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Food Security: Crops for People Not for Cars

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Abstract Humankind is currently faced with the huge challenge of securing a sustainable energy supply and biofuels constitute one of the major options. However, the commercially traded edible crops are barely sufficient to meet food demand of the present world population. Certain regions, for example EU-27, do not even have a sufficient indigenous crop production. Of this follows that motor biofuels based on edible crops should be avoided. To replace more than some percent of the fossil motor fuels, non-edible biomass—rest products and wastes—should instead be considered for conversion to biofuels. In this way, about 10% of the current fossil fuels can be replaced. Feeding a world population expected to grow by some 50% during the next 50 years will be a major challenge. For environmental reasons it seems that agricultural land cannot be expanded very much, maybe not at all. The solution to the increasing food demand seems therefore to be using the present crop production more efficiently and increasing output from present agricultural land, maintaining biodiversity and climate stability within reasonable limits. In the future, agriculture will need more energy and more water irrigation. Food production is, however, already very energy demanding, requiring several times more externally provided energy than the energy content of the food itself. A sufficient energy supply will be a key issue for the future farming!

Keywords Agriculture · Food · Biofuel · Cropland · Residues · Energy

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INTRODUCTION

About 1 billion people are chronically undernourished and for them food security is still far away. In view of this fact, production of bioethanol from sugar cane, wheat and maize and of biodiesel from palm, rape seed and soybean appear controversial. The question to be asked is if agriculture can provide sufficient edible biomass not only for food production of an expanding world population but also for some biofuel production for the world's cars. An often heard argument is that there is no lack of food and agricultural land, and that a main reason for starvation is due to an inefficient trading and distribution system. Another argument is that a lot of agricultural land, still unused for food production, is sufficient for providing food even for the additional 2–3 billion people expected to populate the globe around 2050.

People sceptical to using primary agricultural products for car fuel argue that today's highly intensive agriculture requires lots of fossil energy, threatens biodiversity in large areas of monocultures and leads to deforestation by converting for example rain forest land to agricultural land. A global demand-driven expansion of biofuels such as ethanol can therefore result in further homogenization of ecosystems and landscapes which will have far-reaching effects on fresh water, rivers, coasts and oceans.

These questions will be analyzed in some detail below. Background material as well as references can be found in the bioenergy report from the Energy Committee of the Royal Swedish Academy of Sciences (Fredga et al. 2008). A main ingredient of the discussion is the energy content of the harvested agricultural biomass (Kullander 2009) and how it can be matched to the food needs of the global population (Johansson and Liljequist 2009; Johansson et al. 2010).

"BIOFUEL" FOR PEOPLE

Many organic compounds (carbohydrates) can serve as fuel (food) for human beings. The most important compound is glucose which provides energy to the human cells in a series of complicated chemical reactions. The energy of the carbohydrates permits the cell to accomplish a number of energy-requiring reactions. The "waste" products are CO_2 and H_2O.

On average, 10.4 MJ (2,500 kcal) per day is considered to be an average energy intake required for a human being. This daily need of energy corresponds to the energy content of only 2.5 dl of gasoline or 4 dl of ethanol (Fig. 1). The composition of the food intake varies and depends on habits and availability of food. In Sweden, the annual per capita food consumption is typically 15 kg fish, 50 kg fruits and vegetables, 49 kg meat, 37 kg bread, 65 kg potatoes and 180 kg milk.

Many people in the industrialized world eat more than the average of 10.4 MJ and many in the developing countries eat less than what is required for a decent living. Using the value 10.4 MJ to calculate the food-energy requirement shows that 7,100 TWh are required for the present global population and by 2050, 10,000 TWh will be required. These figures should be compared with the global energy supply which excluding food is at present 140,000 TWh out of which 80% is of fossil origin.

EDIBLE OUTPUT FROM GLOBAL AGRICULTURE

The future potential of agricultural production for food and for fuel can be quite easily assessed from its calorimetric energy content (Kullander 2009). This was done by means of data on global agricultural production for 2005 taken from the UN Food and Agriculture Statistics Global Outlook. The production includes cereals, sugar crops, fruits and vegetables and was 6,108 million tonnes, i.e. nearly 1 tonne per human being. To convert weights to calorimetric energies, the water must be removed. For example, cereals have normally a water content of about 15%, whereas vegetables have a water content of about 80%. Making some very rough estimates of the dry weights and applying a standard value of 17 MJ/kg dry weight, the energy content of the global agricultural production for 2005 was found to be 16,000 TWh. This preliminary result indicates that there should be enough agricultural products for food but insufficient for replacing a major portion of the fossil energy (Table 1).

