Water Quality and Environmental Dimensions in Biofuel Production

Sasha Koo-Oshima
Food and Agriculture Organization of the United Nations
FAO Rome, Italy
Land and Water Division
Email: sasha.koo@fao.org

ABSTRACT

Human uses of freshwater resources and energy demand are increasing rapidly as the world population rises. Alternative energy using biomass feedstocks to reduce dependence on oil imports would entail conversion of million of hectares of farmland to produce profitable energy crops. There is a risk that profitable biofuel crop production will increase at the reduction of human food production which underpins the mandate of the Food and Agriculture Organization in achieving food security for all. In addition, the water needs of food and agriculture and its associated biofuel and bioenergy production have to consider the potential benefits and risks in regional scale environmental impacts and resource allocation and conservation needs. The specific environmental consequences due to land use changes not only relate to water quantity but quality from the standpoint of erosion, evapotranspiration, fertilizer and nitrate runoffs, and pesticide and agrochemical applications – which are generally not different from other farm crops. However, in recent years, alternative energy sources from short-rotation woody crops and herbaceous crops (perennial grasses) have been increasingly receiving interest in providing environmental and economic benefits to improve and utilize marginal lands, in serving as biomass crops in buffer strips to protect watersheds from agricultural runoffs, in providing habitat for local species, in sequestering carbon as well as in meeting human needs for food, fibre and fuel. Thus, affecting the very resources farmers' rely for economic productivity and profitability. This paper will present the current literature on renewable biomass energy and in understanding favourable applications of biofuel production in preventing water quality deterioration and maintenance of biodiversity and ecosystem functions.

INTRODUCTION

Sustainable agriculture implies proper management of natural resource base for agricultural production of both food and non-food outputs as well as preservation of environmental and non-environmental benefits for food safety and security, economic development and rural employment. The Food and Agriculture Organization of the United Nations (FAO) recognizes that agriculture is not only securing a sustained food supply, but that its environmental, socioeconomic and human health impacts are accounted for within national development plans and that sustainable development conserves land, water, plant and animal genetic resources (FAO 1996). Improvement in the environmental performance of agriculture has been a challenge for a broad range of environmental functions such as nutrient cyling, soil erosion control, water quality and watershed protection, landscape for biodiversity and habitat conservation. The challenge for agriculture is manifold – not only will it be required to double its output in order to meet the expected increased global demand for food, fuel and fiber but also to protect its natural resource base, particularly on land and water. Such environmental demands and performance of agriculture are influenced by a wide array of factors; i.e., policies, markets, farm-management practices, structural change, technological developments and socio-cultural preferences which are inter-related driving forces with impacts on one another. Adding to these factors, the new dimension of energy economics and policies towards development of alternative renewable energy from the agricultural sector, transport biofuels, complicates further agri-environmental production and performance.

The rising energy demand and the need to reduce national dependence for imported oil in many countries has called for a renewed interest in agricultural production of high-yielding biofuel crops and energy conversion technologies necessary to achieve this potential. Currently, the two main sources of biofuels, ethanol and biodiesel, are produced from agricultural feedstock commodities traditionally used for food, and they represent the bulk of renewable transport fuels. Ethanol can be produced from sugar cane/sugar beet by fermenting sugar to alcohol which is then distilled to remove water, or starchy feedstocks (grains like maize, cassava, and wheat) that undergo enzymatic process where starch is broken further into sugars. Biodiesel, on the other hand, is produced from transesterification of vegetable oils from feedstocks such as rapeseed, sunflower, palm oil, and soybeans.

There is concern that an increased production of biofuels due to profitability would draw away agricultural resources from other uses and pose risks for food production. Studies from the US, Canada and EU indicate that between 30% and 70% of their respective current crop area are needed in order to replace 10% of their transport fuel consumption by biofuels, assuming unchanged production technologies, feedstock shares and crop yields, and in the absence of international trade in biofuels or use of marginal or fallow land (OECD 2006). However, more environmentally sustainable option of non-food organic materials such as cellulosic materials from grasses and ligno-cellulose feedstocks (such as straw, wood as well as waste paper/materials) can be used to produce biofuels. In this case, more complex digestion called saccharification and fermentation (SSF) processes are required to convert lignocellulosic tissues to ethanol. Technological progress in these 'advanced biofuels' will improve efficiencies (i.e., higher ethanol yield per hectare of land) of biofuel production in both production costs and area requirements and would not compete with agricultural food production. Thus, the long-term implications of these 'advanced biofuels' would suggest a substantial comparative advantage over traditional biofuels from conventional food crops. At present, it is impossible to make an *a priori* assessment on the overall effects of lower land requirements per unit of advanced biofuel energy on agricultural commodity markets. This paper, however, focuses on the advanced alternatives, non-food based biofuel crops that would have greater environmental performance and to understand conditions suitable for their application towards achieving sustainable resource management with water quality benefits.

