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Biomass and Energy Crops III

Fuelling the nine billion – a new challenge for biotechnology and agriculture

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Summary

Concerns over the sustainable future of mankind centre on population increase, food production and global warming. There are enormous uncertainties about food production for a projected nine billion people and whether a rightful desire to remove poverty, the scourge of disease and food insecurity will result in increased greenhouse gas (GHG) emissions. The level of future oil reserves remain uncertain and some countries wish to remove dependence on imported fossil fuel. By recycling carbon through biofuel, emissions could be reduced and dependence minimised.

Key words: Biofuel, crops, cellulosics, biotechnology

Introduction

A recent International Assessment of Agricultural Science and Technology for Development initiated by the World Bank and UNFAO (IAAASTD, 2008: http://www.agassessment.org) has identified the development argi-food-fuel supply chains are a pre-requisite to alleviating poverty. There are many controversial points raised by the IAASTD, particularly with regard to the use of biotechnolgies that are likely to enable agri-fuel supply chain transitions. These issues and an emergent 'cult of the amateur' in agriculture are reviewed by Trewavas (2008). The UN specified criteria for sustainable biofuel production in an earlier report (UN- Energy 2007). The UN- Energy organisation report cited nine caveats for a successful biofuels industry. They are described here and we believe that these can be achieved utilising high yielding and resource efficient agricultural production.

The UN- Energy caveats for sustainable biofuels.

1. Integrated bioenergy generation must alleviate poverty in the poorest nations.
2. Agro-industrial development of biofuels must occur locally for job creation.
3. Health benefits will become evident with national biofuel use because urban and domestic air quality will improve.
4. The structure of the agricultural industry must change to accommodate the development of integrated biorefineries.
5. Food security will be assured if new agronomic and biological technologies are employed to improve food yields, conserve land use and utilise non-food crop feedstocks for bioenergy production.
6. Government budgets of the poorest nations will be more able to invest in public services and food production if their bioenergy economy is secure.

7. Changes in trade, foreign exchange balances and energy security will be sustainable if second generation biofuel technologies are employed.
8. Biodiversity and natural resources can be conserved if integrated agricultural methods are utilised to produce bioenergy feedstocks.
9. Climate change mitigation will be an outcome of a successful bioenergy economy.

Critics have argued that biofuels will further increase human exploitation of fully-stretched natural resources, that they will increase, not reduce emissions and require greater energy input than energy gained (Haberl *et al.,* 2007; Pimentel & Patzek, 2005; Patzek, 2004). Many NGO's support these Malthusian attitudes (e.g. Greenpeace, 2008) from an ideological stance of "Nature Knows Best" (Dyson, 2008). Technological solutions to problems are opposed and emissions are to be reduced by constraining human activity (austere environmentalism). These critics regard low yielding organic agriculture as mankind's future because intensive methods supposedly reduce biodiversity and are unsustainable (Pimental *et al.,* 2005; Maeder *et al.,* 2002) despite contrary evidence from long term agricultural experiments (Rasmussen *et al.,*1998).

Farm crops occupy 10% of the earths surface and 20% is used for rough grazing (Goklany, 1998). Remaining suitable agricultural land is under tropical forest but clearing may increase emissions and reduce tropical biodiversity. The challenge to creative mankind is to grow more food, supply biofuel and conserve the environment on the same area of land. Low yielding agriculture is not obviously a way forward. Indeed, global land-use trends suggest that crop yield improvements are a means of conserving land use (Fig. 1). Fig. 1 shows how increased wheat yield has conserved land use, similar relationships for sugar cane and other existing energy crops have not been met to date (FAO, 2008). Somerville (2008) reports the relationship of land use and biofuel crops is often misrepresented, for example Brazilian sugar cane energy crop production has not been developed in forested regions and US land area in corn energy crop production has declined since 1990. This clearly demonstrates the value of high yielding crops in conserving land use. One area of intense concern is that of palm oil where the land required and crop yield has increased. However, to suggest the demand or increases in resource use are due to biofuel production is misleading because global export of palm oil has increased since the 1980s (Fig. 2). Increasingly, biodiesel is seen to be a future niche market and corn bioethanol has even been termed 'a bad experiment' by Venter (2008). This evidence should focus our attention on current second generation biofuel technologies and future third generation possibilities that are likely to be established over the next 20 year timescale.