A data base has been constructed and used to estimate the edible and inedible energy portions of harvested crops (Johansson and Liljequist 2009). The production did not vary significantly for the years 2004–2007, and the 2006 data were selected for the estimate. A detailed evaluation of the different substances, their dry weights and their energy contents was carried through for 129 different crops. The different losses in the processing were estimated, and the final data on the edible food were compared with the food demand. The expected bioenergy output and the future expansion potential of the agricultural sector were discussed. The global, the EU-27 and the Swedish situations were evaluated (Table 2).

Table 1 Global agricultural production in 2005 according to statistics from the Food and Agriculture Organization of the United Nations (FAO)

Tobacco	7
Fibre crops	29
Pulses	62
Oilseeds/nuts	146
Roots/tubers	712
Fruits/vegetables	1,392
Sugar crops	1,432
Cereals	2,228

In total 6,108 million tonnes were produced amounting to nearly 1 tonne per human being

Table 2 Obtained energy contents of primary agricultural products and of the associated residues from an analysis of the FAO 2006 data (Johansson and Liljequist 2009; Johansson et al. 2010)

	Global	EU-27	Sweden
Population (106)	6,700	490	9
Primary (TWh)	19,900	2,100	31
Residue (TWh)	18,200	1,500	22

The units used are Tera Watt hours (TWh)

The harvested gross agricultural productions were found to be 19,900 and 2,100 TWh for the world and EU-27, respectively. In the analysis, seed for reproduction and various losses were deducted. For the global production, a high case and a low case were considered. For the high case, it was assumed that all rest products after the initial upgrading (oil crop meals, husks and bran from cereals and sugar crop fibers after sugar extraction) are available as food. For the low case it was assumed that all rest products are uneatable. For the high case, the live-stock feed of oil crops, peas and cereals were estimated to be 5,135 TWh and for the low case 7,245 TWh, quantities that were removed from the balance. Then livestock products and game meat, fish and sea food were added to sum up to the net energy edible production. For the EU-27, the live stock feed was estimated to be 1,160 TWh and the rest products were considered uneatable.

Using these figures, the net energy content of edible agricultural products was estimated to be for the world

Table 3 Results on agricultural edible production from (Johansson and Liljequist 2009; Johansson et al. 2010)

People, food demand, food production			
Region	Global	EU-27	Sweden
Population (Million)	6,700	500	9.3
Food demand (TWh)	7,100	526	10
Net edible production (low case) (TWh)	7,225	431	8

The food demand was based on an average consumption of 2,500 kcal per capita and day and neglecting any losses in the food handling. The estimated net edible production (low case) was obtained after subtraction of 7,245 TWh needed for livestock feed

7,225-9,385 and for the European Union 431 TWh. These values should be compared with food requirements of 7,100 and 526 TWh, respectively. The conclusion was that, provided everybody is properly nourished, essentially no primary crops will be available for biofuel production (Table 3).

ENERGY REQUIRED FOR FOOD PRODUCTION

Prior to the industrial era, agriculture and forestry were primary net producers of energy. Today the food system is a net user of energy especially so in industrialized countries, where each calorie of food produced requires many times more externally delivered energy. Between 1950 and 1984, as the Green Revolution transformed agriculture around the globe, world grain production increased by 250%. The Green Revolution resulted in the industrialization of agriculture. Part of the advance resulted from new hybrid food plants leading to more productive food crops. The energy for the Green Revolution was provided by fossil fuels in the form of fertilizers (natural gas), pesticides (oil), irrigation and transportation. In the US, the amount of energy needed each year for the food sector corresponds to 1,500 l of oil equivalents per US citizen, 14 times the energy content of the food consumed (Pfeiffer 2004). If these figures were applied on the whole world population, two times the current global oil production would be needed for the global food sector. The example shows that the American way of food production is by far too energy demanding but it also shows that future global agriculture will require substantial amounts of energy.