ENVIRONMENTAL OPTIMIZATION OF BIOFUEL CROPS

Environmental impacts of conventional biofuel crop production are no different from other farm crops such as the potential for nutrient enrichment of excessive fertilizer applications and sedimentation from land conversions. It is generally recognized that agriculture is a significant source of water pollution with fertilizers and livestock effluent accounting for as much as 40% of nitrogen and 30% of phosphate emissions in surface water (OECD 2004), resulting in oxygen depletion and eutrophication, and pesticide run-off impairing water and wildlife habitat systems. In addition, soil erosion through land use conversion, tilling or overgrazing has exacerbated the water quality of tributaries. Past management approaches have been often driven by narrow resource objectives and did not consider the variety of natural ecosystems nor did they capture environmental benefits. Much knowledge has been gained in the recent years in agricultural practices that provide for environmental benefits such as water quality and ecosystem conservation as well as a wider range of adaptation to drought and enhance nitrogen- and water-use efficiencies and carbon sequestration.

One potential conservation practice aimed at mitigating pollutants is the development of riparian buffer strips with permanent vegetation using perennial biomass crops, such as perennial grasses and short rotation woody crops (SRWC) located within and between agricultural fields and the water courses to which they drain. These buffers are upslope from water bodies and are intended to intercept and slow runoff and function to capture nutrients, soil particles, and pesticides; thereby, providing water quality benefits to surface and groundwater. These strips have been shown to reduce export of particulate pollutants and control concentrated flow erosion with combined benefits of water quality improvement, stream habitat restoration, and migratory bird habitat creation. While buffer performance will vary depending on location due to site and climatic factors, research has shown that buffers can have a positive impact on water quality with 50% sediment trapping and a 50% mean nitrate efficiency (Helmers et al. 2006). Buffers that interact with shallow groundwater moving through the root zone have been found to remove nitrate with varying efficiencies, between 25 and 100% (Helmers et al. 2006). However, to maximize infiltration of runoff, wider buffers or a greater buffer area to source area should be used, and regulations could be promulgated that require riparian buffer strips to be established on agricultural fields or for other reasons to control soil and stream bank erosion and to improve water quality in general. The measurable effects of stream water quality nitrogen level may still be variable due to factors, such as length of stream buffered, buffer age, width, connectivity between buffers in a reparian system, variations in agricultural nutrient sources and nutrient reduction processes such as denitrification (Willard and Schoonover 2006).

Buffer development combined with advanced biofuel crops, such as switchgrass or wood, can provide dual functions of ethanol production and environmental quality enhancement. Studies performed at Oak Ridge National Laboratory reported results of soil erosion reduction, improvement of surface and groundwater quality, better wildlife habitat, and reduction in carbon dioxide emissions from carbon soil sequestration in intensive short-rotation tree crop (SRWC) systems produced on marginal or erosion-prone agricultural land (Shepard and Tolbert 1996). The species of SRWC examined with the greatest potential for rapid growth, wide adaptability, and resistance to insects, pests, and diseases are poplar (*Populus* spp.), sycamore (*Platanus occidentalis*), willow (*Salix* spp.), sweetgum (*Liquidambar styraciflua*), and maple (*Acer* spp.) with experimental yield reported to be 2 to 5 times those currently obtained from conifer pulpwood plantations (Tolbert and Schiller 1995, Smart et al. 2005). In Europe, especially Sweden, willows are planted at dense spacings of 15,300 trees/ha, harvested after three years with diameter breast height of less than 7.62 cm and allowed to coppice. In the U.S. poplars are used and planted at wider spacings with 1680 trees/ha, harvested at 6 to 10 years of age depending on variations in climatic, soil condition, and crop management factors (Culshaw and Strokes 1995). Estimates of biomass costs produced from buffer strips have been studied by Turhollow (2000) where information is collected on the amount of land for the buffer area, fraction of buffer land to be harvested, and the yield of the harvested land. The amount of land needed for the buffer is complex and dependent on the organic load on the agricultural area such as poultry litter application volume. Various research activities are being conducted in the genetic improvement of shrub willow crops by the State University of New York for large scale commercialization purposes to produce high yields on a diversity of site conditions over longer years to reduce the cost of willow biomass production (Smart et al. 2005). Such technology is also being applied for phytoremediation in plant heavy metal uptake of contaminated soils, support for microbial community to degrade organic pollutants, uptake of excessive nutrients among many other benefits. Other perspectives include incorporation of double cropping of energy crops with traditional crops, winter cover crop residues for biofuels, as well as introduction of plantation heterogeneity design to enhance biodiversity as variations in size or shape of plantations may be a strategy for manipulating diverse animal use of plantations (Christian et al. 1993).

