Water Policy 10 Supplement 1 (2008) 83–94

Some insights in the effect of growing bio-energy demand on global food security and natural resources

Alexander Müller[a], Josef Schmidhuber[b], Jippe Hoogeveen[c] and Pasquale Steduto[c]

[a]*Corresponding author. Natural Resources Management and Environment Department, Food and Agriculture Organization of the United Nations, Viale delle terme di Caracalla, 00153 Rome, Italy. Fax: + 39 06 57053064 E-mail:alexander.mueller@fao.org*

[b]*Global Perspectives Studies Unit, Food and Agriculture Organization of the United Nations, Viale delle terme di Caracalla, 00153 Rome, Italy*

[c]*Water Resources Management and Development Unit, Food and Agriculture Organization of the United Nations Viale delle terme di Caracalla, 00153 Rome, Italy*

Received 16 August 2007; accepted in revised form 23 August 2007

Abstract

Growing crops for biofuels is often criticized because of its direct competition for land for food production. The recent price increases on world food markets are partly a result of this competition. For instance, cereals prices have increased by more than 60% since 2005 and in 2006 sugar prices peaked at a level twice as high as the level of previous years. There are concerns whether these increases will continue and if the world will run out of resources for food production. According to the authors, these concerns are largely unwarranted. For one, higher prices for food also mean that feedstocks are becoming increasingly expensive for bio-energy production and this endogenously limits the amount of feedstocks that will be used in the energy market. In addition, there is no imminent *global* resource shortage, neither for land nor for water that would support these concerns. Even with an expanding world population there is globally still enough land and water to grow a substantial amount of biomass for both food and bio-energy production. However, there is an uneven distribution of natural resources, resulting in huge *regional* differences with important areas experiencing major land and water shortages. China and India, for example, account together for more than 35% of the total global population and both have exploited most of the land and water resources available for agriculture. On the other hand, sub-Saharan Africa and South America still have the potential, in terms of suitable land and exploitable water, to expand areas for agricultural production.

The growing demand for bio-energy will have a negative and positive effect on food. Higher food prices can increase food insecurity among the urban poor and the rural landless population. On the other hand higher prices and more marketable production can stimulate the agricultural sector and create new opportunities for rural communities. At the national level it can offer development opportunities for countries with significant resources.

doi: 10.2166/wp.2008.053

Keywords: Bio-energy; Biofuel; Food security; Natural resources; Land; Water

1. Introduction

FAO has a long history of global and regional perspective studies for agriculture (FAO, 1970; FAO, 1981; Alexandratos, 1988; Alexandratos, 1995; Bruinsma, 2003; FAO, 2006a). These FAO studies describe mainly prospective developments in food demand and consumption, implications for nutrition and undernourishment, changes in agricultural production and trade and developments in the use of natural resources for agriculture. In the studies the price that energy had for agriculture was mainly taken into account through classical macro economic effects affecting all aspects of production, consumption and trade. For agricultural markets, higher energy prices resulted in a consolidation of production as the costs for energy intensive inputs such as fertilizer, pesticides and fuels increased. This situation has now changed fundamentally with energy prices that have exceeded price levels where agricultural produce itself becomes competitive in the energy sector. Higher energy prices do not necessarily have to be a brake on agricultural production, they may actually further promote it. Products such as sugar cane, cassava, palm oil and even cereals benefited from higher energy prices. In this special issue of *Water Policy*, Zilberman *et al.* (2008) use theoretical models to analyse the impacts of higher energy prices on agricultural inputs and outputs. However, owing to the uncertainty of future oil prices and energy policies, it is still too early to understand sufficiently the dimensions of the markets for biofuels to develop a realistic scenario that quantifies the trade-offs between increased biofuels production and the provision of food.

Growing biomass for the production of either food or bio-energy requires a substantial use of natural resources. The sun provides free energy, but the process of producing biomass requires a large amount of land and water. Since the amount of land and water resources that can be used for agricultural production is limited, there is widespread fear that the production of biofuels will have a severe impact on the environment and food security. Using new land for agricultural production may have serious consequences for natural vegetation and biodiversity. Food insecurity for the poor may increase if biofuel production pushes aside food production and prices for agricultural products rise.

This paper addresses questions about the potential and consequences of world agriculture becoming a significant source for biofuel production. It presents some insights into the effects of the increasing energy demand on the agricultural sector and its impact on the use of natural resources for food and biofuel production.

