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IMPACTS OF BIOFUEL PRODUCTION ON FOOD SECURITY

Introduction

"Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life".

This definition was adopted at the World Food Summit in 1996 (FAO, 1996) when references to food safety, nutritional composition and food preferences were added (Pinstrup-Andersen 2009). Yet, in 2009, one billion people are still food-insecure (FAO, 2009), global grain reserves are low and have been declining. Trostle (2008), quoting data from the USDA Production, Supply and Distribution Database, stated that global consumption of grains and oilseeds has exceeded production in seven out of the first eight years of the 21st century and the global stocks-to-use ratio has reduced from 30% to less than 15%, the lowest since 1970. An assessment by von Braun (2007), using data from the FAO (FAO, 2003; FAO, 2005; FAO, 2006; FAO, 2007) also demonstrated that grain stocks had reduced from more than 600 million to approximately 400 million tonnes between 2000 and 2006. However, the majority of this change could be attributed to a stock reduction by China. Fuglie (2008) stated that this was a deliberate policy by China as they had accumulated too much grain in the 1990s. Still, more than 40% of the global stock is still held by China, the stock per capita being, on average, twice that of the average of rest of the world.

Increased demand

By 2030, the global population is projected to increase by 17% with the majority of growth occurring in the poorer tropical regions, where food insecurity is most pronounced. Also, as incomes rise, food preferences change with increasing consumption of dairy and meat products which use grain inputs in their production. Thus, world food production must increase by 50% to satisfy these demands. Similar increases in demand are projected for energy and water.

In the 20th century, the green revolution in Asia demonstrated that dramatic yield increases are possible in poorer tropical regions, achieved by combining fertilizer inputs, better agronomy, improved pest management, soil/water management and crop varieties (Huang et al, 2002). Yet, in the 21st century, we need to achieve climate change mitigation targets of reduced greenhouse gas emissions and increased carbon storage in agricultural and degraded soils and through reforestation. This must be achieved under energy and water-constraints, with declining soil fertility and increased input costs. As energy costs rise, manufactured inputs, whether fertilizer or pesticides, that require significant energy input in their production process, will become comparatively more expensive.

Reduced supply and increased wastage

There has been a long-term decrease in freshwater supply, due partially to eutrophication caused by inappropriate nitrogen and phosphorus fertilizer use, in parts of the developed world. In the developing world, rural migration to cities with low capability to cater for such influxes, with few or no sewerage systems, leads to pollution and to significant wastage of fertilizer opportunities. Such rural to urban migrations are projected to continue and accelerate. For example, in Nigeria, the most populous country in sub-Saharan Africa, food is grown in and then transported from the Jos plateau in central Nigeria to urban, southern areas, such as Lagos, a city with limited sewerage and waste disposal systems unable to support its urban population of more than 10 million. This creates a nutrient surplus in the urban area, leaching into the adjacent lagoon and sea, coupled to the nutrient depletion in rural areas. Unless a reverse migration to rural areas is encouraged, such regional imbalances need to be addressed and sewerage systems improved while taking care to manage contamination by agro-chemicals and pathogens. At the same time, global reserves of phosphorus may be depleted in 50–100 years with a projected production peak in 2030 (Cordell et al., 2009). Similarly, Vaccari (2009) states that there are an estimated 15,000 million tonnes of deposits which are economically recoverable with current technology. While this is sufficient to last about 90 years at current use rates, demand is projected to increase, so supplies will be depleted sooner, unless technological advance is made. To improve efficiency, phosphorus contained in urban and human waste should be recycled for agricultural use rather than contributing to water pollution.

Energy demand and biofuels

Globally, there is ever increasing demand for energy, due to population growth, and higher consumption per capita. For example, in China, the number of private vehicles increased nearly ten-fold between 1995 and 2006. Yet, currently, on average, there are only 1.8 private vehicles per 100 persons so the expected future demand is enormous (Yang, 2009). Such projected increases in China and globally, as well as national and international concerns about greenhouse gas emissions, energy security and diversification to renewable sources have stimulated research on future fossil fuel substitutes. One such option is the use of biofuels, particularly those that can be used in combustion engines.

Definition of biofuels

Biofuels are solids, liquids, or gases, derived from recently dead biological material, that can be combusted to produce heat or power. Biofuels such as fuelwood and animal dung have been used for cooking and heating throughout human history and are still widely used in tropical countries. In sub-Saharan Africa, more than 90% of energy needs are met through fuelwood, charcoal, dung and agricultural residues (Bailis et al., 2005) and women/children walk increasingly farther per day to collect them. Pollutants from these fuels are estimated to cause 1.6 million deaths per annum globally (Ezzati et al., 2002).

The internationalisation and scale of the biofuel market is new, driven by their use in internal combustion engines. These '*new*' biofuels include biodiesels from soy, palm, rape, and waste oils; bioethanol from starch and sugar crops such as sugarcane, maize and sorghum; sources of lignin-cellulose such as switch grass, crop residues, tree prunings; and, algal fuels.

In general, conversions of oil crops to biodiesels are easier than to bioethanol. Starch and sugars have to be fermented to alcohols. Lignin-cellulosic materials undergo a further process as they need to be first processed to sugars, either by heating with acid or converted using cellulase enzymes extracted from fungi. Algal biofuels are still at the development stage, however, have huge promise, as they can be grown on an industrial scale, using waste carbon dioxide. This review will focus on the production of crops suitable for bioethanol and biodiesel production as these are major growth areas and interact with food production.