McLaughlin and Walsh (1998) have studied the net energy return and associated environmental benefits of bioenergy production from perennial grasses such as switchgrass (*Panicum virgatum*) relative to annual row crops such as corn. Switchgrass is a native American grass that can be harvested for 10 or more years without replanting, tolerates drought conditions, and produces cellulosic biomass suitable for conversion to liquid fuels (Bransby et al. 1990). In measuring environmental benefits of energy crops, the net energy budget of replacing fossil fuels with biofuels was calculated, not only for the biomass energy itself but also the energy required to grow the crop and its conversion to the usable energy form. The process energy required to produce equivalent amounts of ethanol adjusted for machinery energy inputs showed that the net energy gain of producing ethanol from switchgrass exceeded that for corn, and with reduced energy investments at all steps of the crop production/conversion pathways to ethanol formation. The investigators reported 55% more ethanol energy can be produced per hectare of switchgrass than with corn. Similarly, net CO_2 budget is based on the amount of fossil fuel consumed in producing fuels, fertilizer, pesticides and machinery to produce the crop. Below ground carbon storage estimates for switchgrass-to-ethanol cycle is approximately 30 times more than conventional corn-to-ethanol cycle. Switchgrass also has overall positive environmental attributes for its low nutrient use, low pesticide requirements, and has increased soil organic matter. As a perennial crop, switchgrass require less maintenance and fewer inputs than do annual row crops, cost cheaper and are more sustainable without soil loss and degradation from replanting.

In terms of legislation, the U.S. riparian buffers are established through government cost-share programmes where private landowners/farmers sign-up and are provided either tax incentives or annual payments based on the agricultural rental value of the land. Farmers have found the benefits for growing biofuel crops that considers resource optimization while minimizes negative environmental impacts via the scope of these incentive programmes. At the State level, there are various ordinances, flood plain, zoning policies, and Conservation Reserve Enhancement Programs (CREP) initiated by the U.S. Congress in 1985 toward reducing soil erosion on highly erodible cropland. These legal frameworks were adopted to protect instream water quality with a subsequent Farm Act introduced in 1990 to additionally address water quality and ecosystem functions (Turhollow 2000).

As for emerging countries with biofuel developments, the Indian government in December 2001 launched a pilot programme to test the feasibility of blending ethanol with gasoline as a way to absorb their burgeoning sugar surplus. By 2002, the government approved and mandated the sale of E5 (5% blend of ethanol with gasoline) across the country (OECD 2006). Even though riparian buffers are not established for India, the country's emergence in biodiesel research has shown to be promising. India is growing the oil-bearing crop, *Jatropha curcas*, capable to grow in infertile soil - sandy, gravelly and saline soils - and is resistant to drought, has no pests, not browsed by cattle or sheep, and yields within second year onwards for 40 years.With the country's 60 million hectares of waste land, half of which was estimated to have the potential for Jatropha production. India's Energy and Resources Institute already embarked on a project with BP to cultivate 8,000 ha of wasteland with Jatropha enabling a production of 9 million liters of biodiesel per year (Von Braun and Pachauri 2006). The environmental and social impacts studies are still to be published; however, this development may be indicative of positive impacts in the prevention of land degradation and drought.

Another potentially large emergence for biofuel production and use is in China, where fuel ethanol as a blend with gasoline (E10) has been underway since 2002 for creating a new market for surplus grain in major Chinese corn-producing areas and to reduce its rising oil import bill and air pollution.The government currently subsidises production of ethanol (OECD 2006) with the current ethanol industry numbering well over 200 production facilities in 11 provinces capable of producing more than 10 million tons of ethanol each year from feedstocks such as waste cooking oil and oil plants (Liu 2006). To date the government has not issued an incentive policy on biodiesel although it is soon expected similar to the law established for renewable energy. With food safety concerns for grain supply and attention to substitute energy, China aims to develop biofuels in a stepwise fashion emphasizing development of biofuels from non-food substrates (Liu 2006).