2. Population

For every long-term outlook on global food and agriculture, population growth is the key driving force. It is the main cause for the drastic decrease of the growth rate for global food demand expected for 2030–2050 (Bruinsma, 2003; FAO, 2006a). The population growth rate peaked in the 1960s with developing countries reaching 2.5% per year. About a decade ago, the annual increments in the world population started to decline to 1.5% currently and will further decline to 1.0% by 2030 and to 0.5% by

2050 (UN, 2001, 2003, 2005). This does not mean that population growth is over, it means that growth is slowing down and for 2050, it is slowing down considerably (Figure 1).

Next to the absolute population growth, urbanization is an important factor that influences agricultural markets. It is expected that the current rural population will remain more or less stable until 2030 and that all population growth will be urban (Figure 2). Urbanization has a major impact on markets owing to the high population density and better infrastructure (ports, roads, airports). Consumers are closely integrated into international food markets which results in more food trade and in changes in diet with a greater demand for meat and convenience food and less for traditional diets.

3. Food markets

Globally, food production has doubled over the past 30 years. In developing countries it has nearly tripled. The increase in gross production does not mean that food intake has increased equally as fast. Nevertheless, food production has outpaced population growth; food supply per person has increased by more than 15% in industrialised countries and by 50% in developing countries. Driven by technological progress and investments in agricultural research, the rapid output growth in developing countries is particularly remarkable. Nearly 70% of incremental production came from higher yields, approximately 10% from higher cropping intensities and only about 20% from area expansion. Wheat, rice and maize are the world's most important food staples and have been the major focus of international breeding efforts. On the other hand, there are a number of crops that are very important for the rural poor in some areas of the world like millet, sorghum and pulses, where yield growth has been much slower. In general, agricultural production and productivity growth have helped to reduce hunger and poverty considerably, but where crops did not benefit from technical progress, farmers remained poor and much less progress was achieved in reducing undernourishment.

Prices for food and agriculture have declined by approximately 60% in real terms over the last 40 years (Figure 3). This has helped to improve access to food and to reduce undernourishment: from 1970 to 2000, the share of undernourished people in developing countries has declined from over 35% to 17% and even in absolute terms from 960 million in the 1970s to approximately 800 million in 2000 (FAO, 2004). Lower food prices in conjunction with higher overall incomes made it not only possible for

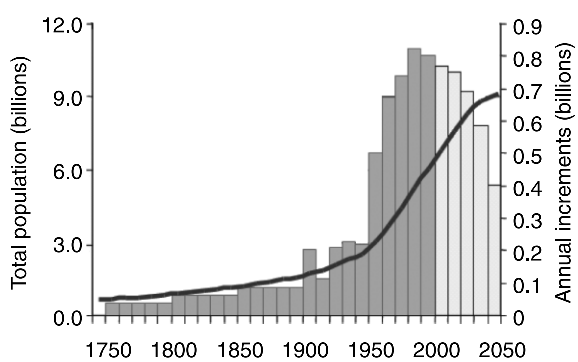

Fig. 1. Total population (as a line) and population growth (as bar graph). Source: Medium variant of the UN World Population Prospects, 2000-revision (UN, 2001).

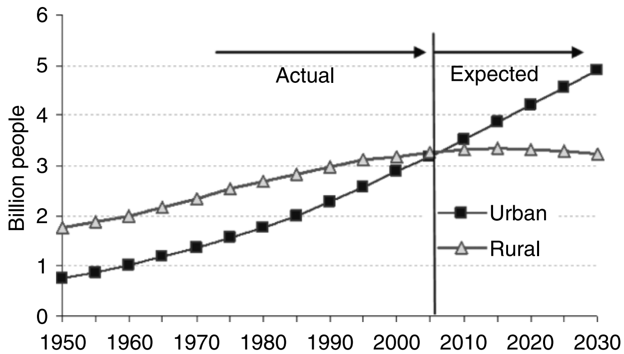

Fig. 2. Rural and urban population towards 2030. Source: UN, World Population Prospects, 2002-revision (UN, 2003).

many consumers in developing countries to increase their overall food intake, but also to shift their diets towards "high-end" food items such as meat and dairy products (Schmidhuber & Shetty, 2005).

