Bioenergy and Agriculture: Promises and Challenges

Environmental Effects of Bioenergy

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As concerns about climate change and energy security rise, bioenergy is often proposed as a renewable energy source that can be cost-effectively scaled up to a level that would allow it to contribute significantly to meeting global energy demand. Given that bioenergy can be generated in myriad ways, however, using various feedstocks and various energy technologies, few universal conclusions can be drawn about its environmental effects. One can easily imagine biomass production systems that are ideally suited to their environment, and even contribute to improving the environment by revegetating barren land, protecting watersheds, providing habitat for local species, and sequestering carbon, all while contributing to livelihoods of rural communities. Yet one can just as easily imagine biomass production systems that are fossil fuel intensive, exhaust the soil of nutrients, exacerbate erosion, deplete or degrade water resources, reduce biodiversity by displacing habitat, increase greenhouse gas emissions, and threaten the livelihoods of local communities. As with agricultural pursuits generally, the net impact of a bioenergy critically depends on how it is generated.

ENERGY AND CARBON BALANCES

Energy balances. Although biomass is invariably called a "renewable" source of energy, biomass production typically involves the consumption of fossil fuels. How much fossil fuel is used depends on the particular form of biomass and the production method. It includes fuels consumed by farm machinery in land preparation, planting, tending, irrigation, harvesting, storage, and transport; fossil feedstocks for chemical inputs such as herbicides, pesticides, and fertilizers; and energy required for processing the bioenergy crop into a usable biofuel.

Energy requirements are generally higher for annual than for perennial crops because they involve greater use of machinery and a higher level of chemical inputs. For many perennial energy crops, energy ratios (the quantity of useful bioenergy crop produced per unit of fossil fuel consumed) for feedstock production are high enough to make them attractive energy resources. For example, some crops (poplar, sorghum, and switchgrass) grown in temperate climates have energy ratios of 12 to 16. In tropical climates with good rainfall, however, these ratios could be considerably higher, owing both to higher yields and less energy-intensive (that is, more labor-intensive) agricultural practices. Energy ratios can be much lower for annual row crops that require high levels of inputs and a high level of mechanization and yield a relatively small proportion of usable bioenergy feedstock per unit of plant matter produced. Some oil crops in industrial countries, for example, have an energy ratio barely greater than 1.

Carbon emissions. Bioenergy can affect net carbon emissions in two main ways: (1) it provides energy that can displace fossil fuel energy, and (2) it can change the amount of carbon sequestered on land. The net carbon benefit depends on what would have happened otherwise—that is, both the amount and type of fossil fuel that would otherwise have been consumed and the land use that would otherwise have prevailed.

To assess the net impact of displacing fossil fuels, the relative carbon intensity must be assessed on the basis of the emissions associated with the biofuel crop production and the efficiency of the energy technology in which the biofuel is used. The table gives some approximate values for the carbon emissions of selected technologies.

This table assumes that the bioenergy crop is harvested in a carbon-neutral manner—that is, that there is no net change in carbon on the cropland and in the soil over the course of a full bioenergy crop cycle. In actuality, the carbon on the land could change significantly. The magnitude of the net change depends critically on how the biomass is produced and what would have happened otherwise.

Consider a case in which natural forest is cleared to provide fuel for a bioenergy facility, leaving a denuded site that cannot readily regenerate. In this case, the carbon emissions from the bioenergy cycle could well be greater than the carbon emissions from a fossil-fuel cycle providing an equivalent amount of energy. There is no justification for this fuel cycle from any environmental perspective. Nonetheless, this is a frequently used model for the production of non-energy biomass commodities and could be the most financially attractive strategy for a bioenergy project from the standpoint of near-term profits.

As a second case, consider a situation in which natural forest is cleared and replanted with an energy plantation harvested sustainably to supply a bioenergy facility with biomass continuously. The carbon sequestered in the natural forest will be released. The amount of carbon released depends on the type of forest, but a rough figure is 300 metric tons of carbon per hectare (tC/ha). As biomass feedstock is grown and harvested in cycles, carbon will be held on the land, partly compensating for the carbon released when the natural forest was cut down. Averaged over a growth cycle, a

Approximate Carbon Emissions from Sample Bioenergy and Fossil Energy Technologies for Electricity Generation

Fuel and technology	Generation efficiency	Grams of CO_2 per kWh
Diesel generator	20%	1,320
Coal steam cycle	33%	1,000
Natural gas combined cycle	45%	410
Biogas digester and diesel generator (with 15% diesel pilot fuel)	18%	220
Biomass steam cycle (biomass energy ratio[a] = 12)	22%	100
Biomass gasifier and gas turbine (biomass energy ratio[a] = 12)	35%	60

[a] The energy content of the biomass produced divided by the energy of the fossil fuel consumed to produce the biomass.

Source: S. Kartha and E. D. Larson, *Bioenergy Primer: Modernised Biomass Energy for Sustainable Development* (New York: United Nations Development Programme, 2000).

typical amount of carbon sequestered on the plantation land might be 30 tC/ha. The natural forest therefore holds 270 tC/ha more than the energy crop. If the bioenergy crop is used to displace fossil fuels, thereby reducing carbon emissions, it will compensate for this 270 tC/ha difference over a period of roughly 45 years. Thus, there might be a case based on carbon benefits for clearing natural forest to plant energy plantations. It is not, however, a very compelling case, and when environmental and social considerations, such as preserving habitat and protecting watersheds, are taken into account, these considerations might outweigh any carbon benefits.