Dale Allan Pfeiffer (Pfeiffer 2004) concluded that "modern agriculture must continue increasing its energy expenditures simply to maintain current crop yields. The Green Revolution is becoming bankrupt".

In a recent study of the U.S. food system (Heinberg and Bomford 2009), it was found that 7.3 times the energy content of the food on the table is needed for the various steps in the food chain (Fig. 2). Farming accounts for less than 20% of this energy expenditure, but still consumes more energy than it delivers. If these figures were applicable to all global food consumption, nearly half of the fossil energy would be needed for the food sector.

During 2006, the global biofuel production was quite small compared with the edible agricultural production as can be seen in Table 4. The biofuel share of the totally supplied global energy was only 0.2% and the share of the fuel for the transport sector was about 1%. The increased food prices in the beginning of 2008 can thus hardly be due to the increasing use of biofuel but rather to the increased oil prices during that period in view of the extreme dependence on fossil energy in the food system. However, if the global biofuel share would increase by a factor ten, very strong effects on the food prices would be expected as can be understood from the energy values in the table.

BIOFUEL FROM PRIMARY AGRICULTURAL PRODUCTS

Sugary and starchy plants such as sugar beets, grains (mainly wheat and maize) and potatoes can be fermented to

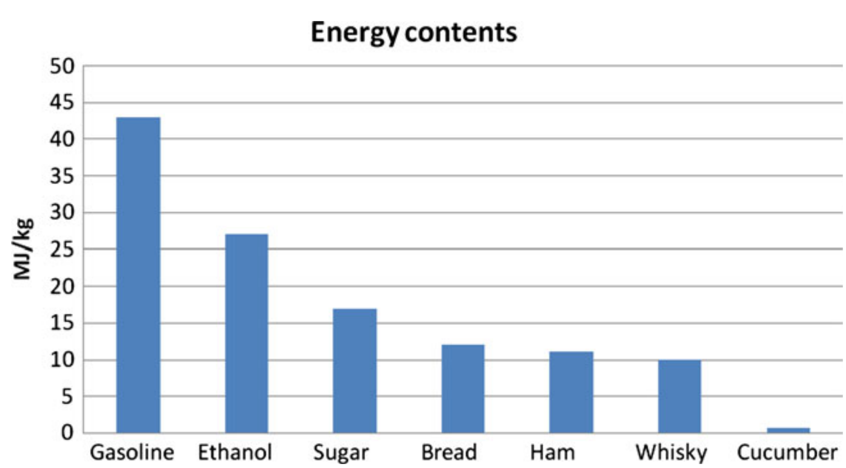

Fig. 1 The energy content in megajoule (MJ) per kilogram (kg) of some fuels for cars and human beings

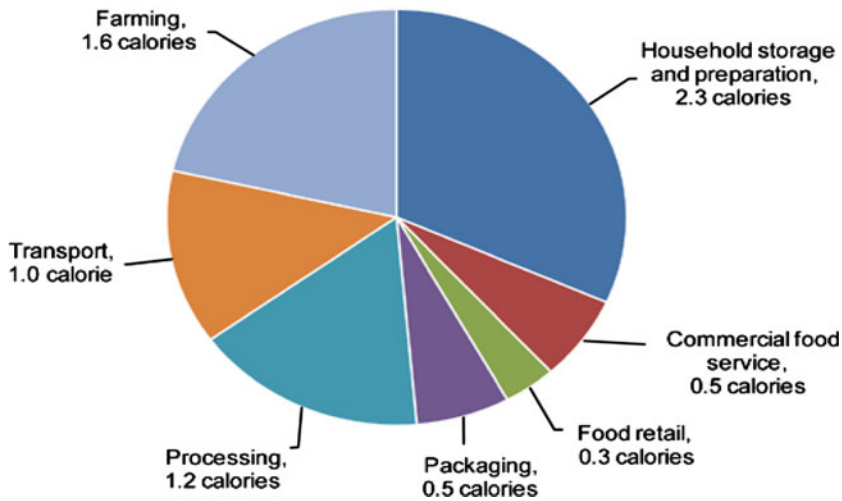

Fig. 2 Energy expended in producing and delivering one food calorie according to Ref. Heinberg and Bomford (2009). Approximately, 7.3 calories are used by the US food system to deliver each calorie of food energy. Farming accounts for less than 20% of this expenditure, but still consumes more energy than it delivers