4. Future agricultural situation

The slowdown in world population growth will contribute to ease the incremental pressure on natural resources and the broader environment that arise from the expansion and intensification of food production. However, getting through the next 50 years involves a large increase in the production of several commodities. Moreover, the growing resource pressures will be increasingly concentrated in

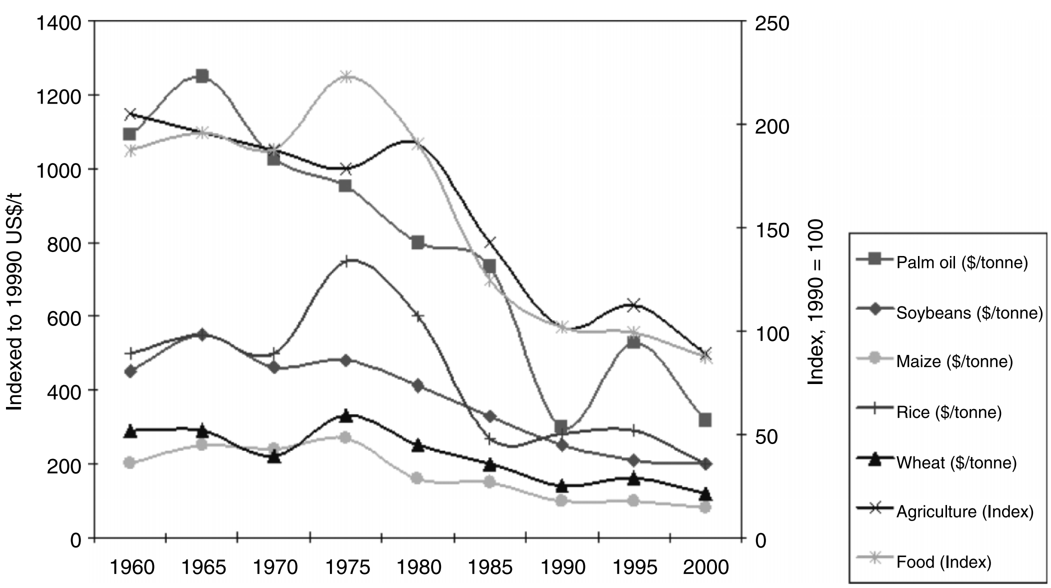

Fig. 3. Decline in prices for food and agriculture. Source: World Bank "Pink Sheets".

countries with high population growth rates and poor agricultural resource endowments, which are often countries with already low food consumption levels. The result could well be a situation of persistent food insecurity in a number of countries in a world with adequate food supplies and the potential to produce even more (Alexandratos, 2005).

The slowdown in the growth of world agriculture may not occur, or at least be attenuated, if the use of crop biomass for biofuels continues to rise. Whether and to what extent this will happen is very uncertain, given the unpredictability of oil prices. Should this occur, the implications for agriculture and development could be significant for countries with abundant land and climate resources that are suitable for the production of bio-energy feedstocks. Several countries in Latin America, South-East Asia and sub-Saharan Africa, including some of the most needy and food insecure could benefit. The issue of alternative energy sources is very alive and questions are increasingly asked about the potential of world agriculture to produce a significant amount of biomass for biofuel production and about the implications for food security and the impact on the environment, for example, further deforestation from the eventual expansion of land under the feedstock crops (oil palm, soybeans, sugar cane, etc).

5. Energy prices

Energy prices can have an impact on agriculture by creating new markets for those products which can be used as biomass for the production of biofuels as substitutes for petroleum-based fuels (petrol, diesel, heating oil). Apart from this they can also raise the competitiveness of agricultural products on the demand side, such as cotton or natural rubber, which compete with oil-based synthetics whose cost rises with the price of oil. With the current high oil prices, Brazil uses some 50% of its sugar cane output to produce fuel ethanol, both for domestic use and export. Ethanol in Brazil is considered to be competitive *vis-à-vis* traditional fossil fuels at oil prices of US$ 30–40/barrel. Ever since oil prices broke through the US$30 per barrel in January 2004, oil and sugar prices moved up in tandem (Figure 4). The main reason is that Brazilian ethanol producers became competitive in producing ethanol as a direct crude oil substitute at about US$35/bbl without requiring subsidies. As a result a growing number of sugar mills in Brazil divert a growing share of their cane conversion from sugar to ethanol production. This leaves less sugar (from the most important sugar exporter) to be exported to the world market and thus increases the price of sugar. The price link between sugar, ethanol and petrol is established and reinforced through energy consumption in Brazil. With a high and rising share of cars that can consume any blend of petrol and ethanol (flex-fuel vehicles) in Brazil, consumers will choose ethanol or petrol or a blend of the two according to changes in the relative prices of the two fuels (Schmidhuber, 2006). Taken together, complete market integration in supply and demand made prices of sugar and petrol move simultaneously. Higher oil and sugar prices also have knock-on effects on other crops and countries. For instance, as sugar prices go up in Brazil, sugar prices go up on the world market. This attracts farmers in other countries to produce more sugar and less of other crops, therefore increasing the prices of other crops as well. Of course only countries that produce at world prices benefit from this effect (Müller, 2006). Moreover, rising oil prices mean that a growing range of crops become competitive sources of feedstocks for bio-energy production; this increases competition for acreage and lifts agricultural prices for essentially all other crops.