In the third case, a bioenergy crop plantation is developed on unproductive land, such as degraded land that could benefit from revegetation. The degraded land most likely held considerably less carbon than the plantation, even in the soil and other below-ground biomass. In this case, the change in land use will offer not only benefits resulting from displacing fossil fuels, but also carbon benefits and other ecosystem benefits.

OTHER ENVIRONMENTAL IMPACTS

Biomass crops are no different from other farm crops when it comes to managing soil, water, agrochemicals, and biodiversity, and the consequences of not following good practice are generally the same as with other crops. But biomass production also presents some specific environmental challenges that need to be managed carefully.

Soil quality and fertility. Biomass crops pose a particular challenge for good soil management because the plant material is often completely harvested, leaving little organic matter or plant nutrients for recycling back into the soil. In many rural areas in the developing world where soil management depends on recycling crop wastes and manure rather than use of external inputs, biomass production could lead to dramatic declines in soil fertility and structure. To maintain soil organic matter, farmers must keep sufficient plant matter on the land, even though this practice may reduce the harvestable yields of bioenergy crop material.

In many cases, farmers can reduce the risk of nutrient depletion by allowing the most nutrient-rich parts of the plant—small branches, twigs, and leaves—to decompose on the field. Timing the harvest for the part of the growing cycle when the above-ground living biomass has relatively low nutrient content also helps.

In some bioenergy systems, the feedstock's nutrient content can be recovered from the conversion facility in the form of ash or sludge and then converted into a form that can be applied to the field rather than put in a landfill. The nutritive value of the ash or sludge may, however, be less than optimal. For example, ash will not contain nitrogen released during combustion, and certain other nutrients may not be in a bioavailable form.

Biodiversity. Bioenergy feedstock production significantly influences surrounding ecosystems, enhancing or suppressing biodiversity. To the extent that bioenergy crop production offers an environment that is more biodiverse and more similar to a natural habitat than other agricultural options, it can enhance biodiversity and fill gaps between remaining fragments of natural habitat. In Brazil, for example, environmental regulations now require 25 percent of the plantation area to be left in natural vegetation to help preserve biodiversity and provide other ecosystem services. Forestry companies have found that the natural areas support predators that help control pest populations in nearby plantation stands. Bioenergy crops can also serve as corridors between natural habitat areas for the benefit of migrating or wide-ranging wildlife.

Exotic industrial crops have proven capable of escaping the cultivated area and thriving uncontrollably at the expense of other indigenous species. For example, *Pinus patula* and *Acacia melanoxylon* in South Africa, *Pinus pinaster* in Uruguay, and eucalyptus in various regions have reproduced widely beyond plantations and become pests to the local vegetation. Similarly, monoculture must be avoided, since widespread planting of a single crop can function as an incubation medium for pests or disease, which can then spread into natural habitats. This situation has occurred in India, where a fungal disease spread from exotic pines on plantations to native pines.

Hydrological impacts. Bioenergy crops optimized for rapid growth generally consume more water than natural flora or many foodcrops. Some biomass crops like sugarcane compete directly with foodcrops for irrigation water. Others have been observed to lower the water table, reduce stream yields, and make wells less reliable; this is one reason local agricultural communities have often opposed the introduction of tree plantations. Certain practices, like harvesting residues, cultivating tree crops without undergrowth, and planting species that do not generate adequate amounts or types of litter, can reduce the ability of rainfall to infiltrate the soil and replenish groundwater supplies, exacerbating problems of water overconsumption.

CONCLUSION

Bioenergy crop systems can—if properly designed—yield significant benefits, both environmental and social. The right choice of biomass crops and production methods can lead to favorable carbon and energy balances and a net reduction in greenhouse gas emissions. But bioenergy production systems also need to be adapted to local conditions to avoid generating environmental problems. As a guiding principle, bioenergy crop systems can potentially provide benefits if implemented on land that is currently under annual row crops or is undergoing uncontrolled degradation. In either case, providing social benefits will require engaging local communities and understanding the current uses of the land, such as food production, livestock grazing, and fuelwood gathering. Bioenergy crop production can be a suitable alternative if designed in a participatory manner with those whose livelihoods will be affected. ■

For further reading, see J. Hill et al., "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (July 25, 2006): 11206–10; A. Moret, D. Rodrigues, and L. Ortiz, 2006, *Sustainability Criteria and Indicators for Bioenergy*, http://www.natbrasil.org.br/Docs/publicacoes/bioenergia_english_final.pdf; D. O'Connell, B. Keating, and M. Glover, *Sustainability Guide for Bioenergy: A Scoping Study,* RIRDC Publication No 05/190 (Barton, Australia: Rural Industries Research and Development Corporation, 2005); and the journals *Biomass and Bioenergy, Bioresource Technology,* and *Journal of Biobased Materials and Bioenergy*.

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