Table 4 Global energy supply, food demand, net edible agricultural production (Johansson et al. 2010) and biofuel production for 2006

Item	TWh	Percent
Total energy supply	140,000	100
Fossil energy supply	112,000	80
Net edible production	7,225	5.2
Food demand 6.7 billion people	7,100	5.0
Biofuel 50 billion litres	280	0.2

Table 5 Physical data of ethanol production which is about two times higher for sugar cane as compared to maize. On the other hand, about six times as much energy is required to produce ethanol from maize

Raw Material	Production/ha (kg)	kg Product/litre ethanol (kg)	Ethanol/ha (l)
Sugarcane	85,000	12	7,080
Maize	10,000	2.8	3,570

Source: Brazilian Agricultural Ministry

produce ethanol (C_2H_5OH) or digested to produce biogas, composed of about 60% methane (CH_4) and 40% carbon dioxid (CO_2). Worldwide, sugar cane and maize are the most important raw materials for ethanol production.

During 2007, world production of bioethanol was 52 billion litres and of biodiesel 11 billion litres. For comparison, the yearly oil production was 4,800 billion litres. The main producing countries for biofuels are the US, Brazil and the EU. In the US, the production was focused mostly on ethanol from maize, in Brazil on ethanol from sugar cane, and in the EU on biodiesel from rapeseed. According to (Bringezu et al. 2009), global biofuel production is expected to increase to 660 TWh in 2015 and to 1,200 TWh in 2030, a threefold increase compared to the present situation. If all agricultural production of maize or of sugar cane or of soy bean or of palm oil was used for biofuel production, the result would be 1,600, 620, 400 or 250 TWh, respectively (Johansson et al. 2010). These figures show that the estimated threefold increase may be hard to achieve without seriously compromising global food supply.

The US has recently passed Brazil as the biggest producer of ethanol, 24.5 billion litres in 2007. This rapid increase implies that nearly half of the global supply of ethanol is produced in the US. In 2007 Brazil produced ethanol from sugar cane grown on 6 million ha of land, corresponding to a mere 0.7% of the country's area. Reportedly ninety million ha of unused land remain available for production of ethanol from sugar cane in Brazil (Aranda 2007). This means that 15 times the 2007 production of 19 billion litres of ethanol—285 billion litres—could be produced annually. But it may also lead to destruction of natural ecosystems often in a fragile environment (Table 5).

The amount of energy needed to produce ethanol from different crops is being vividly discussed. The best values reported are for Brazilian ethanol from sugar cane where an output/input energy ratio of about eight has been reported (Aranda 2007). Production of ethanol from US maize requires much input energy for fermentation and distillation, and in certain cases the energy content of the produced ethanol is smaller than the input energy (Ulgiati 2001; Pimentel and Patzek 2005).

In Brazil, oil crops, mainly soybeans and oil palms, are grown on wide expanses of land. Brazil is currently the second largest producer of soybeans, after the US. Total production in 2004 was 85 million tonnes in the United States and in Brazil, 53 million tonnes where 22 million ha of land were used. In 2006, Brazilian production had

increased to 60 million tonnes. Most of the Brazilian soybean crop (82%) was used as animal fodder. A small amount, 500,000 tons per year, was used for biodiesel production but he Brazilian government encourages increased production of biodiesel with the goal to increase it by a factor of ten.

Cultivation of soybeans is controversial because it is perceived to lead to devastation of the rainforest. Overexploitation of Brazilian rainforests decreased for several years, but this positive trend was broken in 2003.

In Southeast Asia—particularly Indonesia and Malaysia—oil palm plantations for production of biodiesel constitute a major threat to the rainforests. Devastation of the forests to make room for plantations threatens many unique species in the rainforests and causes irreparable damage to the entire ecosystem. Forest destruction also makes a significant contribution to the increasing atmospheric carbon dioxide content.