Effects of biofuels on food security

There is concern that the expansion of biofuel crop production will threaten the food security of poor sectors of communities across the world by affecting food supply and price. In the USA, ethanol requirements are met predominantly by the fermentation of maize starch to bioethanol (Farrell et al., 2006). Mitchell (2008) reported that more than 70% of food price increases were due to biofuels. According to Tollens (2009) 33% of the increase in U.S. maize price from 2007-2008 was related to US bioethanol production. Yang et al. (2009) reported that in China, 3.5–4% of total maize production is used for bioethanol.

Impacts on food security will depend upon the biofuel crop grown and the context in which it is grown. Three contexts for biofuel production are: the use of existing arable land, expansion of the agricultural frontier, and the use of marginal land not otherwise suitable for crop production. These will be explored in more detail and effects on food security discussed.

Biofuel cultivation on existing arable land: competitive or complementary?

International demand for biofuels has led to concern that smallholder agriculture in tropical countries will be threatened as the use of existing arable land could create competition with food production for land, water, inputs and labour. An alternative scenario is that smallholder farmers could grow biofuel crops alongside food crops and within their current land use systems, increasing cash flow and thus permitting them to purchase badly needed inputs to intensify food production.

A detailed study of factor use and land use trajectories would be necessary to establish the significance of direct competition between biofuel and food crop production. What would appear likely is that farmers switch from a food cash crop to a biofuel cash crop, while maintaining subsistence food production. While this would not affect the food security of smallholder producers, it would increase the price of food.

Energy prices affect agricultural output prices strongly via opportunity costs due to direct competition for end-use. For example, Brazil has been producing bioethanol from sugarcane since the 1970s and the price of sugar in Brazil is correlated to that of ethanol (von Braun, 2007, quoting data from CEPEA, 2007). High energy-price fluctuations are thus increasingly translated into high food price fluctuations. From 2001-2006, price variations in oilseeds, wheat and maize have increased to about twice the levels of previous decades. The coefficient of variation of oilseed price in the past five years was 0.20, compared to typical coefficients in the range of 0.08–0.12 in the past two decades. In the past decade, the coefficient of variation of maize increased from 0.09 to 0.22 (von Braun, 2007). Even for non-food biofuels, prices can positively correlate to fossil fuel energy prices through the use of common inputs (irrigation, fertilizer, pesticides, transport, mechanization) which results in higher input costs and less predictable farm-gate prices.

The alternative scenario is that biofuel production could make complementary use of land, water and labour resources, increasing overall efficiency. In this context, biofuels would be seen as a complement, and not a competitor, of food production (Ziska et al., 2009).

For example, smallholder farmers could grow biofuel crops alongside food crops. This could:

- increase cash flow, thus permitting input purchase, agricultural intensification and higher yields;
- create an affordable source of energy to semi-mechanize crop systems, reducing labour requirements in systems where labour is a limiting factor;
- allow the development of fuel-food systems that increase resource use efficiency through spatial or temporal integration by intercropping biofuel crops with food crops or integrating perennial biofuels into long fallow shifting cultivation systems (but data are lacking).

Intercropping systems can exploit a greater amount of limited growth factors when grown together than when apart, particularly if components have different architectures and / or resource demand peaks at different times in the growing season (Midmore, 1993). Furthermore, if farmers intercrop a biofuel with a crop where they commonly apply fertilizers, or use land fertilized during the last cycle, the biofuel may inadvertently benefit through a residual fertilizer effect.

Expansion of the agricultural frontier

Expansion of the agricultural frontier involves conversion of land currently under other uses (forestry, savannah or forested land) to biofuel production. Fischer et al 2004 provide an assessment based on data from 1994-1996 of total land area in all continents except Antarctica, the area of land in cultivation, the area of cultivable land not yet under cultivation, excluding that under forest. Data are presented in Figure 1. Here, cultivable is defined as a classification of moderately suitable, under rainfed conditions, for the cultivation of at least one of 24 crop species, two pasture types, or two fodder crops (Fischer et al, 2004).

According to Fischer et al.'s assessment, the most potential for arable land expansion is in Africa and South/Central America. Yet, these figures may not take account of land in fallow that is part of crop-fallow cycle nor of lands used by pastoralists, so these figures could be substantial overestimates.

While expansion of the agricultural frontier would not cause any increase in food prices, if large scale land conversions are initiated on forested lands, there are associated losses of biodiversity and increases in carbon dioxide emissions. In many cases, conversion will result in significant above- and belowground carbon losses (Figure 2), creating carbon payback times of decades or even centuries (Fargione et al., 2008). However, this is mainly dependent on the carbon stocks of the previous land use rather than the biofuel crop *per-se*. While it is often highlighted that oil palm cultivation creates a large carbon debt, when forest is cut for its establishment, equally this could occur on short fallow land or humid savannahs that occur within the same ecoregion (Meikle et al. 1996).