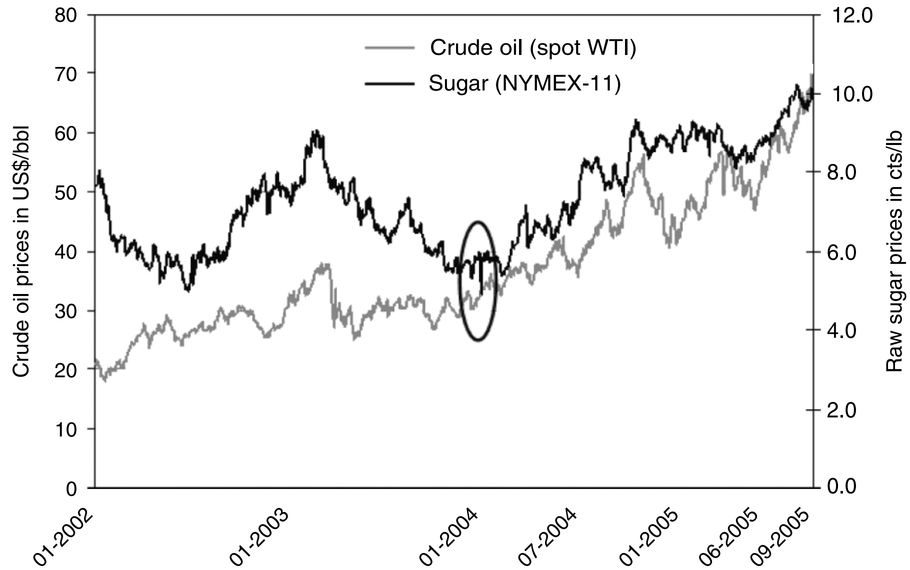

Fig. 4. Crude oil prices above 30 US$/bbl drive world sugar price. Source: Schmidhüber (2006).

6. Potential for biomass use

According to the International Energy Agency (IEA, 2006a, 2006b), the total global primary energy supply is projected to grow from to 463 EJ (Exajoule, 1 EJ $= 10^{18}$ Joule) in 2004 to 691 EJ in 2030. According to the Intergovernmental Panel on Climate Change (IPCC), it could further increase towards more than 850 EJ by 2050 (IPCC). Of the total primary energy supply, the IEA estimates that currently 49 EJ is provided by biomass. However, this estimate is highly uncertain. Most of the biomass used for energy is used for consumption on the household level for cooking and heating and is not traded on the world market. The main feedstocks are fuel wood, charcoal and dung. The total consumption of biomass used as source of energy is probably in the order of 15–60 EJ/year.

The yearly global photosynthesis is estimated at around 3,150–4,000 EJ. Theoretically, a big part of this could be made available for energy. Fischer & Schrattenholzer (2001) of the International Institute of Applied Systems Analyses estimate that, under continued technology improvements, the technical potential in 2050 can be around 400 EJ, of which a third is estimated to be potentially economically viable for exploitation. The figures mentioned refer to energy potential of raw biomass. The energy potential of liquid biofuel which can be used as transportation fuels is less. At current conversion rates, the potential of liquid biofuels would be around 53 EJ in 2050, which is less than the current needs for transport fuels of about 77 EJ (IEA, 2004). At the moment biofuels for transport play globally a very modest role. Ethanol and biodiesel together only provided 0.9 EJ of energy in 2005, which was only slightly more than 1% of the total demand of transport fuel. Estimates for 2006 suggest that the amount has increased to 1.3 EJ and that the contribution to the transportation fuels sector has risen to about 1.7%.

7. Land potential to meet the demand for biofuels

To produce biofuels in addition to food, a lot of extra land will be needed. Assuming current yields, technology and crop composition, an estimated 850 million ha would be required to meet current fuel needs. As a comparison, this would be more than half of the current total global crop land (1540 Mha) and it is in the same order of magnitude as all the crop land in developing countries (904 Mha) (Bruinsma, 2003).

