The Sustainability of Brazilian Sugarcane Bioethanol
A Literature Review

Prepared for:
Energy Efficiency and Conservation Authority
(EECA)

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Andrew Barber[1], Glenys Pellow[1] and
Mariana de Aragao Pereira[2]

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[1] AgriLINK NZ
1 Hall Street
P.O. Box 8
Pukekohe
Auckland

Telephone: + 64 9 237 1273
Fax: + 64 9 237 1299
Email: andrew@agrilink.co.nz
Web: www.agrilink.co.nz

[2] Lincoln University, AERU, NZ and Embrapa, Brazil

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1.0 EXECUTIVE SUMMARY

This report, commissioned by The Energy Efficiency and Conservation Authority (EECA), reports on an international literature review conducted by the authors into the sustainability of Brazilian produced bioethanol using sugarcane as the feedstock.

While sustainability criteria are generally poorly defined this report has taken a broad definition to include greenhouse gas emissions and the biofuels total life cycle energy balance, production parameters (fertiliser, water, agrichemical use), biodiversity, air and water pollution, soil erosion, economic impacts, food versus fuel and social impacts on the community, jobs, wages, working conditions and worker rights. It has not taken into account the impacts of land use changes on the GHG emissions. Very little information is available in this area and what has been published is conflicting and based on limited data and a large number of assumptions.

Overall, our review is that bioethanol from Brazilian sugarcane is sustainable; although that assessment is qualified by a need for demonstrable improvements in a number of key areas, in particular working conditions and worker rights, and improved information on many of the impact categories.

Taking a full life cycle analysis approach from sugar production to delivery of the biofuel to the end customer, bioethanol has an extremely good energy ratio delivering 7.6 units of energy (9.3 prior to shipping) for every unit of input; this energy ratio is projected to improve to 9.9 by 2020 (11.6 prior to shipping; Macedo et al., 2008).

Fundamentally biofuels must deliver significant greenhouse gas reductions compared to the fossil based fuels that they are being substituted for, as it is on this belief that consumer demand for biofuels is soaring worldwide. Sugarcane based bioethanol remains one of the best performing commercially available biofuels. Even with transport of bioethanol from Brazil to New Zealand taken into consideration, the energy output of Brazilian ethanol is still better than fossil based petrol. Landed in NZ bioethanol compared to petrol, on an equal energy basis, will achieve greenhouse gas (GHG) emission reductions of 74% and this is projected to improve to 79% by 2020 (Table 1). This is significantly better than many other bioethanol products produced from grain and sugar beet that the IEA has shown to have GHG reductions as low as 20%.

Table 1 Petrol and Bioethanol Greenhouse Gas Emissions (kgCO_2eq)

	Consumer Energy	Combustion Emissions	Production and shipping	"Seed to Wheels" Total	"Seed to Wheels" GHG Emission Reduction
	GJ/m^3	per m^3	per m^3	per GJ	per GJ
Petrol	34.9	2,339	396	78.4	-
Bioethanol 2005/06	23.5	0	476	20.2	74%
Bioethanol 2020	23.5	0	385	16.4	79%

The GHG balance described in Table 1 does not take into account the impacts of land use changes. Very little research was found in this area and what is available is conflicting and based on limited data and a large number of assumptions. Depending on results from future research this could have a major impact on all biofuels, not just sugarcane.

Brazil is the world's largest producer and exporter of sugar, and the industry is the fastest growing agribusiness in the country. In 2006 production had increased to 455 million tonnes harvested from 6.2 million hectares (FAO, 2006). Most of the production and expansion is occurring in the central-southern region, particularly around São Paulo State where yields are higher due to better growing conditions and logistics. Apart from deforestation reasons, most of the Amazon is not suitable for agricultural reasons for the growing of sugarcane. While direct expansion into the Amazon forest and cerrado (savannas) is extremely unlikely there is the possibility of other crops and pastureland being shifted further north as they become displaced by the expanding sugarcane plantations. Legislative measures are in place to protect these sensitive areas, although weak enforcement may limit their effectiveness, along with international programmes to help in the recuperation of forests.

Direct impacts on biodiversity are considered to be limited as new sugarcane crops are being established on existing pasture land. Production systems are improving and environmental protections are being put in place. Some however point to studies of the cerrado that show large losses to pastureland and the long lasting effects of increased soil erosion and biodiversity loss.

Air pollution caused by burning sugarcane fields has caused significant problems in the past. Air quality has improved in many of the sugarcane producing regions due to a combination of legislation, improved economics and greater use of mechanical harvesting which does not require sugarcane burning prior to harvest.

The Brazilian government sees a clear path for the expansion of the bioethanol industry as a way to alleviate poverty and improve rural development, all-the-while reducing greenhouse gas emissions. Worldwide interest in the causes of recent significant increases in food prices and the food versus fuel debate has also enveloped the sugarcane bioethanol industry. There appears to be no direct link between food price increases, availability and the expansion of sugarcane production. Brazil could increase its sugarcane planted area by 40% without affecting the area of corn or soybeans or cutting down forests. Instead poverty is seen as the main cause of food insecurity in Brazil since the country produces a surplus of food, enough to meet all the national demand. In fact rather than causing a shortage the expansion of ethanol production in Brazil will generate income and new job opportunities, which, in turn will help alleviate poverty and food insecurity.

Poor working conditions remain a controversial subject, with strongly held contrasting views. Some highlight the extremely poor conditions, particularly for migrant cane cutters, while others point towards strengthened government regulations which have resulted in considerable improvements in working conditions in the last decade. This includes the outlawing of child labour and intensifying inspections on working conditions in the sugarcane sector. However despite disagreements over the extent of the problem all agree that further progress is still needed.

2.0 INTRODUCTION

The Energy Efficiency and Conservation Authority (EECA) have commissioned AgriLINK NZ to conduct an international literature review into the sustainability of Brazilian produced bioethanol using sugarcane as the feedstock. The production of biofuel from sugarcane is seen as one of the best currently available options because it has a significantly higher energy conversion ratio than most other biofuel feed stocks, up to 1:8. Even before considering the wide range of possible sustainability criteria many other feedstocks rule themselves out with very low energy ratios with some analyses even showing it to be negative, with more energy being used to produce the biofuels than is contained in the liquid product.

As a consequence of the New Zealand Government introducing a Biofuels Sales Obligation on companies importing petrol or diesel into New Zealand one of the likely biofuel sources will be Brazilian bioethanol. Biofuels have the potential to reduce greenhouse gas emissions and thereby assist in NZ's efforts to reduce the impacts of climate change. However there may be other environmental and social consequences from the global push to switch to biofuels.