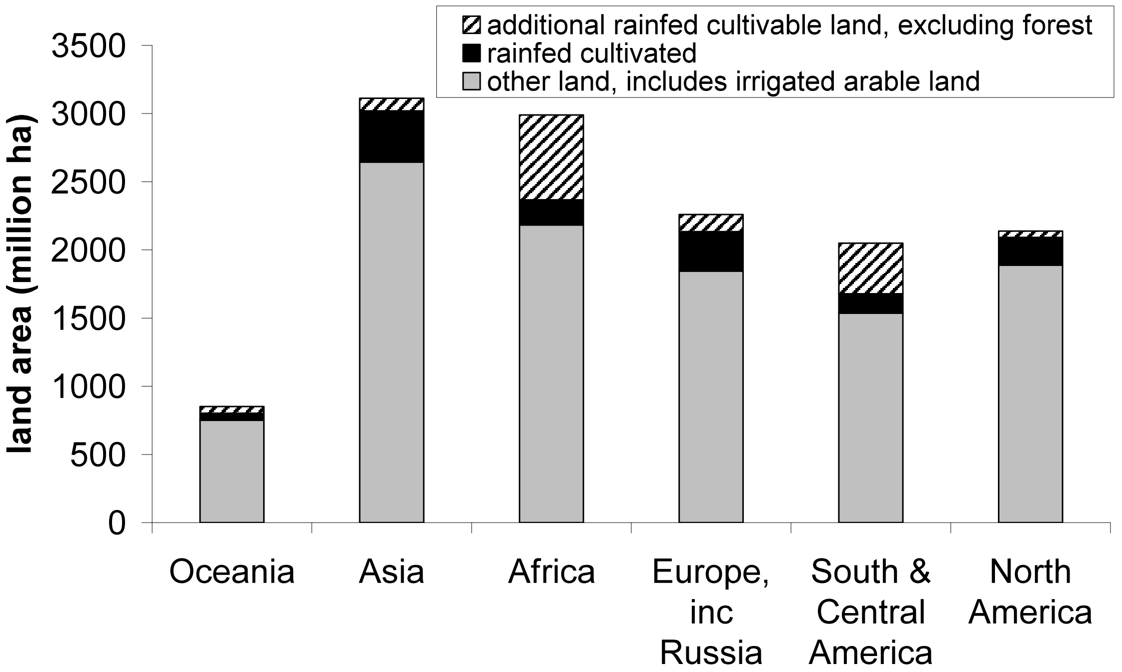

Figure 1 Land area currently under rainfed cultivation, additional cultivable land under rainfed conditions of at least medium potential, excluding forest and not yet cultivated and all other land, including irrigated agriculture and forests (after Fischer et al 2004, using data from 1994-1996)

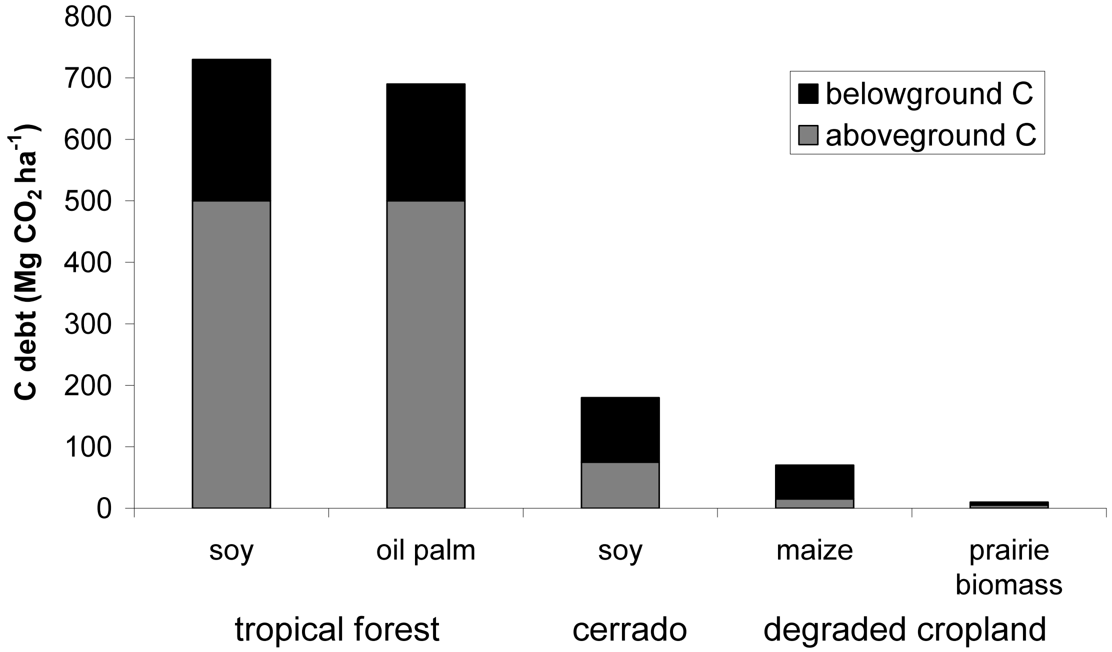

Figure 2 Above and belowground carbon (C) debts created in land use conversion to selected biofuel crops (adapted after Fargione et al., 2008)

Brink and Eva (2009) demonstrated that in sub-Saharan Africa, approximately 5000 ha were brought under cultivation annually between 1975 and 2000, the sources of land being approximately half from forest and half from non-forest natural vegetation. In addition, they calculated an annual average increase of 263 ha in the area of barren land. Converting degraded land or abandoned cropland or pasture has minimal carbon losses and least impact on food security so should be focussed on, yet only certain crops are capable of growing in these conditions.

Von Braun & Meinzen-Dick (2009) have recently collated data on trans-border agricultural frontier expansion (Table 1). The majority of these examples were state to state transactions, predominantly developed countries buying large tracts of land in poorer parts of Africa and S E Asia, often where citizens have weak land tenure rights. While much of this expansion may be for food crop production, it highlights a worrying trend with a high potential for creating landless farmers.