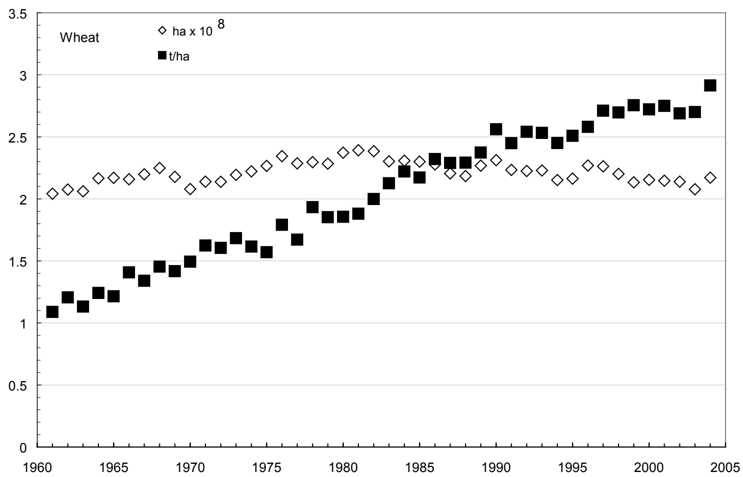

Fig 1. The relationship between global land area in cultivation for wheat and wheat grain yield (FAO, 2008).

Bioethanol is currently the major renewable energy product for transport but ethanol produces less energy/unit volume than petroleum and ethanol absorbs water. For these reasons, the

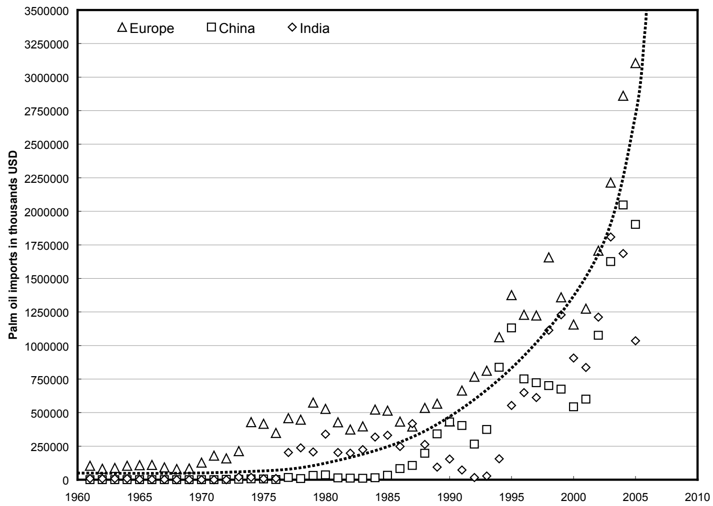

Fig 2. Palm oil import value in USD for Europe, China and India (FAO, 2008).

commonest use will probably be as ethanol/fossil fuel (gasohol) mixtures. Sugar cane is an efficient tropical/sub-tropical grass with N-fixing symbionts thus needing little fertiliser. Sugar cane bioethanol accounts for 40% of Brazilian transport fuel (Solomon *et al.,* 2007) and the residue from extraction is burnt to generate electricity. Improved sugar yields and biomass have emerged from breeding programmes and GM technology will likely take that further (Inman-Bamber *et al.,* 2005). Competition between food production and sugarcane has not yet been substantial; only 1% of Brazilian agricultural land is currently used. Increasing Brazilian ethanol production by 10 fold (replacing 10% of the world's petroleum), would displace just 3% world crop land (Goldemberg, 2007). Foreign investment in Brazilian bioethanol under carbon trading has been used to off-set CO_2 emissions under the Clean Development Mechanism. Brazilian ethanol prices are now comparable to current oil prices (Solomon *et al.,* 2007). The BRIC nations (Brazil, Russia, India and China) have a key role to play in many aspects of the future global energy system. Indeed, Sommerville (2008) estimates a five-fold increase in sugar cane energy crop area in Brazil could supply half the global gasoline requirement. The IAASTD and UN-Energy reports recognise significant change in agricultural infrastructure must accompany an innovative biomass to biofuel industry.