The positive climate effects of biofuels are also being questioned. It has been shown that the crops most commonly grown for use as biofuels (maize, rapeseed, sugar cane) release twice as much greenhouse gases (Crutzen et al. 2007) as assumed by IPCC, the international Panel for Climate Change, since microorganisms transform part of the nitrogen in the fertilizers into nitrous oxides. Nitrous oxide is 300 times more aggressive than CO_2 for absorbing the emitted heat radiation from the Earth. Thus, any positive climate effect in replacing fossil fuels by biofuels may easily be lost by excessive nitrous oxide emission.

The International Energy Agency (IEA) has, in a study from 2007, in a best case scenario estimated that agriculture could provide 306,000 TWh bioenergy per year which entails intensive farming on high quality soils (International Energy Agency 2007). For comparison, the world's total energy supply is about 140,000 TWh. According to IEA, a massive expansion of large-scale bioenergy production world-wide could enable generation of between 60,000 and 120,000 TWh per year. In the same study, the energy content of agricultural residues were estimated to be 10,000 TWh. The report cautions that accessibility of biomass for energy production and other purposes depends on many complex factors, which makes it difficult to assess its future potential. It particularly emphasizes that the constantly growing need for food must be met and that environmental and ecosystem sustainability must be ensured.

BIOFUELS FROM AGRICULTURAL RESIDUES, GRASS LAND, FORESTRY AND WASTE

Second generation biofuels make use of the residues from fields and forests rather than of the primary agricultural products. They are based on the conversion of cellulose from these residues.

Dry plant material rich in cellulose—forest products, energy crops (*Salix*), reed, grass, hemp and straw—can be converted to ethanol through fermentation and hydrolysis, or be gasified to methanol (CH_3OH), DME (dimethylether $(CH_3)_2O$), Fischer–Tropsch diesel, biomethane or syngas. The plant material can also be "refined" to chips and pellets. At present, dry plants are mainly used for production of heat and electricity. Palm oil and soybean are the most important raw materials for biodiesel.

Moist cellulose-rich plants such as forage (grasses and legumes such as clover), cereal straw and beet tops can be digested to produce biogas (digestion gases). Manure, garbage and sludge can also be digested to produce biogas (Fig. 3).

Production of second generation biofuels from cellulose are planned in many places viz the US, Brazil and Sweden where test/demo facilities are tried out at several places. Different cellulose-containing raw materials are of interest. Forest and agricultural residues as well as grasses should be mentioned. In the US, switchgrass, a summer perennial grass which covered must of the great Plains, is considered to have a big potential for bioenergy purposes (McLaughlin 1999).

In Sweden, ongoing projects in Örnsköldsvik aim to establish processes which can be used on an industrial scale to break down cellulose particularly from forestry and produce ethanol through fermentation of the resulting hexoses and ultimately also pentoses. Experiments being done in Piteå aim at producing syngas through gasification of black liquor for production of both methanol and DME. Similar experiments on forest biomass are being carried out in Värnamo at a gasification facility. It is hoped that the

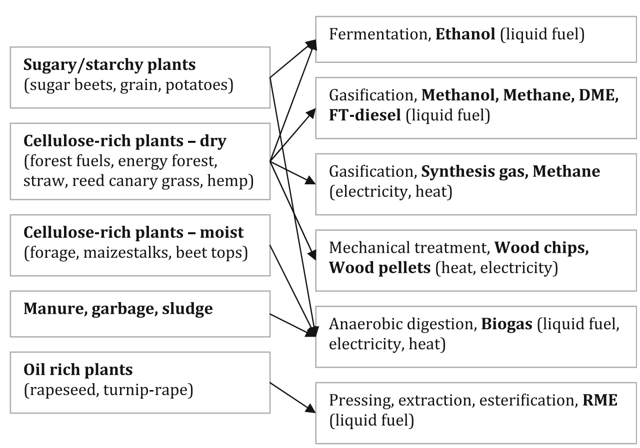

Fig. 3 Energy from biomass. Methods for transforming various raw materials into energy carriers which can be used as liquid fuels or for production of heat and electricity. From Ref. Fredga et al. (2008)

production of second generation automotive fuel can reach full industrial scale before 2020.