One of the key problems is just how do you define sustainability? Purchas and Hutchinson (2008) in their report on biofuel sustainability defined it as the ability to produce biofuels to contribute to today's fuel needs without compromising the ability of productive land to meet current and future food and fuel needs. Issues considered under the sustainability banner include environmental (land use change, fertiliser use, biodiversity, energy intensity), social (labour conditions, land ownership) and economic (net benefit). Smeets et al. (2006) comprehensive analysis into the sustainability of Brazilian bioethanol used similar criteria including competition with food, waste management, soil erosion, water use, airborne emissions, and the use of genetically modified organisms (GMO's).

Setting these criteria is one thing however being able to collect sufficient information to assess them against is quite another. There is also the argument over whether a developing country should be required to meet the standards dictated to them by a developed country that probably could not have met, and may in fact still not meet, many of these standards in its own agricultural production systems. There is also concern that these criteria are simply being used as a trade barrier in disguise.

From the authors own experiences having worked in a wide range of NZ primary production industries the goal of achieving sustainable production is extremely time consuming as it needs to engage with all stakeholders and empower them to move along a path of continual improvement. Part of developing the right conditions for these changes to occur is the influence of the customer, often through sustainability programmes, but critically also recognising that there is a cost to implementing and monitoring these programmes. Simply refusing to purchase a product because it does not meet a particular standard today may relegate those farmers, processors and countries to remaining trapped in a subsistence existence.

2.1 Biofuels

Biofuel is a generic term for fuels that are derived from recently grown biological materials (e.g. plant material and animal fat). The biofuels most likely to be used in New Zealand in the short to medium term are bioethanol, most likely derived from whey (a by-product of the milk processing industry) or sugarcane based bioethanol, both of which will be used as a petrol substitute. A likely partial diesel substitute will be tallow-based biodiesel.

There is a large amount of research and development work focused on what is referred to as second generation biofuels, being cellulosic ethanol utilising feedstock's such as straw, wood waste and willow (Salix). However, processing technologies that would enable woody biomass to be used are probably only going to be available in the medium term (excluding demonstration scale plants) (Purchas and Hutchinson, 2008).

2.2 Biofuels and Sustainability

Concerns have been raised over the production impacts (environmental and social) and greenhouse gas reductions associated with biofuels. Research into the life cycle of different biofuel production methods has shown life cycle carbon emissions can sometimes be equivalent to, or even exceed, petroleum derived fuel. This is largely a result of farming practices involving forest clearance for biofuel crops or the use of large amounts of nitrogen fertiliser. Other sustainability concerns have had wide media coverage internationally and in New Zealand. These concerns relate to detrimental environmental and social impacts such as food versus fuel (a common objection to biofuel production is that it could divert agricultural production away from food crops leading to higher prices which would have a disproportionately large impact on the worlds' poor), loss of ecological diversity, soil degradation, workers' rights and land rights (Purchas and Hutchinson, 2008).

Defining what sustainability really means can be extremely complex and for the most part is subjective. There are a myriad of criteria that can be considered and many of these conflict with each other. For example while the introduction of mechanical harvesting of sugarcane frees labourers from this extremely hard, potentially hazardous and often poorly paid job it will likely result in large scale job losses, in an industry that nevertheless pays more than most other comparable agricultural jobs (albeit still potentially below the poverty line). In parts of Brazil the government specifically aims at reducing the rate of mechanisation to avoid unemployment and consequently poverty.

Life Cycle Assessment (LCA) is often used to examine a range of sustainability criteria but ultimately if a single score is to be produced the environmental criteria by which a product or service is being judged must be normalised and weighted to the different impact categories based on their perceived importance or relevance. How much importance should be assigned to greenhouse gas emissions, compared to energy use, compared to eutrophication or human health; all of which are subjective and will vary by location and time.

The report by Purchas and Hutchinson (2008) provides an excellent NZ based review of biofuel sustainability assessment criteria and the many associated labelling schemes.

3.0 GREENHOUSE GAS EMISSIONS AND ENERGY BALANCE

To have any hope of being sustainable a biofuel must have lower energy inputs than the energy it delivers and it must have lower greenhouse gas (GHG) emissions than the fossil fuel it is replacing. Sugarcane based bioethanol typically has the best energy ratio of all current biofuels at 1:8 and greenhouse gas emission reduction potentials of 75% to 90%.

3.1 Energy Balance

Macedo and co-workers have conducted the most extensive energy and greenhouse gas emission analysis of Brazilian bioethanol. Beginning in 1985 they determined the energy advantages of sugarcane based bioethanol (Macedo, et al., 1985) and by 1992 (Macedo, 1992) they had shown the first GHG emission advantages compared to fossil fuels.

The most recent study estimated the energy ratio and GHG emissions in the production and use of ethanol from sugarcane in Brazil for 2005/2006 (Macedo et al., 2008). The research applied a "seed to factory" approach determining the sugarcane production (including the emissions from production inputs, trash burning and fertiliser use) and processing up to the mill gate. A sample of 44 mills producing almost 100 million tonnes of sugar cane was used, with most of these mills being settled in the Centre-South of Brazil, where 90% of the national ethanol production occurs.

Based on Macedo et al. (2008) most recent analysis, the average energy output: input ratio is 9.3, which is projected to reach as high as 11.6 by 2020. This is an improvement on Macedo, et al.'s previous 2004 study where they found an average energy ratio of 8.3. The improvements were attributed to an overall decrease in fossil energy input and producing an electricity surplus from the industrial processing phase. While production and transportation energy increased, due to the growth of mechanical harvesting and trash recovery, the energy used in processing sugarcane to ethanol decreased. The increase in the electricity surplus in the processing phase is one of the key factors in being able to achieve a 25% improvement in the energy ratio (11.6) by 2020.

A crucial aspect of the industrial bioethanol production process, that improves both economic viability and the overall energy balance, is the bagasse (the low moisture content sugarcane fibre residue) fed combined heat and power plants. These cogeneration plants supply enough electricity and steam for the process to be self-sufficient, and as efficiencies improve are increasingly selling excess renewable electricity to the national grid (Macedo, et al, 2004; Smeets et al., 2006).