Globally there is still potential for suitable land for expansion of agriculture; around 35% of land suitable for agriculture is currently under cultivation. In developing countries about 32% of the land suitable for agriculture is under cultivation compared to 45% in industrialized countries. Land suitable for agriculture as presented in this paper is defined as land with rain-fed crop production potential as used in FAO's perspective study "*World Agriculture: towards 2015/2030*". The production potential excludes protected areas and closed forests and is crop specific, so the total land suitable for agriculture is not necessarily suitable for biofuel crops.

8. Suitable crops and their potential to meet the demand for biofuels

The most important crops that are being used as biofuels are listed in Table 1. In this table some indicative yields per ha are listed. The yields are expressed in litres of fuel per ha and in energy per ha. Biodiesel has a higher energetic density per litre than ethanol (around 35 MJ l^{-1} for biodiesel compared to 20 MJ l^{-1} for ethanol). This explains why the yield in litres of fuel/ha for sugar cane and sugar beet is higher than for oil palm, while the energy value per ha is the highest for biodiesel from oil palm. Currently sugar cane is the crop that is most widely used for biofuel production. Ethanol can be made of sugar or from starch, however making it from sugar is more efficient.

What is not shown in the table are crops that produce ligno-cellulosic biomass such as switch grass or *Miscanthus* and fast growing trees such as willow or eucalyptus. The technology of converting cellulosic biomass to produce ethanol is advancing fast, however the availability of commercial conversion processes for such feedstocks is still 5 to 10 years away (FAO, 2006a).

Sugarcane is the best known crop that is used to produce biofuel, since it is used widely in Brazil. In new and modern facilities, crop residue powers fuel production and adds power to the electricity grid (Marris, 2006). The biggest potential for rain-fed production of sugar cane is in the humid (sub-) tropics

Table 1. Crop potential for the production of biofuels.

Crop	Fuel product	Annual obtainable yield [l/ha (indicative)]	Energy yield (GJ/ha)
Sugar cane	Ethanol (from sugar)	6,000	120
Sugar beet	Ethanol (from sugar)	7,000	140
Cassava	Ethanol (from starch)	4,000	80
Maize	Ethanol (from starch)	3,500	70
Oil Palm	Biodiesel	5,500	193
Rapeseed	Biodiesel	1,200	42
Soybean	Biodiesel	400	14

Sources: FAO, 2006b; Global Petroleum Club; Marris, 2006; USDA, 2006.

of South America (Brazil) and in sub-Saharan Africa (Democratic Republic of the Congo). In more temperate zones sugar beet is also a crop with potential. In terms of energy production, sugar beet is slightly more efficient than sugarcane. Most land potential for rain-fed production of sugar beet lies in the USA, Argentina and Europe (from France to Russia).

Cassava is a tropical root crop with potential for ethanol production from starch. Thailand is one of the largest cassava producers. The leading Thai petroleum company has announced a feasibility study for a factory that would use cassava to produce one million litres of ethanol per day. Cassava and sugar cane production can be found in roughly the same areas; humid tropics notably in South America and sub-Saharan Africa. Maize is the main crop for ethanol production in the USA.

Maize-based ethanol production in the USA is both benefiting from high tariffs protection (about 0.54 US$/l) and high governmental support (about 0.50 US$/l). A recent study by Food and Agricultural Policy Research Institute (FAPRI, 2007) suggested that without protection and subsidies, ethanol production would "contract by 30% and biodiesel production by more than half". The FAPRI study further concludes that "net returns would fall so dramatically that many of the factories would be unused because of their inability even to cover operating costs".

Oil palm is grown in the wettest parts of the tropics. Most of its land potential lies again in South America, sub-Saharan Africa and also in Indonesia and Malaysia. In the last two countries particularly, oil palm plantations carved from tropical forests raise environmental concern.

Rapeseed is the most import crop for biofuel in the European countries. Here the biodiesel is mixed with ordinary diesel. The European Union set 2010 as a target when 5.75% of the diesel market should come from biodiesel. Like ethanol produced from maize, biodiesel can only be produced from rapeseed if it is subsidized. Europe, the United States and South America (especially Argentina) have a great land potential to produce rapeseed.

Soybean, like maize, is another crop that cannot be economically profitable for the production of biofuel. However, its common use in the United States for food and feed products has led to soybean biodiesel becoming the primary source for biodiesel.