Production of biofuels in one part of the world might cause indirect land use change (ILUC) elsewhere. Searchinger et al. (2008) projected that hectarage under maize for bioethanol in the USA would exceed 12 million hectares by 2016 by converting areas previously under soy and wheat. They hypothesised that this would lead to more than 10 million hectares being brought into production elsewhere in the world, particularly Brazil for soy and China for wheat and maize and that, if current patterns continue, much of the increase would come from forest conversion. However, this analysis assumes no changes in yield over time as well as making many other assumptions. In US legislation, the Environmental Protection Agency thus had to consider ILUC when calculating greenhouse gas emissions (Mathews and Tan, 2009). Critics of the Searchinger et al. paper state that there are too many variables involved so there is no reliable way to predict how biofuel production will affect land use in the rest of the USA or internationally. In May 2009, the Renewable Fuel Standard Improvement Act Bill (H.R.2409) introduced in the USA eliminated the requirement to consider such changes.

Table 1 International land purchases documented during late 2008 and early 2009. After von Braun & Meinzen-Dick, 2009

Country investor	Country target	Plot size (hectares)	Current status	Source
Bahrain	Philippines	10,000	Deal signed	Bahrain News Agency, Feb 09
China (with private entities)	Philippines	1,240,000	Deal blocke d	The Inquirer, Jan 09
Jordan	Sudan	25,000	Deal signed	Jordan Times, Nov 08
Libya	Ukraine	250,000	Deal signed	The Guardian, Nov 08
Qatar	Kenya	40,000	Deal signed	Daily Nation, Jan 09
Saudi Arabia	Tanzania	500,000	Requested	Reuters Africa, Apr 09
South Korea (with private entities)	Sudan	690,000	Deal signed	Korea Times, 09
United Arab Emirates (with private entities)	Pakistan	324,000	Implementing	The Economist, May 08

Cultivating biofuel crops on degraded or arid land

Certain biofuel crops can grow on degraded land, exhibit drought-resistance and might also have the potential to improve soil properties. Two frequently quoted examples are *Jatropha curcas* and *Pongamia pinnata.* Both species produce oil-rich seeds, which can be pressed or cold-pressed to biodiesel (Jain and Sharma 2010). However there are few data on yields, nutrient and water requirements or effects on soil.

*Jatropha curcas (*Euphorbiaceae) is native to central America but now with a pantropical distribution. *Jatropha curcas* seeds yield between 20-30% inedible yet high quality oil, depending on the extraction technique (Achten et al., 2007). A study on production in India found that a blend of 20% jatropha oil to 80% diesel would reduce greenhouse gas emissions by 12%, displace 17% of crude oil and increase the net energy ratio by 13% (Whitaker and Heath, 2009) . A greenhouse study by Maes et al. (2009a) found that jatropha has a conservative transpiration rate, high growth rate, good transpiration efficiency and water productivity, characteristics that suggest drought tolerance and the ability to establishment on degraded sites.

Achten et al. (2010) list further potential advantages for jatropha cultivation in a smallholder context. It permits farmers to diversify cropping systems, it can be used as a live fence or hedge to exclude herbivore grazers (Zahawi, 2005) or reduce soil erosion. Finally, as oil can be extracted locally using low technology techniques, the seed cake can easily be used by local farmers as a soil amendment.

Pongamia pinnata, a Fabaceae, native to India, can fix nitrogen and therefore could potentially increase total nitrogen in the soil. Trials are being undertaken at ICRISAT in central India to assess growth and yield, nitrogen balances and water relations. However, data are still scarce and while such species may survive drought and poor edaphic conditions, crop profitability is questionable, and such systems could still compete for labour with food systems. Clearly, more research is needed to assess the sustainability, viability and profitability of these systems.

Other crops cited by authors as suitable for growing on degraded land and require few external inputs include cassava and sweet potato (Ziska et al. 2009). This study focused on the US. Both crops are also used in sub-

Saharan Africa as staples. Sweet potatoes are often grown as the last crop in a rotation before land abandonment, as they can grow in low-fertility soil.

Other options: use of biomass

Plant materials rich in lignin and cellulose can also be used for bioenergy, either after conversion to fermentable sugars by treating with lignocellulase enzymes (Sun & Cheng, 2002) or by burning it. Material sources include inedible crop residues, waste crops, or high biomass producers that have a low nutrient demand yet high growth rates such as perennial grasses (*Miscanthus* spp.) or wood producers. The use of crop production by-products or of species that can be grown on degraded land with few inputs minimises competition with food crop production. However, for such a process to be efficient, high-performance, low-cost cellulase enzymes and/or cellulolytic organisms need to be found and the process of the separation of lignin from cellulose industrialised and made cost-effective. This will require screening fungal collections for species that contain suitable enzymes and can be cultured easily. Currently the enzyme technology used means that the energy input to output ratios are unfavourable. Lal (2005) estimated from FAO data (FAO, 2001) that global production of crop residue is 3.76 x 10^9 Mg p.a., the majority coming from cereals, of which the major sources are wheat, rice and maize.

Furthermore, crop residue has competing uses so there remains indirect competition with food production. Traditionally crop residues may be grazed, burned or decomposed in-situ. All these processes return some proportion of the nutrients to the soil, through conversion to animal dung, exchangeable cations and phosphorus in ash (although loss of nitrogen in the burning) or leaching from decomposing mulch minus any proportion locked up in microbial biomass. In contrast removal will export nutrients from the system and, compared with mulching, could exacerbate soil organic matter losses and soil erosion rates (Lal 2009). Currently, particularly in tropical systems, nutrient conservation is improved when residues are mulched or incorporated rather than burned (see, for example, Hemwong et al., 2009 for sugarcane). Sustainable offtake rates need to be calculated. Kim and Dale (2004) calculated that, globally, 7.4 x 10^7 Mg of wasted grain is produced annually, predominantly rice, maize and wheat. This could be more easily converted into ethanol than lignin-cellulose so energy input to output ratios would be more acceptable.

