO_2 levels, and better grazing management. It is not clear, from the comparisons of fluxes on adjacent sites at the same network locations, that management has consistent effects on NEP.

Management options for rangelands are limited to grazing management and prescribed burning. Controlled fire dramatically enhanced fluxes and C storage rates in tallgrass prairies in Texas and Kansas with undisturbed soils high in organic C content, but not on sagebrush steppe where a herbaceous response to fire apparently was insufficient to account for the loss of the shrub component in CO_2 assimilation. Grazing did not appear to alter C fluxes into shortgrass steppe or northern mixed prairie, but measurements of soil C contents at those sites suggest that grazing at reasonable intensities for decades increased soil C contents relative to un-grazed controls. A similar response to grazing is reported in the Southeast (Schnabel et al., 2001), but other reports document declines in organic C contents after grazing Interest in the potential quantities of C that can be stored in grazingland soils is generally predicated on their large areal extent. But, in addition to relatively high NPP, western grazinglands are also often characterized by vegetation with high diversity of species and growth forms. This diversity may maximize the length of time during the year when assimilation exceeds ecosystem respiration. Perennial grassland species are deeply rooted, partition high proportions of total biomass into below-ground tissues, and exhibit high root turn-over rates. Rangeland soils, like those of forests but unlike those of most crop land, are never subjected to intense disturbance.

Knowledge of CO_2 fluxes has implications beyond providing estimates of C storage rates. They also provide a measure of NPP, to the extent that NEP and NPP are related. Fluxes measured at each of the 10 locations in the network vary widely with year, but are closely correlated to growing conditions, especially precipitation, at monthly, seasonal and annual time scales. Annual fluxes also relate to documented productivities of the grassland ecosystems in which the sites occur, being low in arid environments and highest at the most mesic location, in central Texas, where precipitation is greatest and the site's soils are a relatively deep, productive vertisol.

The apparent responsiveness of fluxes at seasonal and annual time scales suggests that they have potential for use as indicators of ecosystem status or health, or as an approach to verification of other assessment methods. The assimilation component of CO_2 fluxes is a direct reflection of the processes associated with the vegetation's capacity to capture energy and carbon. However, the critical advantages of using NEP as a criterion may be that it is quantitative. Other indicators often represent or depend upon subjective estimates of ecosystem processes, such as visible indicators of soil stability and watershed function, or vegetation characteristics (cover, species composition, evidence of recruitment) which evaluate the integrity of nutrient cycling and energy flow.

5. REFERENCES

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