9. Water potential to meet the demand for biofuels

Apart from land resources, water resources are necessary to produce the crops needed for biofuels. Table 2 shows the same crops as Table 1 with the main producing countries and the estimated share of production which is grown under irrigation. Of these crops, the sugar crops are the most water demanding and therefore the main crops that are grown under irrigation. Sugar beet can be found mainly in temperate climate zones where it is regularly cultivated under supplementary irrigation (especially in the USA). In India, sugar cane is often grown under full control irrigation, while in Brazil sugar cane is generally grown under rain-fed conditions. Depending on the climatic conditions, both sugar crops can be grown under rain-fed conditions. Irrigation is applied to boost yields in areas where water is easily available and cheap.

For the perspective study "*World Agriculture towards 2015/2030*", FAO estimated current and future water withdrawals for irrigation and compared these with available water resources (Figure 5). It should be noted that Figure 5 refers only to the classical FAO-projection not including higher oil prices that cause rising demands for biofuels. It is expected that water withdrawals will increase everywhere, especially in South Asia. The biggest potential for increasing water use for agriculture can be found in

Table 2. Major crops used for the production of biofuels, main producing countries and the share of the production under irrigation.

Crop	Main producing countries	Land under irrigation (estimates) (%)
Sugar cane	Brazil/India/China/Thailand	14/80/28/64
Sugar beet	France/USA/Germany/Russia	15/53/5/5
Cassava	Nigeria/Brazil/Thailand/Indonesia	0
Maize	USA/China/Brazil/Mexico	21/40/0/17
Oil palm	Malaysia/Indonesia/Nigeria/Thailand	0
Rapeseed	China/Canada/India/Germany	3/0/8/0
Soybean	USA/Brazil/Argentina/China	10/0/0/29

Source: FAO – FAOSTAT and AQUASTAT.

Latin America and sub-Saharan Africa. In both areas less than 5% of the total available renewable water resources are being used, indicating a substantial potential for water use if compared to the more than 50% of available water that is being used in Near East and South Asia.

FAO also estimated the amount of currently irrigated land and compared that to the irrigation potential (Figure 6). The combined information as presented in Figures 5 and 6 shows clearly that the potential for growth for both the Near-East/North Africa regions and South Asia is reaching its limits. While Figure 5 still showed an abundance of water resources in East and Southeast Asia, Figure 6 shows that there is very little land available for extra irrigated agriculture. Most potential for expansion is limited to Latin America and sub-Saharan Africa. For the sub-Saharan region it is expected that the current low levels of irrigation water withdrawals will increase slowly. The picture does not show the situation in

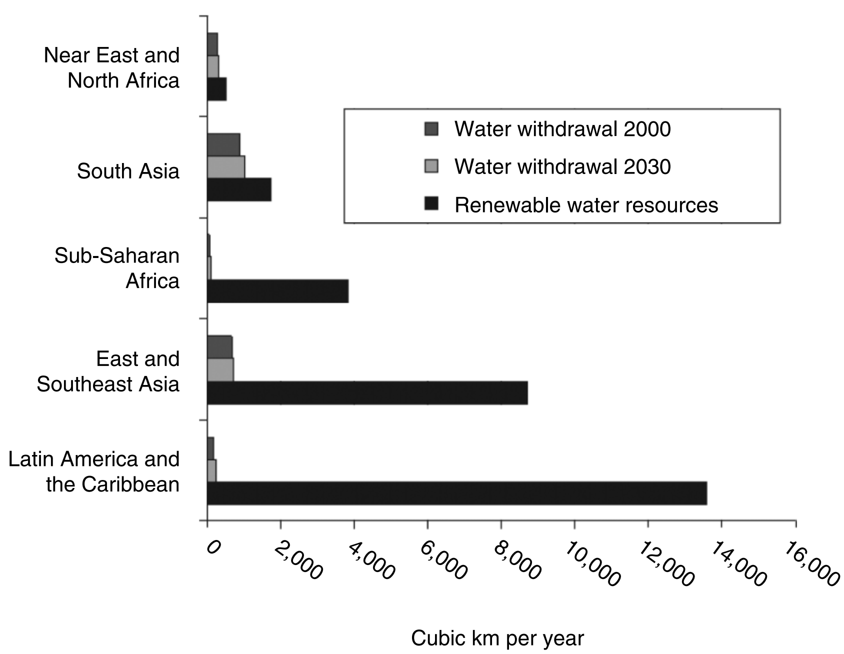

Fig. 5. Current (2000) and expected (2030) water withdrawals for irrigation compared to available renewable water resources. Source: FAO – AQUASTAT.