Evaluation methods

Life Cycle Assessment

Life-cycle assessment (LCA) is a tool to analyse the impact that a product has on the environment throughout its life span, through extraction of raw materials, conversion, manufacture, packaging, transport and use, to disposal of the product at the end of its useful life and management of the waste (Berg, 1997).

Using this approach, environmental impact, land and water footprints and energy balances can be calculated over the entire crop cycle, including inputs used and the energy costs of product transport, including information on the distances between production sites and processing units.

In addition, it is appropriate to consider carbon cycle impacts including initial carbon debt of conversion, estimates of green house gas emissions from soil carbon sequestration rates and stocks, Yet, this is more dependent on the previous land use, rather than the crop *per-se* (Figure 1).

However, when conducting life cycle assessments, it is important to define the reference system, as well as comparing different crops. For example, in poorer tropical countries, a comparison between energy production through jatropha cultivation versus through fuelwood gathering and/ or dung burning would be appropriate and this analysis might also take into account differential health risks for the different energy source scenarios. In developed countries, a comparison with fossil fuels would be more appropriate.

Energy balance

Figure 3 details energy output to input ratios of some common biodiesel and bioethanol crops and also includes the use of waste vegetable oils. Clearly, palm oil, jatropha, and sugarcane have the most favourable ratios, whereas maize production and transformation costs nearly as much energy as that contained in the bioethanol produced. However, these data are strongly dependent on the intensity of the production system used (for example, Achten et al 2008 for Jatropha). Maize grown under low input conditions with no fertilizer, manual harvesting, and local transformation will have a much higher ratio than maize grown using high levels of inorganic nitrogen fertilizer produced under the energy-intensive Haber process, with mechanised planting, tillage and harvest.

Yet, these data still compare favourably with balances of many food crops. For example, Blanke and Burdick (2005) calculated the energy balance, in Megajoules per kg of fruit for local apple production in Germany. Taking into account cultivation (2.8 MJ kg^{-1}), transfer to packer and cooling (0.16 MJ kg^{-1}), packaging (0.65 MJ kg^{-1}), storage (0.81 MJ kg^{-1}), transport (0.33 MJ kg^{-1}) and consumer shopping (1.2 MJ kg^{-1}). In total, energy input requirements were 5.95 MJ to provide 1kg of apples containing approximately 1.97 MJ of energy. For potatoes, the energy cost of production is 4.5 MJ kg^{-1}, including the above processes and adding cooking (Williams et al. 2006) and 1 kg supplies just 3.14 MJ kg^{-1}

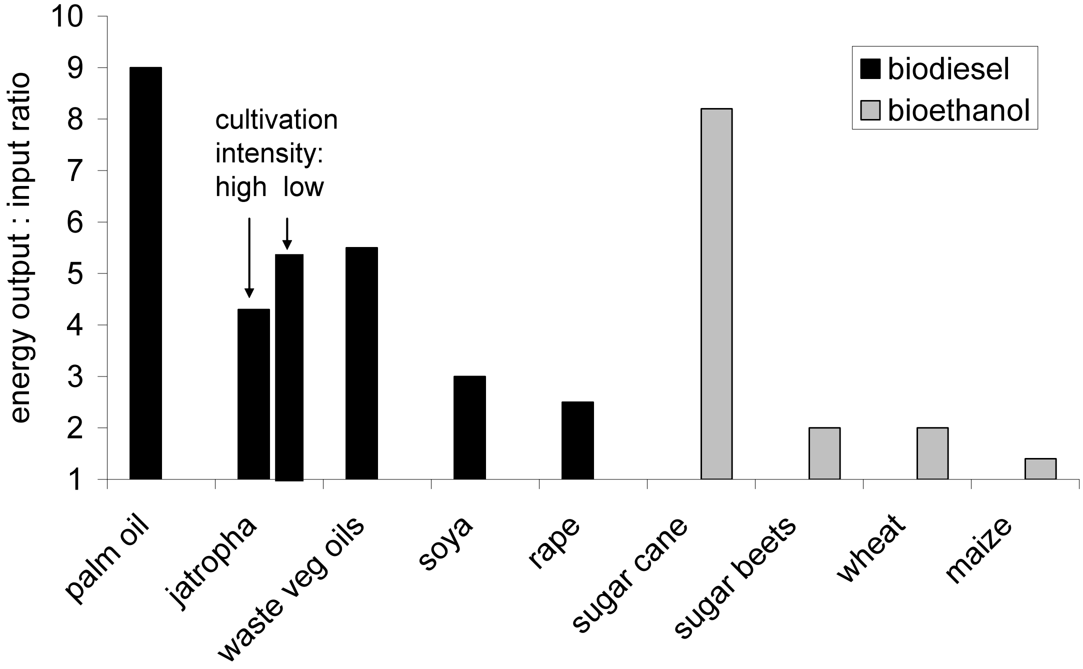

Figure 3 Energy output to input ratios of selected biofuel crops. Data for jatropha after Tobin & Fulford (2005) and Prueksakorn & Gheewala (2006), quoted in Achten et al (2008). Other data from Worldwatch Institute (2007). Data depend on distance between production and consumption and also on cultivation method (see jatropha example).