The US uses 14% of its current corn grain for bioethanol fermentation but this displaces only a few % of current transport fuel (Solomon *et al.,* 2007; Hill *et al.,* 2006). The principal reason for the recent competitiveness of the US corn grain bioethanol market has been the systematic banning of Methyl Tertiary-Butyl Ether (MTBE) as an oxygenating additive in gasoline. A very much smaller amount of biodiesel is derived from soy. Careful systems and life cycle analyses show that corn grain bioethanol and soy biodiesel generate more energy than consumed in production (Hill *et al.,* 2006: Farrell *et al.,* 2006) contradicting earlier contrary claims. Products made from starch-depleted grain residues (e.g. corn oil, protein-rich animal feed) help ensure overall energy gain. Second generation fuels from grain starch, like dimethyl furan, require no fermentation at all (Schmidt & Dauenhauer, 2007).

But if all the current US grain and soy crop were used, no more than 6–12% of US transport fuel would be produced (Hill *et al.,* 2006). And the effect of N fertiliser on soil N_2O emissions suggests there may be no saving of GHG emissions either (Crutzen *et al.,* 2007). Despite these caveats, government subsidies are increasing the amount of corn grain directed to refineries; corn prices are rising (Odling-Smee, 2007) as bioethanol prices decrease (Kruse *et al.,* 2007). In parallel, world food prices, underpinned by US corn, are rising reversing a beneficial downward trend in the last 50 years that benefited the poorest most. Food aid may also come under pressure if this trend continues. Despite political caveats, food aid does ameliorate potential starvation and enable agricultural production to resume (UN Food and Agriculture Organisation, 2006).

The imaginative alternative is to derive ethanol from plant waste. A detailed US survey uncovered a projected 1.3 billion tons waste but excluding all food grains (Perlack *et al.,* 2007; Somerville, 2006). Detailed assessment suggests that 1.3 billion dry tons of plant biomass waste will be available by 2030 sufficient to provide 30% of US transport fuel when fermented whilst continuing to meet food, animal feed and export demands. The aim is to offset oil imports, foster rural employment/ economies and agricultural growth. Refineries using cellulase are already operational and receiving subsidy (DOE, 2007). Forestry will supply sustainably nearly 400 million tons from timber treatment residues; the rest is from agriculture as annual/perennial crop residues, manures, process residues and from food consumption and energy crops. Second generation refineries are planned which will use different microbes to generate other useful chemicals. Research targets include cellulase reconstruction to improve activity, sustainable solubilisation of cellulose and isolation of yeasts able to tolerate much higher levels of ethanol than present.

Conversion of this material (cellulose and lignin) to ethanol could provide 30% of US transport fuels by 2030 and increase local employment. The net energy gained/net GHG emissions for cellulose bioethanol is estimated to be 100 fold better than grain bioethanol (Farrell *et al.,* 2006). Intense research interest is focussed on the termite gut. These insects eat wood and with an array of some 200 gut microbe species digest it into sugars in 24 hours, producing both hydrogen and methane as side products (DOE, 2007). Lignin interferes with cellulose digestion but levels have been advantageously reduced by GM (Chen & Dixon, 2007). Termite microbe investigation may also solve the lignin digestion problem and produce a useable product. Fast growing biofuel crops for cellulose-bioethanol such as switch grass and Miscanthus are being grown on mainly marginal land with established biodiversity advantages (Semere & Slater, 2007). Third generation biofuels will utilise the emergent bioethanol infrastructure to ferment all biomass sugars (pentoses and hexoses) and improve current enzyme and synthetic catalysis so that fatty acids can be converted to alkanes (Sommerville, 2008). Industrial catalysis is likely to be part of the third generation biofuel folio of technologies. Huber *et al.* (2005) have reported the catalytic conversion of carbohydrate into alkanes using hydrogen gas. These third generation approaches demonstrate the requirement for infrastructure changes in the energy sectors.