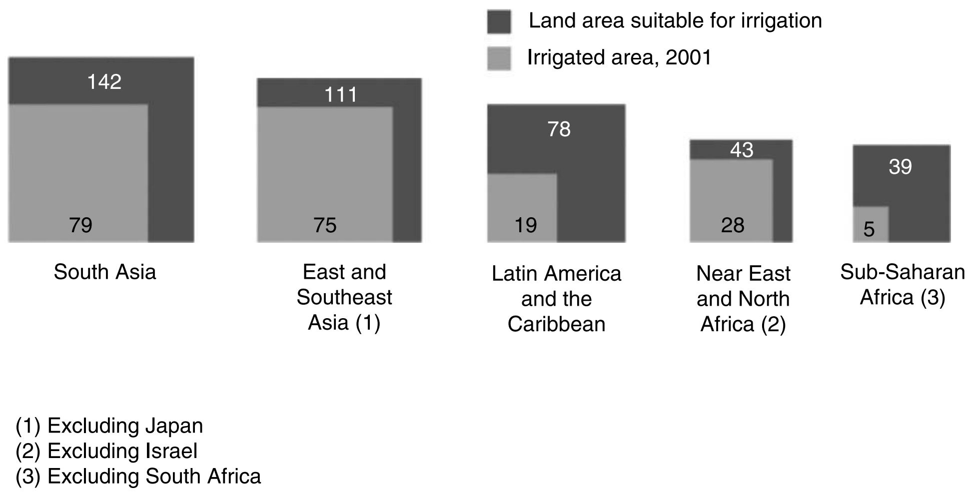

Fig. 6. Irrigated land and land suitable for irrigation in 2001 (million ha). Source: FAO – AQUASTAT.

industrialised countries. In some critical areas in these countries, increasing demand from the domestic and industrial sectors has already resulted in a decrease in irrigated agriculture. The real problem areas are China and India where there is over 35% of the world population. Currently the per capita energy demand in the USA is 10 times higher than in China; this is expected to change rapidly. According to the World Energy Outlook (IEA, 2006b), it is expected that by 2030 China and India will account for 30–40% of the global energy demand. Both countries have already exploited most of their natural resources available for agriculture and there is little land and water left to expand areas for crop production.

10. Concluding remarks

Growing crops for biofuels has often been criticized as it would compete for land with food crops. It is not yet clear how the pattern of competition between fuel crops and food crops will evolve, especially where food-security policies are not in place. But it is likely that food prices will rise again after many years of decline in real terms. Growing biomass for biofuel production may give farmers greater flexibility to switch between commodities for food production on the one side and bio-energy commodities on the other.

Globally there is still land and water available to grow a substantial amount of biomass for bio-energy production. But regionally there are shortages, both with regard to land and water. China and India, being the two countries that will account for 30–40% of the global energy demand by 2030, have very little land and water available to expand agriculture.

Another big global issue will be the impact that feedstock production will have on biodiversity. It is very likely that valuable ecosystems like native rainforests and wetlands will be cleared to make expansion of the agricultural sector possible and this will result in large losses of natural biodiversity. If feedstock production comes predominantly from large monoculture cultivation it may reduce both the number of species and, with a growing specialisation on particularly suitable varieties, even the number of varieties grown. These practices may result in greater vulnerability of the agricultural sector to non-standard crop growing conditions like extreme weather patterns, pests and diseases.

The biodiversity issue underlines the general trade-offs between different efforts to reduce greenhouse gas emissions where biofuels substitute for petroleum and the adverse impact of land expansion. To disclose accurately the potential of bio-energy there will be a continuous need to invest in improving agricultural management in general and improving the efficiency of agricultural production in particular.

Bio-energy can affect food security both positively and negatively. At the household level higher prices for food will have a negative impact on food security for the poor, of which the urban poor will be affected the most. On the other hand new stimuli in the agricultural sector will offer new opportunities for rural communities. At the national level bio-energy can offer development opportunities for countries with significant agricultural resources; this is particularly the case if import barriers for biofuels in developed countries are removed. Africa, with its significant sugar cane production potential, is often cited as a region that could profit from Brazil's experience and technology, although obstacles to realizing it (infrastructure, institutional, etc.) should not be underestimated.

In the long term, second generation technologies that can convert ligno-cellulosic biomass (from crop residues, grasses and wood) to produce "cellulosic" ethanol will become available. New species that are suitable for biofuel production and can be grown on marginal land can be introduced. This may contribute to mitigating eventual pressures on land with food crop production potential.