In Ref. Johansson et al. (2010), a detailed assessment of the energy content of the residues within global agriculture was done. Use was made of the harvest index which is the ratio between harvested production and total biomass above ground. Hence roots are excluded, provided they do not constitute the harvested product as for root crops. The data for the harvested production of primary crops were used to calculate the amount of residues produced in terms of dry matter. The residues were divided into two categories; annual and perennial. The annual residues are made up of crops which are annually planted, and thus harvested every year. The perennial residues are estimates of annual increment of perennial plants such as bushes or fruit trees. The total amount of residue energy was estimated to be 18,000 TWh.

In practice, it is not possible to harvest all residues because there is a limit to how close to the ground, the plant can be cut. Furthermore, it is necessary to leave residues on the field to maintain the fertility of the soil. In many places throughout the earth, the soils are degrading due to erosion and nutrient leakage. Leaving the residues on the fields helps to cover and protect the fields from erosion, as well as contributes to keeping or increasing the humus content which is important for many different reasons.

Four scenarios were presented in the study (Johansson and Liljequist 2009). It was assumed that 2/3 of the total production of residues is the maximum technical limit that can be harvested [I]. However to maintain the soil organic carbon only 50% of the residues can be removed for a country like Sweden [II] and for the world as a whole on average only 1/3 can be removed [III]. The fourth scenario implies that the residues are removed only once per crop sequence. Usually a crop sequence spans over 4 years, which means that approximately 25% of all residues can be used for this purpose. However, only 2/3 of this is technically possible to harvest, giving a total available amount of residues of 1/6 of gross production [IV] (Table 6).

By using all residues and bioorganic waste for biogas production, about one-fourth of the fossil fuels used for transport, 25,000 TWh could be replaced (Johansson and Liljequist 2009). These findings should be compared with those of the recent IEA report (International Energy Agency 2007), where it was stated that at least 11,000 TWh bioenergy could be provided from field and forest residues.

Table 6 Energy contents, TWh, in harvestable residues for four different scenarios

Scenario	Gross production	I	II	III	IV
Global	18,200	12,100	9,100	6100,	3,000
EU-27	1,500	1,000	760	500	250
Sweden	22	15	11	7	4

From Johansson and Liljequist (2009)

FUTURE LAND USE

The progress towards food security has been threatened in recent years not only because of the increasing use of crops for biofuel production. Slowing productivity growth, falling investment in irrigation and agriculture worldwide, loss of genetic diversity, salination, land degradation, land use changes, water scarcity and population growth are some of these factors.

According to an MIT report (Xiao et al. 1998), the area of global potential croplands is about 33 million km^2 under contemporary climate. This represents 25% of the land area of the Earth and is an average of several studies. For the estimate, a cropland distribution model based on climate, soil and topography was used. The potential cropland is expected to grow between 1977 and 2100 by between 7 and 12% depending on different climate change predictions. Among 12 economic regions studied, the countries of the Former Soviet Union and the Other OECD Countries have the largest increases in potential croplands, while developing countries have little increases.

In another report from the Potsdam Institute (Krause et al. 2009), the potential cropland is predicted to have increased by 9.4%, 3 million km^2, between 2005 and 2055. This projection of land use patterns is based on historical cropland conversion rates with the future water supply being a question mark. The largest increases of potential cropland are estimated to occur in Latin America and in Africa whereas decreases are expected for Europe and North America.

The estimates of the theoretical potential for global cropland areas have been based on soil, climate, and topography. However, it must be noted that the productivity of a large proportion of these lands will be limited due to poor soil fertility, soil depth and access to water. In reality, actual cropland areas are shrinking in recent times as a result of soil degradation, urbanization, desertification and global warming. In future, increased crop production in developing countries will have to come largely from intensification: higher yields, increased multiple cropping and shorter fallow periods.

In a recent report (Thenkabail et al. 2010), the actual global cropland area is estimated amongst different studies to range between 14.7 and 15.3 million km^2 in agreement with FAO (2002) statistics. However, significant uncertainties exist in determining the irrigated areas which, globally, consume nearly 80% of all human water use. The

estimates are that between 2.8 and 4 million km^2 are irrigated. In the report more efficient use of water is recommended as a means of ensuring global food security in the 21st century, when land and water become more limiting factors as populations and economies grow.