Water footprint

At present, the production of biomass for food and fibre in agricultural systems requires 86% of worldwide freshwater (Hoekstra and Chapagain, 2007). Water footprints as a function of crop biomass yield for a range of staple crops, including those used for biofuels, and also stimulant crops are given in Figure 4. Here, sugarcane, with a low water demand, has the lowest footprint. Coffee and tea have extremely high footprints, attributed to the washing process.

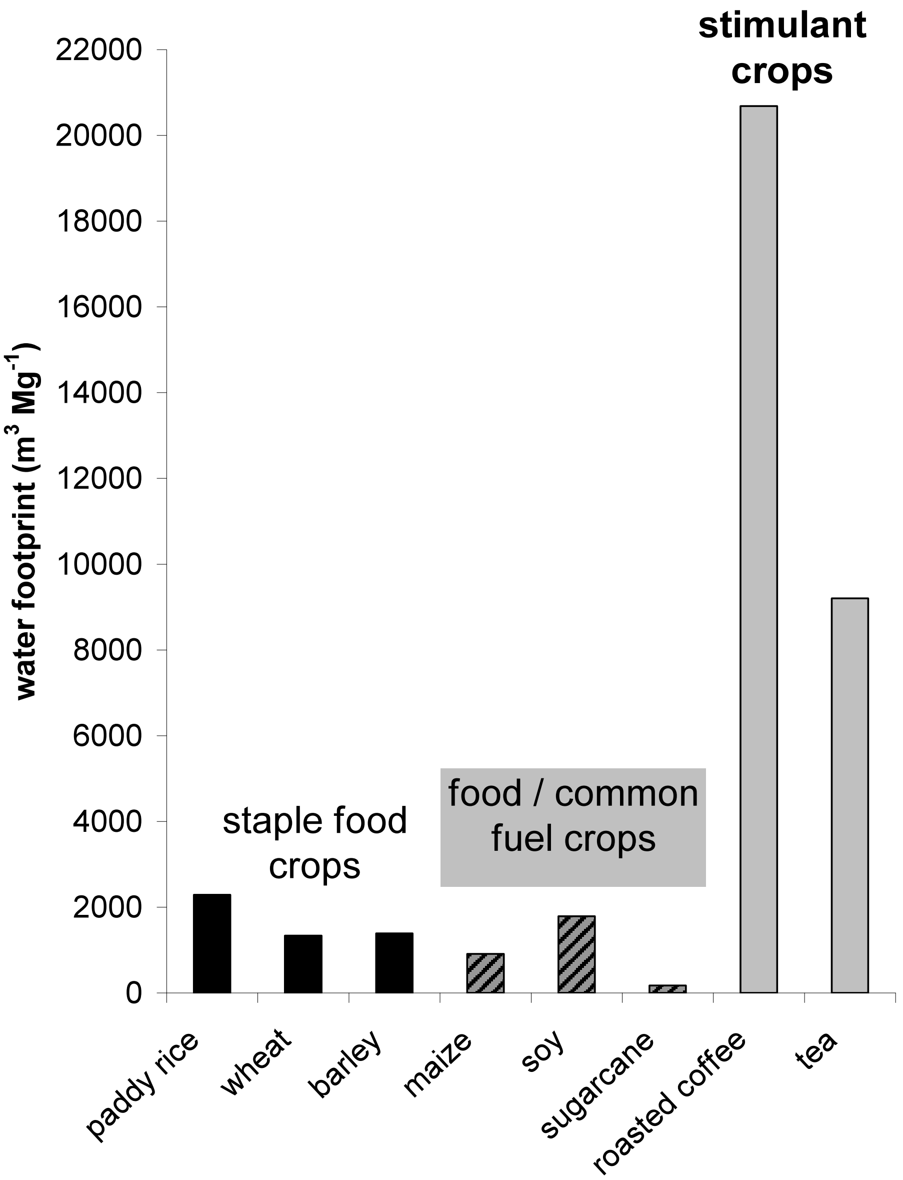

Figure 4 Water footprints (m^3 Mg^{-1}) of some selected common staple foods, biofuel crops and stimulants (data from Hoekstra and Chapagain, 2007)

For the assessment of the comparative water footprint of different biofuels, calculated as the volume of water to produce one litre of biodiesel or bioethanol, calculations were made by Gerbens-Leenes et al. (2009) by adding up daily crop evapotranspiration (mm/day) using the model CROPWAT 4.3 (FAO, 2007) and combining with FAO yield data (Postel, 2000). However, other authors have disputed this approach and have stated that the water footprint should be calculated by relating energy yield to actual water under real climatic conditions during the growing season (Jongschaap et al., 2009), that the methodology is flawed and data inadequate (Maes et al., 2009b) and that some of the crops, particularly *Jatropha curcas*, are vastly overestimated (Figure 5).