If policies that integrate bio-energy farming with food and feed farming are implemented, there is a potential to decrease local food shortages and increase the income of the world's poorest people. As long as these policies are not yet in place, each bio-energy programme will be judged on a case-by-case basis, taking in account the pertinent economic, ecological and social criteria (Fresco, 2006).

References

Alexandratos, N. (ed.) (1988). *World Agriculture: Towards 2000, an FAO Study*. Belhaven Press, London/New York University Press, New York.

Alexandratos, N. (ed.) (1995). *World Agriculture: Towards 2010, an FAO Study*. John Wiley, Chichester, UK/FAO, Rome.

Alexandratos, N. (2005). Countries with rapid population growth and resource constraints: issues of food, agriculture and development. *Population and Development Review*, *31*(2), 237–258.

Bruinsma, J. (ed.) (2003). World agriculture: towards 2015/2030, an FAO perspective. Earthscan, London / FAO, Rome.

FAO (1970). *Provisional Indicative World Plan for Agriculture*. FAO, Rome.

FAO (1981). *Agriculture: Towards 2000*. FAO, Rome.

FAO (2004). *The State of Food Insecurity in the World 2004*. FAO, Rome.

FAO (2006a). *World Agriculture: Towards 2030/2050, Interim Report*. FAO, Rome.

FAO (2006b). *Starch market adds value to cassava,* on-line available at: http://www.fao.org/ag/magazine/0610sp1.htm.

FAO, *FAOSTAT*, various data bases, on-line available at: http://faostat.fao.org/default.aspx.

FAO, *AQUASTAT*, *FAO's Information System on Water and Agriculture*, on-line available at: http://www.fao.org/nr/aquastat.

FAPRI (2007). *Economic Impacts of Not Extending Biofuels Subsidies*. FAPRI - UMC Report, #17-07, Food and Agricultural Research Institute, Missouri, May 2007.

Fischer, G. & Schrattenholzer, L. (2001). Global bioenergy potentials through 2050. *Biomass and Bioenergy*, *20*, 151–159.

Fresco, L. O. (2006). *Biomass for Food or Fuel: Is There a Dilemma? The Duisenberg Lecture*. Rabobank, The Netherlands, Singapore, 17 September 2006.

Global Petroleum Club, *Energy Content of Biofuel*, on-line available at: http://en.wikipedia.org/wiki/Energy_content_of_Biofuel.

IEA (2004). *Biofuels for Transportation*. International Energy Agency, Paris.

IEA (2006a). *Key World Energy Statistics – 2006 edition*. International Energy Agency, Paris.

IEA (2006b). *World Energy Outlook 2006*. International Energy Agency, Paris.

Marris, E. (2006). Drink the best and drive the rest. *Nature*, *444*, 670–672, 7 December.

Müller, A. (2006). Competition between food and non-food uses. Presented at *Economic Diversification, Food Security and the Interlinkages Between the Agricultural and the Energy Sector – Expert meeting*, 29 November – 1 December. Palais des Nations, Geneva.

Schmidhuber, J. (2006). *Impact of an Increased Biomass Use on Agricultural Markets, Prices and Food Security: A longer-term perspective*. Paper presented at a conference organized by Notre Europe, Paris, November 2006. Available at: http://www.fao.org/es/ESD/BiomassNotreEurope.pdf.

Schmidhuber, J. & Shetty, P. (2005). The nutrition transition to 2030. Why developing countries are likely to bear the major burden. *Acta Agriculturae Scand Section C*, *2*, 150–166.

UN (2001). *World Population Prospects, the 2000 Revision – Highlights*. United Nations, New York.

UN (2003). *World Population Prospects, the 2002 Revision*. United Nations, New York.

UN (2005). *World Population Prospects, the 2004 Revision – Highlights*. United Nations, New York.

USDA (2006). *The Economic Feasibility of Ethanol Production from Sugar in the United States*, on-line available at: http://www.usda.gov/oce/EthanolSugarFeasibilityReport3.pdf.

World Bank, *Commodity Price Data (Pink Sheet)*, on-line available at: http://go.worldbank.org/MD63QUPAF1.

Zilberman, D., Sproul, T., Rajagopal, D., Sexton, S. & Hellegers, P. (2008). Rising energy prices and the economics of water in agriculture. *Water Policy*, *10* (Suppl. 1), 11–21.