In the last 40 years, global crop production has more than doubled, although actual cropland area has increased by only 12% (Foley et al. 2007). As a result, the cropland per person fell by 40%, from 0.43 ha to only 0.26 ha. It was concluded, that in Sub-Saharan Africa, the positive effect of high investments in early intensification is strongest, referred to the relative and absolute area of conservable forest, due to the highest absolute rates of yield increase. If natural forest conservation in Africa gains priority in international discussions on mitigating climate change, yields would have to more than double until 2055.

There are thus many different boundary conditions against increasing the actual global crop land from present values. Whatever the future cropland will be, it is interesting to note that the current agricultural production has a potential to feed more than the present global population (Johansson and Liljequist 2009; Johansson et al. 2010). More efficient use of the primary crops, avoidance of some of the 20% storage losses and less of concentrated crop feed for livestock production can contribute to an increased food output.

In a European perspective, the European Biomass Association (AEBIOM) has assumed that 0.16 ha arable land per capita is sufficient (AEBIOM 2007). This figure is considerably smaller than the Fig. 0.26 given in (Foley et al. 2007). One reason for this discrepancy may be that the traditional import of protein feedstock from abroad is not included in the AEBIOM figure. Since according to AEBIOM, agricultural land in EU-27 is about 108 million ha, there should be enough food for EU's 500 million inhabitants and in addition a surplus of land for bioenergy crops. This means that more than 30 million ha of agricultural land would be available for energy production. This availability comes mainly from land that was previously used to grow crops for export, and from set-aside land.

According to a study by the European Environmental Agency (AEBIOM 2007), the potential of biomass is 188 Mtoe for the EU-27 by 2010 and 236 Mtoe by 2020 (1 Mtoe = 1 million tonne oil equivalent). Translated to energy units, the EU-27 bioenergy potential is 2,200 TWh by 2010 and 2,700 TWh by 2020. These figures are between three and four times the 2005 figures, so according to these estimates, bioenergy could provide a substantial portion of the EU 2020 goals, 20% renewables and 10% motor biofuels. However, the estimates are very far from the current European situation where the indigenous European agricultural production does not even suffice for food production (Johansson and Liljequist 2009; Johansson et al. 2010).

CONCLUSIONS AND OUTLOOK

There are many different opinions on how much bioenergy that could be provided from agriculture. The optimists are of the opinion that in spite of the fact that one billion people are chronically undernourished there is really no lack of food and that in addition substantial amounts of biofuel could also be obtained from agriculture. They argue that some of the current problems are due to the large amounts of food being wasted due to inefficient handling and poorly developed trade of agricultural products. Furthermore, agricultural land is badly utilized especially in developing countries, and plenty of land remains which could be cultivated, for example in the previous Soviet Union.

The pessimists reason that crops will be needed primarily for human food and animal fodder so that biofuel cannot be an important non-fossil energy alternative since. They contend that the expansion potential for global agriculture is limited by availability of land, water and energy. A future decrease in supply of fossil energy and ongoing land degradation will cause difficulties for increased production from agriculture.

Nearly all of the present crop production will be needed for feeding people and cattle. The biofuel from crops represents presently only about 1% of the liquid-fuel consumption. If instead 10% of the oil were to be substituted, about half of the crops used for food would be needed. This is clearly impossible since it is hard to see any drastic increase of crop production. During the years 2004–2007, annual crop production was roughly constant. Any potential increase of crop availability should be reserved for the anticipated increase of the global population by about 50% during the next 50 years. With a growing global population, in the competition between food and fuel, food production must take priority.

Increases in food production must come to the largest extent from a more efficient use of actual crops and intensified farming since a large increase of crop land cannot be expected. Intensified farming should be planned so that excessive leakage of greenhouse gases and nitrogen and phosphorous is avoided and preservation of the humus layer is secured. Intensive farming requires an ample supply of water, and energy for machinery, fertilizers and transportation.

The biggest potential for new farmland is to be found in Africa and South America. On the other hand farmland will be lost due to erosion, salination, cities and roads so the net increase may be marginal.