When accounting for the shipping energy to transport the bioethanol from Brazil to NZ the energy ratio decreases from 9.3 to 7.6. Based on the carbon dioxide emissions per t-km described in the section below, heavy fuel oil having 2,997 gCO_2eq/L (MED, 2007a) and 40.7 MJ/L (MED, 2007b) the average shipping tanker energy use is 0.059

MJ/t-km. Consequently the energy cost of shipping is 549 MJ/m^3. Added to the energy to the factory gate of 2,530 MJ/m^3 (23.5/9.3) (Macedo et al., 2008) the total energy cost of Brazilian bioethanol landed in NZ is 3,079 MJ/m^3, of which shipping contributed 18% of the total production and transport energy. Consequently the energy output: input ratio then decreases from 9.3 to 7.6, this is still better than fossil based petrol at 5.2

Table 2 Petrol and Bioethanol Total Energy Use (GJ/m^3)

	Consumer energy	Production	Shipping	Total Energy	Energy ratio
Petrol	34.9	6.06	0.68	6.74	5.2
Bioethanol (sugarcane)	23.5	2.53	0.55	3.08	7.6

3.2 Greenhouse Gas Emissions

The environmental impact of biofuel production is a controversial issue. Compounding the problem for even the most quantitative sustainable measure of greenhouse gas reductions is the lack of a standardised measurement. According to "Inovação Unicamp" (2006), while some researchers calculate the GHG emissions based on the direct effect of producing and processing sugarcane for ethanol production, fewer still include the indirect effect it may cause, i.e. the replacement of forests and pastures by sugarcane.

Macedo et al., (2008) determined that for anhydrous ethanol the total GHG emissions were 436 kg CO_2 eq.m^{-3} (this does not account for land use changes). Compared to Macedo, et al.'s 2004 study the emissions have increased by 12% from an average of 389 kg CO_2 eq.m^{-3}. The difference is mainly attributed to refinements in the methodology used to calculate GHG emissions that now incorporate N_2O emissions from agriculture/industrial residues that are returned to the soil and CO_2 emissions from lime and urea that were previously not included.

Macedo et al.'s analysis included a 2020 scenario based on the likely evolutionary changes in the sugarcane/ethanol industry, particularly taking into account the banishment of the cane trash pre-burning, the use of more productive varieties of cane, more efficient processes of ethanol extraction as well as the use of surplus biomass for electricity generation. The results showed a 21% decrease of GHG emissions from 436 to 345 kg CO_2 eq.m^{-3} of anhydrous ethanol.

What stands out in all of Macedo's work is the level of detail and transparency of his reports. Unfortunately many other LCA studies only report the final aggregated results. Macedo's level of detail, progressive refinements in the raw data and methodology give us a high degree of confidence in the results.

A report by Oliveira et al., (2005) determined quite different energy and greenhouse gas emissions of Brazilian bioethanol. Their analysis determined that the energy output: input ratio was much lower at between 3.1 to 3.9. Smeets et al. (2006) compared the two studies and excluded Oliveira's results from their analysis as they were found to be incorrect. Having conducted our own comparison we agree that these results have been determined based on errors in the methodology. The key error was using Ortega et al.'s (2003) agricultural emergy[1] production figure (not energy) and converting this into litres of diesel. The result was an assumption that 600 litres of diesel per hectare is used in sugarcane production, an enormous overestimate. The conclusions that they then drew that ethanol as a substitute for petrol was neither sustainable nor an environmentally friendly option, must also be ignored as they are not based on correct data analysis. We have included reference to and an explanation of the errors in this report as it is sometimes quoted, particularly on blog (weblog) sites as evidence that bioethanol has a poor energy output: input ratio.

As stated above Macedo et al., (2008) study applied a "seed to factory" system boundary. Smeet et al., (2006) noted that reports of GHG emission reduction potentials above 80% most likely do not include transport of ethanol from Brazil. However they noted that Hamelinck (2004) had shown that transport of biofuels have marginal influence on the overall energy balance. While we were unable to locate the Hamelinck report our own analysis shows that transport to NZ (just 26% further than shipping to the Netherlands where Smeets destination was) while it does not substantially alter the picture it is a significant contribution given the low energy and GHG emissions to the factory gate.

The following analysis is expands Macedo et al., (2008) system boundary to be "seed to wheels", and is often referred to as "well-to-wheels". CE Delft (2006) determined that CO_2 emissions from crude oil tankers averaged 4.3 gCO_2/t-km (converted from 8 gCO_2/ton n.mile). Based on shipping from Brazil to NZ, a distance of 6,870 nautical miles (www.maritimechain.com) or 12,730 km and a bioethanol density of 735 kg/m^3 shipping contributes 40.2 $kgCO_2eq/m^3$. Added to the GHG emissions to the factory gate (436 $kgCO_2eq/m^3$) total GHG emissions of bioethanol landed in NZ is 475 $kgCO_2eq/m^3$, of which shipping contributes 8%.

As the energy density of bioethanol is lower than petrol at 23.5 GJ/m^3 (Macedo et al., 2008) compared to 34.9 GJ/m^3 (MED, 2007b) for petrol it is important to compare these two fuels on an energy rather than volume or litres basis. Using a life cycle assessment analysis to determine the GHG emissions of the two fuels landed in NZ, petrol emits 78.4 $kgCO_2eq$/GJ (Barber, 2008) while bioethanol emits 20.2 $kgCO_2eq$/GJ, or a 74% reduction. Prior to shipping bioethanol was achieving a 76% reduction, which is slightly lower than GHG emission reduction estimate of between 85 – 90% determined by the IEA (2004).

[1] Emergy includes solar energy and is called the solar emjoule, which is designated with the symbol "sej"

Table 3 Petrol and Bioethanol Greenhouse Gas Emissions (kgCO_2eq)

	Combustion Emissions	Production	Shipping	"Seed to Wheels"			
				Total		GHG Emission Reduction	
	per m^3	per m^3	per m^3	per m^3	per GJ	per m^3	per GJ
Petrol	2,339	346.2	49.8	2,735	78.4	-	-
Bioethanol 2005/06	0 †	436	40.2	475	20.2	83%	74%
Bioethanol 2020	0 †	345	40.2	385	16.4	86%	79%

† There are no net emissions to the atmosphere from the combustion of biofuels as the plants they are derived from have just recently sequestered the carbon from the atmosphere

As stated above fuels should be compared on an energy basis, rather than volume, but some say a true comparison (or functional unit) should be per distance travelled (e.g. kgCO_2eq/km). They point to studies that show the higher octane rating of ethanol makes the engines more efficient per unit of energy than petrol and that this should be taken into account. A number of studies have tested (or retested) the fuel economy impacts of low-level ethanol blends (cited in IEA, 2004 Ragazzi and Nelson, 1999; EPA, 2003; Novem/Ecofys, 2003. and Duncan, 2004). These studies have found a wide range of impacts, from slightly worse to substantially better energy efficiency than the same vehicles on straight petrol. Duncan (2004) cited Australian research that found fuel savings, on an energy basis, of about 1% in E10 fuel consumption trials. While an assumption could be made that performance is improved per unit of energy for ethanol blended fuels it is subject to too many assumptions, including vehicle size and type, maintenance, engine tuning, driving conditions etc. Even if these could be standardised for the purposes of comparison the choices made will impact on the results. For these reasons our analysis assumes no vehicle efficiency impact from blending, which is the same assumption made in the IEA (2004) report.