However the billion ton project requires, firstly, a continued annual yield increase of 1.7% up to 2050 (Perlack *et al.,* 2007). Projections based on past yield increases suggest this is feasible. Recent corn yield improvements owe much to insect- resistant GM crops. New GM corn plants with greater stability to disease and water stress are currently under trials to improve yield again. Asexual cereal reproduction is anticipated to be developed soon, enabling individual corn, wheat or rice clones to be tailored to individual farm microclimates, increasing yield further. Current trends in global crop yields show significant scope for yield improvement. Yield gaps are closing in response to the utilisation of agricultural technologies and agronomic improvement (Fig. 3). In Europe, the current EC Common Agricultural Policy mid-term review or health-check has suggested developing policies that will release agricultural land that is in set-aside (farm land not being utilised for production agriculture) for biofuel production. This will result in more feedstocks for biofuel programs but the emerging second and third generation biofuel technologies are currently considered investments with increased risk. Proven biotechnologies will help to reduce risk and potentially increase investment opportunities required by the crop biofuels industry.

Second is a continued advance of no-till agriculture that currently occupies 10% of US crop area. No-till eschews the plough, leaves crop residues on the soil and seeds by direct drill. While no-till and intensive yields are similar, GHG emissions including N_2O are one third of organic agriculture (Robertson *et al.,* 2000) and close to emission levels of undisturbed woodland. Introduced by Faulkner in 1943 who performed initial experiments on his own farm (Faulkner, 1943). The plough is the most damaging soil treatment consequently vegetation is left on the surface and after several years provides for a rich surface layer of humus in which crops readily root. Farm traction fuel is reduced by half (Patzek, 2004). Run-off of N or pesticides into water courses is either greatly diminished or disappears altogether when min-till is utilising with

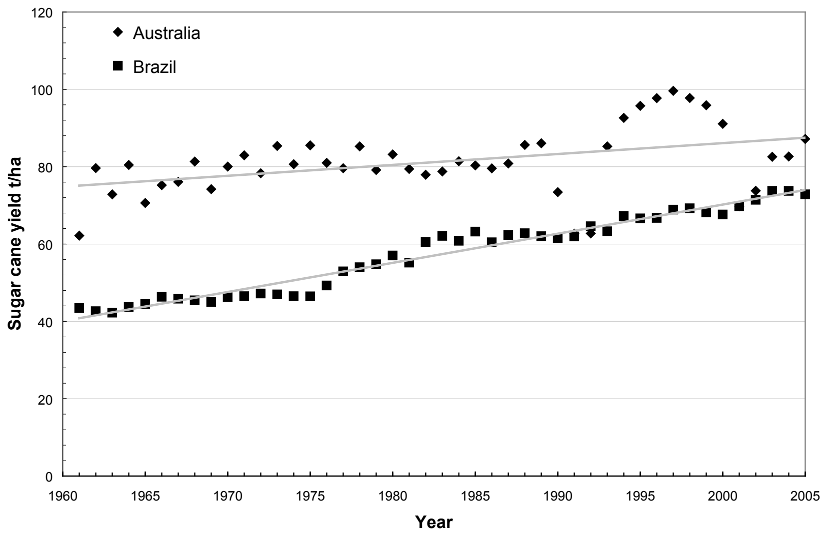

Fig 3. Improvement in Brazilian sugar cane yield 1961–2005 (FAO, 2008).

a rotational programme of sub-soiling if required. Greatly increased populations of pest predators, insect and earthworm biodiversity and nesting birds have been recorded. Very high populations of large earthworms and intact capillaries rapidly drain the soil when flooded and bring water up from great depths in drought. Ploughing the soil permits rapid oxygen penetration; bacterial oxidation of organic material causes an order of magnitude increase in carbon dioxide and methane release. No-till mimics the seasonal changes in meadow and prairie (references to the above summarised in Trewavas, 2004). Herbicide tolerant GM crops have greatly accelerated use of no-till in the USA. Although, historical consideration of soil loss and the application of the soil loss equation in extension programmes have also had an impact on the uptake of min-till recent changes in it's popularity have been enabled by herbicide resistant crops.