DISCUSSIONS ON RISKS AND BENEFITS OF BIOFUELS

However the positive environmental attributes of SRWC, switchgrass, and Jatropha as alternatives for conventional biofuel crops, long-term environmental studies are needed to examine soil improvement and stability for various soil types and previous land use characteristics and operational studies for commercial scale testing. If SRWC is not managed properly, it can lead to deforestation and loss of biodiversity, thereby degrading the land and water resources consequently. Similarly, riparian buffer systems need to be carefully managed and timed for harvest, post raining seasons, in order not to impact on soil erosion. Thus, harvesting time should be regulated, allowed on a periodic basis, and at certain areas and distances from the water body to preserve the integrity of the system. In addition, harvest window period of SWRC should also observe wildlife patterns avoiding April to August (Turhollow 2000) depending on the geographic region and wildlife reproduction seasons. In addition, the improvements to water quality are indirect at best. Even the most environmentally sensitive production of biofuels using switchgrass and short-rotation woody crops as buffer strips are limited by introduction of illegal channels or drainage of the field runoff, by-passing the remediation effects that the buffer design intends. The caveat is that buffer strips are not as effective unless the integrity of the system is maintained and its function respected via the legislations that should be instituted in place.

As with any new technology, advanced biofuels need to consider all the potential environmental impacts in addressing the net benefits or risks. The total accounting principle or the full cost internalization evaluated with investments in the biofuel industry and the agricultural sector combined to produce the most favourable outcome for environmental improvements and energy optimization. Thus, it should lead to an increase of marginal external benefits and a decline of marginal external costs, and where cash and noncash, variable and fixed costs are all included in full cost accounting.

Currently, to produce as much as 4% of domestic energy requirement projected by 2010 could require as many as 100,000 ha of SRWC (Hohenstein and Wright 1994). Although the current process costs for lingo-cellulosic biofuels exceed those of commodity-based biofuels, but it and is anticipated to mature in 5-10 years to reach commercial optimization. The impact of biofuel production on agricultural markets is expected to change significantly once alternative, non-food biofuels become competitive. The advanced ligno-cellulosic biofuels renders the cost advantage in terms of area requirements for a given quantity of ethanol would be much lower as these fuels could be produced either from waste materials or from designated fuel crops with a much higher ethanol yield per hectare of land.

Stimulating incentives to correct environmental damage and encourage innovation in pollution abatement has been promoted in agri-environmental policies of certain countries. There is yet scope to develop a consistent management strategy rooted in good science and policy. Due to the potential risks that crop production for biofuels may compete with food production, farmers can combine food production with energy production as these innovative technologies come into play and the right mix of solutions identified under respective conditions, or if energy crops are targeted to more marginal lands. Riparian zones represent important ecotones in forested landscapes. They provide such critical ecosystem functions in wildlife nesting and rearing sites, habitat for rare plants, mediation of stream temperatures, and the growth of trees. Policies that aim in encouraging farmers to feel part of the solution, rather than victims of yet another regulatory mandate could help resolve conflicts between farmers, citizens, and regulatory agencies. Development of demonstration sites and involvement of local resource users would contribute much in understanding complex ecosystem management, optimal resource utilization, and recognition of the biophysical links between many natural systems. The heterogeneity of the natural resource base, farm structures and production systems used by farmers, and the assimilative capacity of ecosystems differ from place to place. These complex systems challenge resource managers who operate in isolation. Part of the solution in the sustainability of biofuel production chains is identifying opportunities for interaction. The change in the product mix for an agricultural area may also result in an improvement of the rural landscape and water quality. The internalisation of external benefits can be expected to give an incentive to farmers to change land use patterns and provide a more diverse rural landscape with valuable elements such as trees, hedges, natural pastures and water courses. With greater consciousness for water savings, treated wastewater reuse in SWRC and other alternate biofuel crops provide an additional means in saving the fresh water for other purposes. Altogether, we can reasonably expect that the internalisation of external costs and benefits will have a positive effect on the rural environment and agricultural income.

International institutions and CGIAR centers can help foster and transfer the knowledge and technology on developing an efficient and sustainable utilization of natural resources for biofuels with joint agri-environmental dimensions. Because renewable fuels are generally still more expensive to produce than fossil-based fuels, their commercial viability often depends on policy interventions by governments, although in the future this will depend on the further development of crude oil prices. Thus far, biofuel production has been promoted by government programmes, either through the provision of market incentives or by market regulations. Intergovernmental organizations have a role in assisting governments and local farmers to assess the benefit and risks of new technological biofuel applications in line with consistent multi-objective policies leading to win-win solutions with positive outcomes for the poor.

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