The production of ethanol and other automotive fuels from primary crops is thus questionable for several reasons. However, there is a great potential to obtain bioenergy from agricultural residues, forestry and waste. Estimates have shown that some additional 10% of the global energy supply can come from these biomasses. Obvious uses are for production of heat and electricity. Other uses are conversion of the residues to second generation biofuels for the transport sector especially for heavy transports on land, sea and air. However, it will take some years to develop technologies needed to establish processes that can be used on an industrial scale to utilize the cellulose of the residues for biofuel production.

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REFERENCES

AEBIOM Newsletter. 2007. http://www.google.com/search?sourceid=navclient&ie=UTF-8&rlz=1T4SUNA_enSE299SE300&q=AEBIOM++0%2e16.

Aranda, D. 2007. On Brazilian biofuel. Private communication.

Bringezu, S., H. Schütz, M. O′Brien, L. Kauppi, and R.W. Howarth. 2009. Towards sustainable production and use of resources: assessing biofuels. UNEP report. http://www.unep.fr/scp/rpanel/pdf/Assessing_Biofuels_Full_Report.pdf.

Crutzen, P.J., et al. 2007. N_2O release from agro-bio-fuel production negates global warming reduction by replacing fossil fuels. *Atmospheric Chemistry and Physics Discussions* 7: 11191–11205.

FAO. 2002. World agriculture towards 2015/30. Summary report. Rome: FAO. ISBN: 9251047618.

Foley, J.A., C. Monfreda, N. Ramankutty, and D. Zaks. 2007. Our share of the planetary pie. *Proceedings of the National Academy of Sciences of the United States of America* 104(31): 12585–12586. http://test-globalchange.mit.edu/files/document/MITJPSPGC_Rpt18.pdf.

Fredga, K., K. Danell, H. Frank, D. Hedberg, and S. Kullander. 2008. Bioenergy—opportunities and constraints. http://www.kva.se/Documents/Vetenskap_samhallet/Energi/Utskottet/rapport_energi_bio_eng_2008.pdf.

Heinberg, R., and M. Bomford. 2009. The food and farming transition: toward a post-carbon food system. http://pc-ds.webvanta.com/files/PCI-food-and-farming-transition.pdf.

International Energy Agency. 2007. Potential contribution of bioenergy to the world's future energy demand. IEA Bioenergy, ExCo 2007:02. http://www.idahoforests.org/img/pdf/PotentialContribution.pdf.

Johansson, K., K. Liljequist. 2009. Can agriculture provide us with both food and fuel?—a survey of present agricultural production. http://www.tsl.uu.se/uhdsg/publications/agriculture.pdf.

Johansson, K., K. Liljequist, L. Ohlander, and K. Aleklett. 2010. Agriculture as provider of both food and fuel. *Ambio*. doi:10.1007/s13280-010-0017-4.

Krause, M., H. Lotze-Campen, and A. Popp. 2009. Spatially-explicit scenarios on global cropland expansion and available forest land in an integrating modeling framework. International Association of Agricultural Economists Conference, Beijing, China. http://ageconsearch.umn.edu/bitstream/51751/2/Krause_%20et_al_iaae_090630_final.pdf.

Kullander, S. 2009. Energy from biomass. *The European Physical Journal* 176: 115–125.

McLaughlin, S.J. 1999. Developing switchgrass as a bioenergy crop. In *Perspectives on new crops and new uses*, ed. J. Janick, et al., 282–299. Alexandria: ASHS Press.

Pfeiffer, D.A. 2004. Eating fossil fuels. http://www.fromthewilderness.com/free/ww3/100303_eating_oil.html.

Pimentel, D., and T.W. Patzek. 2005. Ethanol production using corn, switchgrass, and wood. Biodiesel production using soybean and sunflower. *Natural Resources Research* 14(1). doi:10.1007/s11053-005-4679-8.

Thenkabail, P.S., et al. 2010. A holistic view of global croplands and their water use for ensuring global food security in the 21st century through advanced remote sensing and non-remote sensing approaches. *Remote Sensing* 2(1): 211–261.

Ulgiati, S. 2001. A comprehensive and economic assessment of biofuels. *Critical Reviews in Plant Sciences* 20(1): 71–106.

Xiao, X., et al. 1998. Transient climate change and potential croplands of the world in the 21st century. Report 18, Joint Program on the Science and Policy of Global Change, MIT.

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