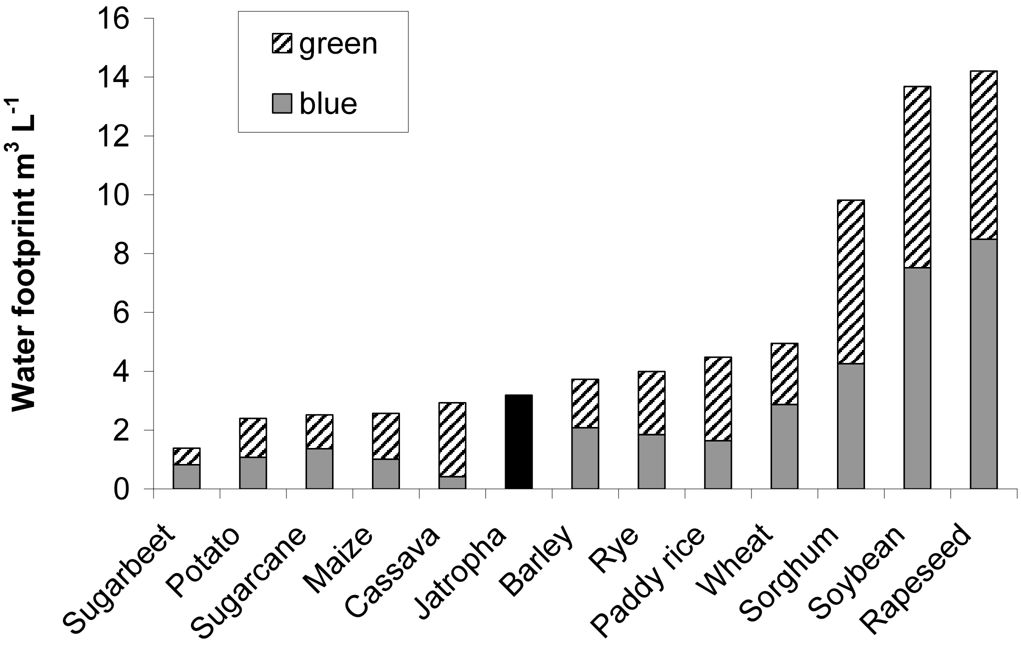

Figure 5 Water footprints (m^3 water L^{-1} biofuel) of common bioethanol and biodiesel crops divided into green water (rainwater that evaporated during production) and blue water (surface and groundwater for irrigation evaporated during crop growth). Data after Gerbens-Leenes et al., (2009) from a crop model. Data for jatropha from a field experiment (Kheira and Attab, 2009, calculated in Maes et al., 2009b), not divided into green and blue water.

Again, sugarbeet, sugarcane and potato bioethanol have low water footprints. The biodiesel crops soy and rape have very high footprints but that of jatropha is medium.

Trade offs between water, land, energy and carbon balances

The studies quoted have considered land, energy and carbon footprints of various biofuel crops. However, in general they have not considered all factors simultaneously or considered trade-offs and dependencies between factors.

For example, the Indian government has set targets that biofuels account for 20% of its transportation fuel consumption by 2017, from the present 5%.To obtain this from jatropha, Lapola et al., (2009) concluded that under rainfed conditions, 410,000 km^2 would need to be planted on low fertility land whereas only 95,000 km^2 would be needed of high fertility land. Irrigation could reduce these figures by 63%.

A study by Yang (2009) considered simultaneously the water and land footprints of biofuel crops grown in China (Figure 6). The bioethanol crops had lower footprints than the biodiesel crops, agreeing with the analysis of Gerbens-Leenes et al. (2009). While the overall land / water footprints of cassava and sweet potato were similar, the ratio between land and water demand changed with the higher yielding cassava requiring more water yet less land than sweet potato.

Clearly there are trade offs between energy balance and water and land demands of different crops.

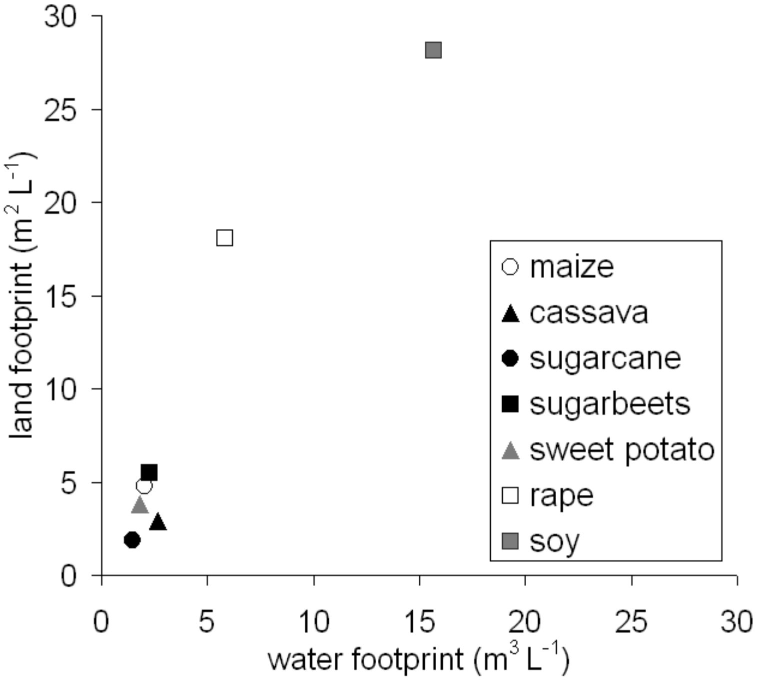

Figure 6 Water and land footprints of biofuel crops in China (after Yang, 2009). Calculations depend on the biofuel conversion ratio to bioethanol and biodiesel crops, crop yield, and specific water demand (NB does not consider energy cost of processing).

Who benefits?

" *Cash crops, that occupy nearly half of the cultivated area in developing countries, contribute substantially to higher incomes for farmers who grow them*" (von Braun and Kennedy, 1986).

The national effects of biofuels on food security in developing countries will be similar to that of any export commodity crop (pineapples, bananas, cocoa): as they will compete for labour, land, and inputs in a similar way. Furthermore any increase in food prices would benefit net producers at the expense of consumers.

