Comment on "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass"

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Tilman *et al.* (Reports, 8 December 2006, p. 1598) argued that low-input high-diversity grasslands can provide a substantial proportion of global energy needs. We contend that their conclusions are not substantiated by their experimental protocol. The authors understated the management inputs required to establish prairies, extrapolated globally from site-specific results, and presented potentially misleading energy accounting.

Tilman *et al.* (*1*) reported that biofuels derived from diverse mixtures of native grassland perennials can provide greater energy yields and environmental benefits than monoculture grown on fertile soils. We agree that growing herbaceous perennial species on land of marginal value for agriculture is desirable for several reasons, but we take issue with the authors' contention that low-input high-diversity (LIHD) prairie can provide a substantial contribution to our nation's energy needs. We argue that their experimental results do not substantiate their conclusions and that the authors overstated the global importance of their results.

Tilman *et al.* suggest that LIHD plantings could provide a sustainable source of harvestable biomass for fuel production, but they reported sample yields from an experiment in which nearly all the biomass was burned in situ, not harvested. Although several plant nutrients are lost from burned vegetation as gases or particulates, most cations are returned to the soil (*2*). With mechanical harvest, all nutrients are removed. Although legumes can replace nitrogen, nutrient replacement will be an important requirement for many marginal, and especially acidic, soils if yields are to be sustained. Limestone additions would be required to maintain symbiotic N_2 fixation on soils with poor pH buffering capacity. Liming represents a major energy input (*3*, *4*).

More seriously, the experimental approach of Tilman *et al.* is a form of double accounting with respect to carbon. The authors estimated harvestable biomass from small samples taken in late summer, then burned the remaining biomass on the plots the following spring [see supporting online material for (*1*)]. Combustion of this sort is incomplete, so some, if not most, of the soil C sequestration they measured is almost certainly due to charcoal additions that would not have occurred with harvest for biofuel production. Burning also has multiple, and often unpredictable, effects on prairie plant ecology. In general, burning reduces the presence of woody species in mixed stands, as the authors observed (*1*), but also helps control other undesirable species and may increase root biomass, tillering, soil temperature, and nitrification (*2*). With the exception of the decline in woody species, these benefits would not accrue with mechanical harvest of herbaceous perennials.

Tilman *et al.* (*1*) also ignored the difficulty of establishing and maintaining stands of native prairie species. Species composition was maintained artificially in the Cedar Creek plots with hand-weeding four times per year [see supporting online material for (*5*)], a practice that would be impossible in a commercial biomass production system. Because phenology differs among plant species, timing of biomass removal will influence species survival and composition of the grassland through interspecific competition. For instance, switchgrass, one of the dominant North American tallgrass prairie species, requires 6 weeks of regrowth to persist if harvested during the growing season (*6*). Resulting alterations in species dominance could affect grassland productivity and yield resilience under stress. Thus, the yields reported by Tilman *et al.* and their assumption of a 30-year useful stand life may need to be reconsidered. In temperate climates, delaying harvest until after a killing frost in the fall would avoid the problem of interspecific competition during late summer regrowth, but it would also remove protective winter cover of great value for wildlife.

Tilman *et al.* base most of their report (*1*) on one experiment, yet extrapolate their results globally. The experiment was conducted at one site in central Minnesota, USA, on soils that have low soil organic C, low water-holding capacity, and relatively shallow groundwater. The authors then estimated the amount of energy that might be provided by LIHD biomass, assuming 5×10^8 ha of "abandoned and degraded land." This land area, attributed to (*7*), derives from studies estimating the potential for reforestation of degraded lands primarily in the tropics (*8*). However, we are not aware of large areas of "abandoned and degraded" agricultural lands in temperate regions of the globe that would permit establishment of large-scale LIHD biomass prairies without affecting food production, as the authors claim. In the entire United States for example, there are only about 1.5×10^7 ha of land classified as idle cropland (*9*), and a substantial fraction of that area is in regions too arid to support the annual biomass yields projected in (*1*). We contend that, rather than attempt to make global calculations, the authors should have limited their interpretations to similar soil and climatic conditions in the United States, on clearly identified land where these practices could be implemented.

Finally, Tilman *et al.* make the misleading claim that LIHD biomass from degraded infertile land would produce more usable energy per hectare than corn grain ethanol from fertile soils [figure 2 in (*1*)]. The biofuel energy output (GJ ha^{-1}) for corn grain ethanol is four times as large as either of the two LIHD alternatives that include biofuel outputs. It also appears that most of the energy for the conversion process for LIHD biofuels, but not corn grain ethanol, was assumed to come from biomass co-products. Co-products from corn grain ethanol can provide all of the conversion energy (*10*), and applying them as conversion energy rather than co-product energy credit to their net energy balance ratios [figure 2 in (*1*)] results in a net energy of more than 50 GJ ha^{-1} for corn grain ethanol, with corresponding reductions in greenhouse gas emissions. Alternatively, using only half the corn stover produced from each hectare of corn grain that is used for ethanol production could provide all the energy required for distillation, or at least as much cellulosic ethanol as a hectare of LIHD prairie, thereby substantially improving the energy balance of corn-based ethanol. To be meaningful, net energy and greenhouse gas emission comparisons among biofuel systems must be based on consistent assumptions about conversion technologies.

Alternative energy based on biomass has captured public attention, and considerable resources are being devoted to research, development, and implementation. There is potential for substantial environmental benefit, but also for unproductive expenditure. Many agree that no single biomass feedstock or product will suffice because of the disparate economic, environmental, edaphic, climatic, technological, and logistical factors involved. We suggest

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that the results and conclusions presented by Tilman *et al*. be treated with appropriate caution until they have been subjected to more rigorous examination.

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