Another parameter analysed by Macedo and peers was the avoided emissions of ethanol and co-products use in substitution to fossil resources. The avoided emissions calculations depend on the blend of gasoline: ethanol considered. For ethanol-dedicated engines (E100), which use hydrous ethanol, the savings were 2,181 kgCO_2 eq/m^3 in 2005/2006 and 2,763 kgCO_2 eq/m^3 in 2020 scenario. The use of anhydrous ethanol, in blends of gasoline (E25), represented savings of 2,323 kgCO_2 eq/m^3 in 2005/06 and 2,930 kgCO_2 eq/m^3 in 2020. Macedo et al. (2008) also estimated the avoided emissions for flex-fuel vehicles (FFV) in 2020 and found 2,589 kgCO_2 eq/m^3 savings.

According to the US Department of Energy (cited in Marris, 2006), Brazil's total carbon dioxide emissions from fossil fuel are estimated in 92 million tonnes a year. This amount could be mitigated by 25.8 million tonnes per year if ethanol was used instead of fossil fuel, (as pointed out in Marris (2006), based on Macedo). The author argues that one tonne of cane processed as ethanol saves 220 kg of carbon dioxide when it replaces petroleum.

3.3 Accounting for Land Use Changes

Further research is needed into the impacts of land use changes on the GHG balance. Very little research was found in an area that is in its infancy and consequently is currently based on limited data and a large number of assumptions. The conversion of land from pasture to sugarcane could directly lead to a significant loss of soil carbon and potentially have a major impact on the GHG balance.

De Almeida et al. (2007) states that the expansion of sugarcane onto low producing pasture will have a positive soil carbon balance, by replacing the degraded pasture with the higher biomass of sugarcane. They state that more detailed analysis is needed to quantify these impacts.

A 2005 report by WWF for the International Energy Agency was commented on by Ho (2006):

> *"suggesting that [while] Brazil's bioethanol programme reduced transport emissions by 9 Mt/year, [but] 80% of the country's greenhouse gas emissions came from deforestation. A study found that a hectare of land in Brazil grows enough sugarcane to make ethanol to save 13 tCO_2/year. But if forests were allowed to regenerate on the same hectare of land, the trees would absorb 20 tCO_2/year."*

3.4 Conclusions

While the environmental impact of biofuel production is a controversial issue, it is clear that bioethanol produced from sugarcane has significantly lower energy inputs and greenhouse gas emissions than any other commercially produced bioethanol. More importantly Brazilian sugarcane based bioethanol landed in NZ reduces greenhouse gas emissions by at least 74% compared to the fossil based petrol it is substituting for and this is projected to improve to 79% by 2020.

The available research suggests that the impact of land use changes on soil carbon and the resulting GHG balance will be significantly affected by the alternative use of the land. However there has been very limited research conducted in this area for sugarcane or any other biofuel crop. Quantifying the impact of land use changes on soil carbon is an area of ongoing research across the world for a wide range of production systems.

4.0 SUGARCANE PRODUCTION

4.1 Land Use

Brazil is the world's largest producer and exporter of sugar (Mendonça, 2005), and the industry is the fastest growing agribusiness in the country – increasing sugarcane derivatives by 27% in 2005 (Mendonça, 2005). In 2006 production had increased to 455.3 million tonnes harvested from 6.15 million hectares (FAO, 2006).

Other crops grown in Brazil include soybeans, corn, rice, and pasture crops.

As demand for sugarcane increases pressure increases on suitable land for production. Currently sugar cane is mainly grown in two regions with the characteristics described in Table 4

Table 4 Brazilian Sugarcane Production

	North-East	Centre-South
2001 sugarcane production [1]	20 – 25%	75 – 80%
2003/04 sugarcane production [2]	16% of production	84% of production
Yields	Low [2]	High [2] 78 – 85 tonnes cane/ha [3]
Ethanol production 2001 [1]	15 – 20%	80 – 85%
Costs [2]	High	Low
Harvest period [2]	August - February	March/April – January

Sources:
1 World Agriculture Outlook Board, USDA in Bolling and Suarez, 2001
2 Knapp, 2003
3 Macedo, 2008

The Centre-South region, which is dominated by São Paulo, has both rich soils and a warm tropical climate resulting in high yields of sugarcane, whereas in the North-East centred on Pernambuco and Alagoas states, soils are poorer and cost of production is higher. The North-East terrain is hillier than the Central-South so mechanisation is more limited. Bolling and Suarez (2001) reported that sugarcane is economically important to the North-East region, so central government allocates the total US minimum price sugar import quota to this area and provide them a small production subsidy. However, Knapp (2003) reports that the allocated subsidy (R$5.07/mt sugarcane) has not been paid in recent years. This must make the economic sustainability of sugarcane in the region questionable with their higher production costs.

The sugarcane industry is complex and controlled by several large producers, often now with foreign interests, especially French companies. There are over 300 mills and distilleries growing over half their sugarcane requirements and buy the remainder of the cane from over 16,000 planters (de Hollanda, Poole, undated). In Pernambuco state the number of mills has almost halved in the past 20 years, but the planted area supplying the remaining mills has remained the same. It is similar in the region of Riberão Preto, where just 8 families own all the land area.

Grunwald (2008) reports that while Brazil has strict environmental laws there is very little enforcement; this was also commented on by Smeets et al. (2006). The Regional Governor in the Province of Mato Grosso says *"There is no money for enforcement, so people do what they want"*.

4.2 Expansion

In Brazil the expansion of sugarcane is limited by the quality of the soil, precipitation patterns and logistics. The areas for the greatest future expansion need to combine these three conditions. Among the areas that stand out in the short term are Triângulo Mineiro (Minas Gerais State), northwest of São Paulo State, Mato Grosso do Sul State, Goiás State and the north of Espírito Santo State. Apart from deforestation concerns most of the Amazon is not suitable for agronomic reasons for the growing of sugarcane (Goldemberg et al., 2008).

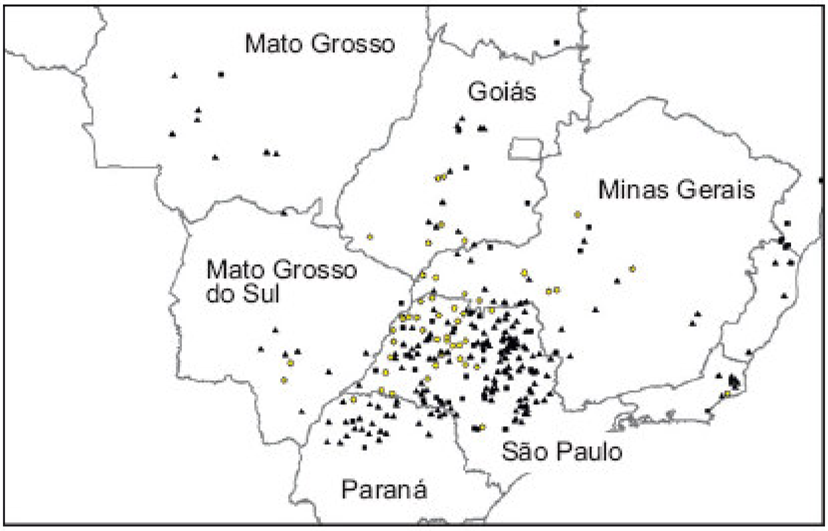

Figure 1 Location of new mills as expected in the expansion plan (December 2005)
Note: the dark triangles represent existing mills and the light circles the planned new mills. Source: Leal (2007), cited in Goldemberg et al., 2008.