While food price increases are generally viewed as negative, many smallholder net producers have had declining farm profits due to decreased commodity prices and rising input costs. This has contributed to urban migration as people seek other opportunities. For those farmers remaining, biofuels, with their wide demand, could be a cash crop opportunity. The net effect of biofuels in a country will, therefore, depend on the ratio of net (predominantly rural) producers to net (urban) consumers. For poor net food-importing countries, where the numbers of poor consumers exceeds the numbers of rural producers, biofuel expansion will reduce overall food security (Tollens, 2009).

Furthermore, the impact on producers will depend on the land tenure system and business model in place. For example, Arndt et al. (2009) compared plantation sugarcane and outgrower jatropha production in Mozambique, a land-abundant country, with one sixth of its estimated 30 million hectares of arable land currently under cultivation. They concluded that both biofuel investment systems reduced poverty yet the jatropha outgrower approach was more pro-poor.

All governments with biofuel programmes have provided support or production incentives. Reasons cited for this include that expected environmental and social benefits are externalities not valued in the market so need support. Also, domestic biofuel production enhances energy security, making a country less reliant on petroleum imports (USAID, 2008). Methods by which this can be achieved include producer subsidies, import tariffs, and government support. For example, maize and soybeans in the United States and sugar beets and rapeseed oil in the European Union are supported. In the USA, there is a tax credit available to blenders of ethanol of $0.51 per gallon (1 gallon = 3.79 L) and an import tariff of $0.54 per gallon, as well as a biodiesel tax credit of $1.00 per gallon. In other countries, export taxes are levied on food crops exported, making biofuel exports relatively more lucrative. Only Brazil has withdrawn subsidies, after thirty years of investment. In the USA, the subsidisation of maize-based ethanol costs US$10 billion per year (USAID, 2008) and this intervention is considered to have elevated domestic and international maize prices given that the USA is a major exporter of maize.

Globally, agricultural and energy markets are distorted because of various taxes, tariffs, and subsidies. Policies on biofuels need to be reconsidered within the context of all energy and agricultural subsidies as well as international aid policies so that they are complementary and not contradictory.

Conclusions

Biofuels do offer an opportunity of localizing fuel production from renewable energy sources with the potential of improving fuel security and independence at regional, national, and remote, rural community levels.

The profitability, energy balance, social and ecological impacts of biofuels and their effects on food security will depend on the crop used, how it is grown, with which inputs, on what type of land, what, if any, are the alternative uses of that land, and who reaps the benefit. Water, energy and land footprints are interdependent, depending on crop yield response to edaphic and abiotic conditions, as well as distance to markets. So whether biofuel production is a threat or an opportunity is context specific. The challenge for governments is to manage market forces to obtain an equitable and sustainable compromise for both poor urban consumers and rural producers.

Of the three contexts presented, for maintaining food security, reducing potential competition with food crops and avoiding higher greenhouse gas emissions, currently the least risky scenario for biofuel production is to focus on the use of degraded or arid lands and crops that can grow under these conditions or the conversion of inedible cellulosic parts of food crops. For jatropha, local opportunities of production are optimal in areas where Jatropha suitability on marginal land and poverty (associated with low fossil fuel usage) co-occur, such as in Tanzania, Ethiopia, and Madagascar (Muys et al., 2008). However, few data are currently available so more research is required to assess viability. In the future, once technology has advanced, the fermentation of biomass to bioethanol may become the most efficient process and has low competition with food production.

However, many small holders in poor countries have weak land tenure so legislation should be developed to protect individual and communal land rights to avoid ‘land grabs’, either from investors from within or outside the country. Legislation should also ensure that prime agricultural land is retained for food crop production purposes.

Generally, future energy limitations require a drastic rethinking of all our production systems, giving new consideration to the use of fossil fuel inputs and the need for achieving positive energy balances in production systems, staple food crop production as well as biofuel production. Energy constraints will not only affect farmers in poorer countries. Many modern mechanised agricultural systems are fossil-fuel based and have energy output to fuel input ratios of less than one. Ironically, energy constraints may deliver a comparative advantage to smallholder farmers in poorer countries, who are less reliant on mechanisation and fossil-fuelled inputs. Nitrogen fertilizers require significant energy input in their production process so will become comparatively expensive, providing an opportunity for techniques such as nitrogen-fixing cover crops to become economically viable. Positive soil carbon, nutrient and water balances will need to be created and soil structure and water holding capacity improved. Technological fixes include the expansion of precision agriculture to developing countries, optimising fertilizer applications and reducing variation in soil nutrient heterogeneity. Similarly, remote sensing of plant physiological responses can be used to optimise irrigation. The use of zeolites and slow release fertilizers will synchronise nutrient supply with crop demand.

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The International Union of Food Science and Technology (IUFoST) is the global scientific organisation representing over 200,000 food scientists and technologists from more than 65 countries. It is a federation of national food science organisations linking the world's food scientists and technologists. IUFoST has four regional groupings: ALACCTA representing Central and South America, EFFoST representing Europe, WAAFoST representing Western Africa and FIFSTA representing the countries in the ASEAN region. IUFoST Contact: J. Meech, Secretary-General, IUFoST, P O Box 61021, No. 19, 511 Maple Grove Drive, Oakville, Ontario, Canada, L6J 6X0, Telephone: + 1 905 815 1926, Fax: + 1 905 815 1574, e-mail: jmeech@iufost.org