No-till puts $½^{-1}$ ton of carbon/acre/year cumulatively into the soil (Fawcett, 2001) and sees increases in many beneficial insects and nesting birds (Robertson *et al.,* 2000). GM herbicide resistant crops have enabled the huge advance of US no-till. Although all degrained shoot residues are left on the soil eliminating erosion, the billion ton project asks for research to optimise the actual amount needed. Successful no-till may only require leaving crop roots undisturbed (Gale & Cambardella, 2000). A single cereal plant can grow 300 miles of root in one season (Torrey & Clarkson, 1975).

Short rotation coppicing of willow can provide biomass for energy generation. Bertilsson, using detailed life cycle analysis showed that farms with more than 10% of area in willow, produced more energy than the farm used (Bertilsson, 1992). Willow provides 4× the energy yield ha^{-1} of crops like rape or sunflower and if used for cellulose-bioethanol could supply all UK transport fuel using just 25% of arable land (Eyre *et al.,* 2002). The half million ha of UK set- aside farmland could be used for willow. Breeding programmes and biotechnology are improving willow yield. Willow plantations are like very wide hedgerows, they act as refuges for large and small mammals including deer, numerous species of nesting birds and the edges act as reservoirs of predatory beetles (Semere & Slater, 2007). GHG emissions will be similar to natural woodland. Plantations may increase farmland habitat diversity regarded as the key to maintaining biodiversity, rather than farming type (Bengtsson *et al.,* 2005). Perennial crops have the potential for significant early season growth (Sommerville, 2008) and they prevent soil erosion on susceptible soils when root systems are well established. For these reasons, perennial grasses such as *Miscanthus* and switchgrass and short rotation coppice, such as willow are likely to remain an important part of the biofuel infrastructure.

The EU target is to generate bioethanol (wheat, sugar beet) and biodiesel rape, sunflower) sufficient to displace 5.75% fossil fuels by 2010 (European Commission, 2007), however, there is doubt whether this will be achieved. But more energy is gained than consumed in European production of these biofuels and emissions are reduced (UK Parliament, 2005). However a 10% fossil fuel replacement using food crops alone (EU aspiration for 2020) would occupy nearly 40% of EU crops with knock-on effects in EU food security (Righelato & Spracklen, 2007) if second generation technologies are not enabled. EU estimates suggest 150 million tons of biomass waste might be available for biofuel (European Commission, 2005). Some European cellulose-ethanol pilot-scale refineries are already operational. The EU is half the land area of the USA and with a similar proportion of forest. What characterises the difference between the US 1.3 billion tons and EU 150 million tons is the lack of aspiration in EU for continued yield increases and encouragement to use no-till. Some integrated farms in the UK use no-till or min-till (Leake, 2000) but development is hampered from lack of suitable herbicide-resistant GM crops freely available to UK farmers. There is no scientific reason for delaying the introduction of GM crops for European no-till (Dewar *et al.,* 2003).

EU biofuel development is mired in complex regulations, a stifling of innovation from precautionary attitudes and lack of political will to deal with reactionary activists who damage agricultural trials. Mankind is part of nature not separate from it. The only way that nine billion will live in harmony with nature is through scientific and technological development; not removing themselves from it altogether. By targeting only biomass, not grain, for transport fuel and increasing no-till agriculture, food production will increase, GHG emission substantially decline and transport continue sustainably conserving biodiversity as well. These solutions best fit the UN criteria (UN Energy, 2007). Yet again technology will defeat Malthusian attitudes to energy and food security.

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