While there is unlikely to be a direct problem with sugarcane expansion, indirectly it could place pressure on the expansion of existing crops and cattle production in sensitive areas. There is protection through Brazilian environmental legislation for a reserve of 80% of rural properties in the Amazon region, 35% in the Amazonian Cerrado (savannas) and 20% for the rest of the country, including São Paulo State (Goldemberg et al., 2008). Smeets et al. (2006) concluded that in many regions law enforcement is generally weak.

Goldemberg also highlights that a special program funded by World Bank/Global Environment Facility (GEF), launched in 2005, on recuperation of the 10,000km^2 of riparian forests. To put this in perspective this project is equal to 17% of the area (in 2006) covered in sugarcane plantations.

Being a tropical plant, sugarcane needs dry conditions during harvest, which limits where it can be successfully grown. Traditionally sugarcane production has been concentrated in the North-East and Centre-South regions but recently has expanded to the north of the state of Rio de Janeiro, to Minas Gerais, Espirito Santo, north of Paraná and states of Midwest (Mendonça, 2005). Figure 2 shows the production area in relation to the Amazon, while Figure 3 shows the enormous potential for agricultural expansion in Brazil, more than almost any other country in the world.

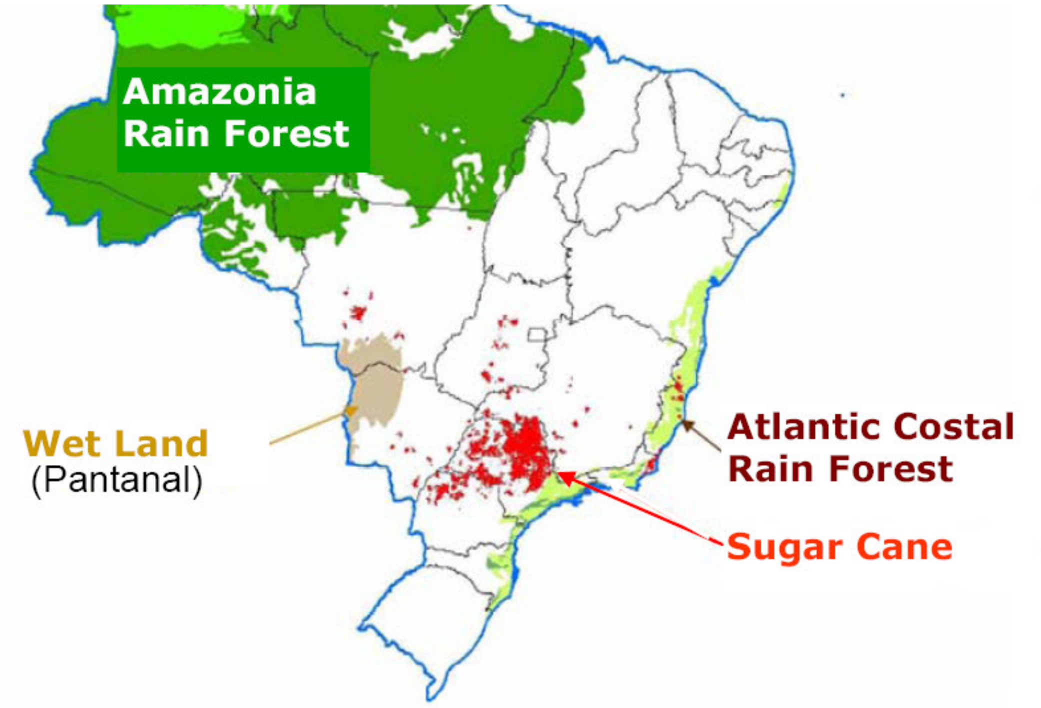

Figure 2 Location of the sugarcane plantations and Amazonia Rain Forest
Source: Guerreiro (2006)

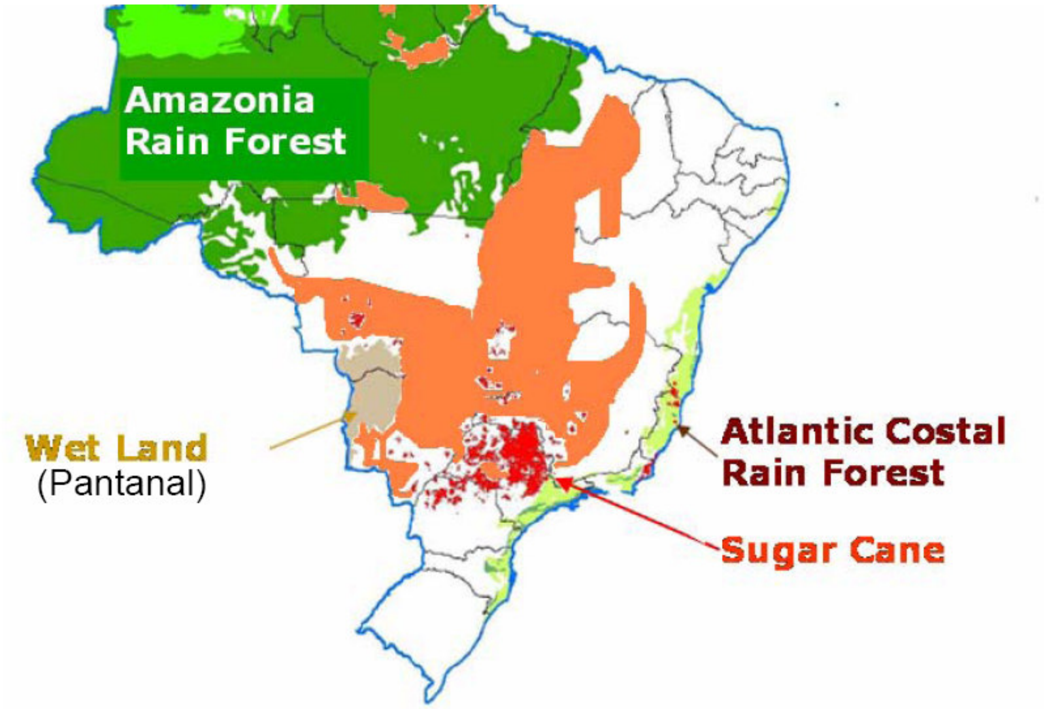

Figure 3 Potential for Agricultural Expansion in Brazil
Source: Guerreiro (2006)

