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Biofuels, Soil Carbon Balance and Sustainability

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The following is a brief summary of some critical issues in agricultural biofuel production. It is meant to serve as an initiator of discussion that may lead to a differentiated strategic planning on the use, expansion and management of biofuels and the associated land base.

Key words: agriculture, biofuels, carbon climate, land use, mitigation, soil

Substituting fossil fuels

Climate change has drawn attention to carbon used for energy. If fossil carbon is burned for energy, it is added to the atmospheric carbon dioxide and aggravates global warming and has other detrimental effects such as ocean acidification. If carbon from plants is burned instead, that recycles carbon recently fixed from the atmosphere, and thus can provide a "carbon-neutral" energy source for mitigation of greenhouse effects.

A number of options exist for land-based biofuel plant production. Wood burning is a principal energy source for many households in developing countries, and is also for industrial processes such as iron ore smelting using charcoal. For mobile (automotive etc.) use, liquid fuels are needed, either ethanol to substitute for gasoline, or unmodified or esterified plant oils to substitute for diesel.

Biofuel sources

Sugar cane is the main source of ethanol. Cane sugar is extracted from the vegetative parts of the plant, fermented and distilled into fuel grade alcohol. Part of the cane residues are usually burned to generate heat for the distillation. Increasingly starch, principally from maize grain, is also being used to make fuel alcohol. Starch is not directly fermentable, so must be converted to sugars first by industrial enzymatic processes. A small number of distilleries have now begun to use the more complex conversion of cellulose to fermentable sugars, but the technology has not yet been developed into a viable large-scale industrial process. Substitutes for fossil diesel are derived from oil plants such as rape seed, soy bean or oil palm, either by direct admixture to the diesel or upon transesterification of the oils.

In all cases, the aim of biofuel production is to substitute fossil carbon with biologically fixed carbon. This makes sugar cane and to a lesser degree oil palm and rape seed relatively straight-forward energy crops because carbon (sugar or oil) is their main product. Maize and soy beans have been selected and bred for nutrition and protein content. Using these crops for the carbon content of their seeds, needs careful consideration of their nitrogen and therefore fertilizer requirements. Seeds normally contain 2-3 times the amount of nitrogen and phosphorus per unit of carbon than vegetative plant tissues. Using vegetative tissue as a carbon source therefore simplifies biofuel production. If seeds are used fuel production should be coupled to the utilization of the proteins remaining after fermentation for instance for feed. Several grasses, but also fast growing trees are being considered as cellulose sources for the future. Crop residues are vegetative plant parts that come "for free" after seeds have been harvested for other purposes. As cellulosic technologies evolve, the hope for non-fossil, renewable energy production is therefore to be able to use plant materials and crop residues that are currently not used.

Fuel carbon vs. soil carbon

Farmers know that organic matter is needed to maintain soil quality. Soil scientists have quantified typical carbon losses associated with arable agriculture, as well as the carbon gains that occur when land is reverted to forest or grassland. Carbon levels in soils are determined by the balance of inputs from plants and their residues and outputs by decomposition. Reducing inputs will reduce carbon levels unless decomposition is slowed at the same time. In agriculture introducing zero till or other conservation practices will slow decomposition and aid carbon build-up in soil. Reduced soil organic matter causes problems with infiltration, erosion and nutrient availability, and a very low level of soil organic carbon will cause soil to become unproductive. Carbon therefore needs to be returned to the soil from crop production. Balancing carbon needs of soils and human energy consumption therefore is a task that needs to be introduced into planning now as the bioenergy sector grows.

In a recent review of a large number of land use conversions between conservation reserve lands and agriculture (Piñeiro et al. 2009), soil organic carbon accumulation on reserve land was on average near 0.5 Mg C ha^{-1} yr^{-1} over some 15 years, after which accumulation slowed significantly to reach its final steady level after some 80 years. The total carbon sequestered in an average soil under conservation reserve therefore amounts to over 10 Mg ha^{-1}. Carbon losses upon converting natural vegetation to agriculture are faster but of similar magnitude. These changes in carbon storage compare with approximately 1.5 Mg in ethanol-carbon obtainable from an average US maize crop of 9 Mg ha^{-1}. Piñeiro et al. (2009) analysed the whole lifecycle of ethanol production and arrived at net avoided fossil carbon emission of 1.2 Mg of carbon dioxide equivalents, i.e. a carbon saving of near 0.4 Mg ha^{-1} yr^{-1}. Carbon for carbon, during the first 15 years of biofuel production on former native or conservation reserve land, there is therefore no reduction in net carbon emission. The world average maize yield at only 2.5 Mg ha^{-1} yr^{-1} is much lower than the US average, so calculations for other regions would have to consider much lower efficiencies, but also lower fossil fuel inputs in the maize production. Taking into account the economics of maize production and carbon credits for the US, Piñeiro et al. (2009) conclude that soil C sequestration by setting aside former agricultural land was greater than the C credits generated by planting corn for ethanol on the same land for 40 years.

Piñeiro et al (2009) also indicate that producing cellulosic ethanol from grasslands provides higher rates of net carbon dioxide savings because it does not cause tillage-induced soil C losses. In addition using grasses may increase C storage in soils if grasslands are replanted on current agricultural lands (Ogle et al. 2003, Tilman et al. 2006). Even permanent plant cover, though, relies on the carbon recycling from above ground biomass litter to maintain soil carbon levels. How much could be harvested for biofuel production without reducing soil C remains to be determined, although experience from grazed pasture provides pointers for appropriate management.

The development of cellulosic technologies will permit using crop residues, but removal of crop residue from the field must be balanced against impacting the environment (soil erosion), maintaining soil organic matter levels, and preserving or enhancing productivity (Willem et al. 2004). Maize stover can provide a renewable carbon source. Because of its relatively large biomass, maize produces 1.7 times more C than other common grains, but suitable sustainable removal rates will vary depending on yield, soil type, and cultural practices (Willem et al. 2004).

The concerns about maintaining soil organic matter and soil quality under regimes of increasing carbon diversion to fuel uses are greater for many tropical soils than for the cases above because these soils have a lower ability to stabilize soil carbon and depend more on conservative management of residues.

Summary - biofuels to replace fossil carbon emissions

- Biofuels will play a mayor role in carbon mitigation.
- The soil's need for carbon adequate carbon content and inputs will have to be considered when more and more carbon is removed from the land for energy production.
- Ideally, energy crops should produce carbon with few associated nutrients to reduce fertilizer needs and subsequent contaminants problems.
- If high nutrient plant (parts) such as seeds are used for biofuel production the coupled production of feed is a vital component of the production process. This may actually diversify rural economies. Accounting of the environmental benefits will not be easy, since renewable carbon and other products result.
- Much of the needed information for guiding decisions on fossil fuel substitution by agriculture and forestry is available. It must be synthesized in a format and forum suitable for strategic planning.

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