In the state of Goiás the local government in the town of Rio Verde have imposed a limit on sugarcane expansion to 10% of the municipality's farmland i.e. 50,000 ha or 8 times current planting area. Sugarcane can not be planted within 50m of water sources, and the chaff not burnt within 20km of urban areas, environmentally protected areas, or near power lines or highways. The limit was demanded by agribusiness leaders and unanimously approved by the municipal Council. They are concerned that sugarcane as a monoculture is a *"green tsunami that is breaking the agribusiness productive chain, causing social tragedies and environmental problems if not controlled*". Rio Verde has enjoyed 30% economic growth since 2001 with a diversified agricultural industry and they do not want to see this threatened by the "*euphoria for ethanol*". Their city does not have a poverty issue and they are concerned expansion threatens to decapitalise farmers due to low commodity prices, together with an unfavourable exchange rate making farmers vulnerable to offers from sugarcane or ethanol producers to rent or buy their land. The Goiás syndicate of alcohol manufacturers, who charge that the law is unconstitutional because it violates the private property rights and infringes on national jurisdiction, is challenging the law in court. It will take several years to sort out (Osava, 2007).

One of the hindrances to expansion of production areas is the cost of processing plants and transportation of products to markets. There has been some migration of family owned sugar/alcohol groups moving from the North-East to the Centre-South region onto new lands and to take advantage of the sugar mills' better logistical systems and improved efficiencies compared to some of those in the North-East (Knapp, 2003).

Table 5 describes the projected increase in production out to 2012/13.

Table 5 Current and Estimated 2012/13 Production

	Production in 2006	Estimated Production 2012/13
Sugarcane processed (million tonnes)	386 (425 ton [1]) 415 (457 ton [2])	621 (685 ton)
Number of mills	310	387
Production area (million ha)	6.2 [2]	6.4
Sugar produced (million tonnes)	27 (30 ton)	
Ethanol produced (million m^3)	17	35.7

Sources:
1 Macedo, 2007
2 Rideg & Smith, 2007

Expansion is being driven by a number of factors including:

1. The Governments' proposal to negotiate access to markets within the WTO – World Trade Organisation. Their aim is to generate commercial advantages to the agricultural sector based on increasing exports.

2. Increased global demand, so consequently returns, for fuels suitable for powering vehicles, generating electricity and producing food.

As the sugarcane area increases it will push soybeans, rice, corn, and pasture into the more marginal areas and towards and onto the forest areas. In a Time Magazine article "Brazil's Counterattack on Biofuels" (28 April 2008) Downie (2008) reports:

Brazilian officials deny "that the thirst for ethanol is causing deforestation in the Amazon, as farmers clear trees to plant crops. Because sugarcane is grown in the more fertile center of the country, they point out, no forest is cleared"

However, environmentalists counter this with the fact that cattle land south of the Amazon has been sold to sugar growers and replaced with cheaper land on the edge of the forest. The tragedy with this chain of events is deforestation accounts for 20% of all current carbon emissions. These forests store carbon and their removal is contrary to the goal of a clean fuel source that will reduce carbon emissions. In Time magazine Grunwald (2008) writes:

"unless the world can eliminate emissions from all other sources – cars, power plants, factories, even flatulent cows – it needs to reduce deforestation or risk an environmental catastrophe. That means limiting the expansion of agriculture, a daunting task as the world's population keeps expanding. And saving forests is probably an impossibility as long as vast expanses of cropland are used to grow modest amounts of fuel. The biofuels boom, in short, is one that could haunt the planet for generations – and it's only getting started."

Time magazine reports some experts as saying:

"With proper management Brazil can ensure its sugarcane expansion occurs on readily available farm land. But that is a major "if". And Brazil's track record in land husbandry is hardly a stellar one."

4.3 Fertiliser Use

Studies of fertiliser use in sugarcane show variations in practices, as is normal for any crop grown on a range of soil types. In São Paulo region vinasse (a fluid rich in organic compounds formed during the distillation process of bioethanol production) is used for fertigation[2] of some sugarcane crops, which reduces the volume of other fertilisers required (Varghese, 2007).

4.4 Water Use

Sugarcane is mostly rain fed, although the use of irrigation is increasing. In the Northeast region where droughts are common, sugarcane will receive some irrigation as the crop can require up to 1,500 to 2,500mm of water evenly distributed over the growing season (Varghese, 2007). Brazil is in the fortunate position of having plentiful water supplies in most regions (Moreira, 2007).

De Oliveira et al. (2005) commented on the large quantity of water used to remove soil off canes prior to processing. No mention was made of differences in soil contamination and therefore water use rates for mechanically harvested versus manually harvested canes. Water requirements for cane washing are reducing with new technology allowing recycling of water and a dry cane washing system (Moreira, 2007).

In recent years mills and distilleries have improved water efficiency, with reuse and recirculation of water within the plant, so that in 2005 21 litres of water were used per litre of ethanol (Varghese, 2007).

4.5 Agrichemical Use

Like most conventionally grown crops, biofuel crops require agrichemicals to manage pests and control weeds. Total sugarcane agrichemical use varies with seasonal changes and locations. Usage is lower than in soybean and corn production. Herbicide use is about the same in sugarcane as in soybean and higher than in maize (Moreira, 2007).

4.6 Mechanical Harvesting

Mechanical harvesting can only occur on flat to rolling terrain with slopes of less than 12% (6.9º), and areas of greater than 500 ha (Pinto et al., 2001). This change to mechanical harvesting has positive and negative impacts. There is a reduction in the emissions of carbon dioxide emissions and reduced risk of forest fires, and more biomass can be left in the fields to provide protection to the soil from soil erosion (see soil erosion section for further details). On the negative side it will cause the loss of

[2] Fertigation is the application of fertiliser, applied through an irrigation system.

between 86,000 to 230,000 migrant workers jobs and sugarcane production will become uneconomic for many of the 11,000 small holders who can not use mechanical harvesters.

Smeets et al. (2006) comment that there are losses of 6 – 10 kg per tonne of reducible sugar within the first 72 hours of harvesting cane in the traditional system using burning. Mechanisation if coupled with improved logistic and transportation systems, allowing shorter delays between harvesting and processing, would improve sugar returns per tonne of cane harvested.

4.7 Conclusions

There is no direct link between the expansion of sugarcane production and deforestation in Brazil. The plantations are located in the North-East and Centre-South regions, while the vast Amazon is in Northern Brazil (see Figure 2). Expansion has replaced other crops particularly in the state of São Paulo. Climate and access to processing facilities limits the regions where sugarcane can expand into. Brazil is one of the few countries with large areas of available land that agriculture can expand into (Figure 3). The indirect link through sugarcane forcing more marginal cattle raising into the Amazon boarder region is fiercely debated and open to further research.

The increasing use of mechanical harvesting is bringing with it environmental benefits of less air pollution, reduced erosion and higher soil carbon levels. Harvesting jobs will be lost, although this could also be viewed positively given the hard physical nature of the work.

5.0 FLORA AND FAUNA PROTECTION

5.1 Forests

Rideg and Smith (2007) report there are 405 million hectares of Amazon forest or legal natural forest reserves and 90 million hectares of cerrado (savannah). Sugarcane production, they claim, could expand onto the cerrado and 100 million hectares of pastureland that is degraded could be planted.

Ho (2006) comments that sugarcane has destroyed or degraded 66% of the cerrado and encroached on the Atlantic forest and to a lesser extent the Amazon. If the expansion of sugarcane production area leads indirectly (or other crops directly) to further deforestation of the Amazon, scientists are concerned that the entire Amazon ecosystem could collapse and cause wide reaching impacts. It is estimated that 7 trillion tonnes of water in the area is recycled; rainfall is absorbed by the trees and returned to the atmosphere by evapotranspiration cooling the atmosphere immediately above the forests. If the water cycle breaks it is likely to affect agriculture across the region, maybe as far as the USA Corn Belt, and result in a drought in the Amazon Basin. This would affect global food supply and increase carbon emissions (Ho, 2006).

More detailed comments on forests can be found in the Section 4.2 Expansion.

5.2 Biodiversity

Direct impacts on biodiversity were considered to be limited in Smeets et al. (2006) as new sugarcane crops are being established on existing pasture land.

As production systems improve and environmental protections are put in place, like riparian plantings to protect water courses, these will also have a positive impact by increasing biodiversity in the long run (Goldemberg, et al., 2008).

However the Copernicus Institute report states that the protection of biodiversity in sensitive areas is considered weak (Ho, 2006) with the setting of a limit of no more than 5% conversion of forest to plantations within 5 years. Ho and Osava (2007) point out that the cerrado is a very diverse and unique forest savannah type ecosystem that is being degraded or destroyed by sugarcane production. Ho warns that expansion of the area of sugarcane production would significantly affect the world's natural biodiversity.

Hearn (2007) refers to a study of the cerrado that determined 50% of it has already been lost to pastureland and suffering from soil erosion, biodiversity loss, fragmentation and spread of non-native grass species.

5.3 Conclusions

There are starkly differing views on whether sugarcane production is leading to deforestation, although most seem to agree that any threat is indirect rather than directly being caused by farmers felling forests to make way for sugarcane plantations.

Similarly direct impacts on biodiversity are considered to be limited as new sugarcane crops are being established on existing pasture land. While some point to biodiversity increasing in the long run as farmers adopt more sustainable production practices, others see progress as being slow coupled with weak protection.

The indirect impacts are extremely difficult to quantify, but are a potential obstacle to sustainable sugarcane production.

6.0 ECOLOGICAL IMPACTS

6.1 Air Pollution

Burning of the cane prior to harvest is used to facilitate harvesting, fertilise the fields with ash and remove venomous animals and reptiles. The burning of cane and field residues "quimadas" causes substantial air pollution in the sugarcane producing regions as the smoke turns the sky grey and fills it with particles (Hofstrand, 2007). The pollution leads to increased respiratory problems for the population in these areas and often contaminates native forest fragments near production areas (De Oliveira et al., 2005). This burning also destroys a large number of micro-organisms in the soil (de Hollanda and Poole, (undated); Mendonça, 2005).

Pinto et al. (2001) discuss new environmental legislation prohibiting the burning of cane before harvesting in the state of São Paulo. Despite this in 2005, the National Institute of Space Research reported the area of burning had increased 48% compared to the previous season. Technicians of National Institute of Space Research want a moratorium on burning of sugarcane.

In Goiás the air pollution from burning of cane is more harmful because the atmosphere of the Cerrado at that time of the year is very dry which keeps the concentrated particulate material suspended longer (Osava, 2007).

Federal laws have been passed to end these practices, but whether they are enforced will be another matter. Intentions are to:

- mechanise the harvesting of 55% of cane production which is faster than by hand but will put many migrant workers out of work;
- permit burning where ground slope is 12% or more (too steep for machines), or small landholdings; and
- leave 40% biomass on the soil to reduce erosion and harvest the remainder to generate power for mill and distillery use and sell the remainder to the national grid.

Macedo et al. (2008) reports a protocol of intentions has been recently signed by UNICA in which its associates (individually and voluntarily), may accept to phase out trash burning practice by 2014 in mechanisable areas, and by 2017 in non-mechanisable areas. If adopted it should improve soil organic carbon levels and reduce soil erosion rates, thereby improving air and water quality. However it is noted that the implementation of government regulations restricting load capacity for cane transportation in the next few years may be a barrier.

6.2 Water Pollution

Almeida (2007) discusses water pollution of rivers from the dumping of vinasse (a by-product of ethanol distillation) during the 1970's. However by the 1980's Braunbeck and a team at the Sugarcane Technology Centre found vinasse was a useful fertiliser and developed a transportation system from distilleries to production fields.

Nowadays disposal of vinasse to water is prohibited and the liquid must be applied back onto the land as fertigation (Goldemberg, 2008)

Mendonça (2005) reports waste residues of sugarcane are dumped in rivers leading to deaths of fish, crustaceans and vegetation. The dumping also pollutes the riverbeds and underground aquifers.

Water used to remove soil contamination of sugarcane is often not treated sufficiently before it is released into rivers, contaminating them with biological oxygen demands of over 100mg/litre (De Oliveira, et al., 2005).

Gunkel et al. (2007) studied the water quality of the Ipojuca River in Northeast Brazil, including Pernambuco state. Sugarcane cultivation and processing resulted in contamination of the lower catchment. The reduced water quality comes from:

- Rainfall related wash-off and wash-out of sediment
- River water heating
- Nitrate leaching
- Acidification
- Increased turbidity (muddiness of water reducing clarity)
- Oxygen imbalance.

In São Paulo region, vinasse increases water acidity in the area and contributes to nutrient run-off into rivers. The problem with vinasse is it requires large amounts of oxygen to decompose it and it is acidic. If large volumes are dumped in rivers the dissolved oxygen levels in the water are reduced and aquatic life killed (Varghese, 2007). Vinasse can have a biological oxygen demand of 18,000 – 37,000 mg/l. (Pimentel and Patzek, 2007). Vinasse application has resulted in high concentrations of magnesium, aluminium, iron, manganese and chloride in groundwater (De Oliveira et al., 2005).

Varghese (2007) comments that in

> *"the early 1990's an IDRC publication warned that "São Paulo is facing a difficult environmental future unless careful management of its water resources and appropriate environmental policies are implemented." With the expansion of the biofuel industry, the situation may need urgent attention"*

The sugarcane industry could improve the water quality of rivers by developing environmentally friendly methods. Some suggestions have been no-till cultivation, waste-reduction technologies for processors and water recycling (Gunkel et al., 2007).

In contrast to these water degradation reports, the Brazilian Agricultural Research Corporation (Embrapa) rates sugarcane, both growing and processing, as having no impact on water quality (cited in Goldemberg, et al., 2008). They point to the recognised problems with vinasse as now having been overcome through prohibition in identified risk areas, and the development of adequate technologies.

6.3 Soil Erosion

Soil erosion of sugarcane fields can be high, up to 31 tonnes soil/ha/year in São Paulo (Martinelli, 2007; Pimental and Patzek, 2007) and a typical rate of 10.9 t/ha/year (12 ton/ha/year) where cane is burnt before cutting and 5.4 t/ha/year (6 ton/ha/year) for green mechanical harvesting (Maciel, 2006). These rates are significantly lower than can occur in other tropical crops. Although not specified, probably these rates would have been measured on fields where the biomass has been burnt leaving the soil unprotected and exposed to erosion from rainfall and wind energy.

Soil erosion rates are site specific, varying depending on field slope, crop stage when heavy rain occurs and amount of residue on the surface, so high soil erosion rates will not be happening on all sugarcane fields. A study by Macedo (2005) showed that retaining residues on the surface of fields reduced erosion rates to 6.5 t/ha/year.

If the mechanised harvesting system is adopted and up to 40% of biomass retained on the soil as residues this will protect the soil from some erosion and should reduce these rates. This has been shown as possible by Razafimbelo et al. (2006) where in São Paulo, mechanical harvesting and mulching surface residues were compared to the traditional burning system. Soil organic carbon concentrations (SOC) increased in the 6-year period by 15% at the 0 – 10cm depth (0.65 t C/ha/yr). Also macro fauna activity was stimulated by the mulching, especially earthworm activity as they buried residues leading to an enrichment in the fine fractions of carbon. An increase in water-soluble carbon was also measured. This will result in long-term storage of carbon in the soil with a slow turnover rate. The increase in SOC was comparable to that under no-tillage in a wet tropical area.

De Oliveira et al. (2005) reported Aloisi and colleagues' 1994 work that found soil erosion rates of 12.4 tonnes of soil per ha of planted sugarcane (12.4 Mg/ha). When compared with soil formation rates De Oliveira calculated the erosion rate to be 5.2 times larger than the soil formation rate. This means they are loosing soil at a rate faster than it can be replaced which will impact on yields and inputs required to sustain production.

6.4 Conclusions

Air pollution caused by burning sugarcane fields has caused significant problems, however through a combination of legislation and improved economics the area being burnt is decreasing, which should lead to improved human and environmental health.

Water pollution has been a problem in the past, particularly the discharge of vinasse, but the use of this by-product now as a soil additive in fertigation appears to have overcome this issue, certainly in the opinion of Embrapa, although some studies have shown this to be an on-going problem.

Soil erosion is a site specific problem, although it will be higher than occurs in pasture production particularly during the establishment phase. Soil erosion can be reduced; one method being employed at present is leaving more crop residues on the surface of fields. This problem is similar to what outdoor vegetable growers faced in the Franklin Region (Auckland) where through the Franklin Sustainability Project they were able to significantly reduce the rate of soil erosion through the implementation of a wide range of measures including increasing soil organic matter, wheel track ripping, and using silt traps.

7.0 ECONOMIC IMPACTS

7.1 Financial Constraints

Wilson (2007) reported the Brazilian government is advocating biofuel partnerships between developed and developing countries as a way to alleviate poverty, improve rural development, and reduce greenhouse gas emissions. In February 2007 Brazil and Jamaica signed agreements for technical assistance in the production of ethanol, as has Guyana. The USA and Brazil produced 70% of world's ethanol production in 2007 and are working together to create a global standard for ethanol that defines levels of impurities and solid residues. It was also stated that there is a need for the WTO to set rules and standards for biofuel trades as to their classification – agricultural, industrial or environmental goods.

De Hollanda and Poole (undated) note that in approximately 2002 many of the distilleries were close to the end of their life cycle. This is an opportunity for newer processing technology to be installed including co-generation plants for electricity generation. The constraint will be funding.

Rideg and Smith (2007) report currently Brazil does not have the financial capacity to substantially increase exports and address logistic bottlenecks. They are in talks with the USA.

7.2 Food versus Fuel and Land Prices

In recent months (early 2008), there has been worldwide attention on the soaring cost of food and the impact that this is having on the most venerable in developing countries. While sugarcane isn't a direct cause it is intrinsically linked, if at the very least by association and perceptions, but more tangibly by the impact the growth in production is having on other more staple food crops like soybeans and corn (Downie, 2008).

While food prices have been rising in the last two years, some commentators have laid part of the blame on biofuel production (Saucer, 2007; Evans, 2008). However, the increase in biofuel production amounts to only a small percentage of total demand which is not likely to produce such large price shifts (Saunders, et al., 2007). Other things affecting agricultural markets worldwide are: severe weather events in several countries; changes to Westernised diets in China, India, and elsewhere; and the enormous increase in oil prices, with flow-on effects to the price of diesel and agricultural petrochemicals. The exact impact of increased biofuel production on food prices is a current topic of research worldwide, but initial results suggest that it has a small effect relative to the observed increases in food prices.

The sugarcane harvest area in Brazil is around 5.2 million hectares (UNICA, 2006 cited in Martines-Filho et al., 2006). The increasing demand for ethanol production is encouraging the sugar/alcohol industry to expand to other regions, including the Centre-West, the main food and feedstuff production region. An immediate effect has been the increase on competition for land uses resulting in price increases. According to Martines-Filho et al. (2006), while land prices in São Paulo State were US$ 1,350/ha in June 2002, they reached US$ 3,070 by June 2005.

Although land prices have been increasing recently (by on average 115% in São Paulo between 2001 and 2006, Goldemberg et al., 2008) the Brazilian Agricultural Research Corporation (Embrapa) estimates that there is still 90 million hectares available for agriculture expansion (not including forests and pastures) as well as 30 million hectares of under-utilized pastures that could be converted to other agriculture activities (Hoffmann, 2006; Marris, 2006). The expansion is anticipated not only for sugarcane for ethanol production but also other crops, increasing agriculture production for both fuel and food/feed purposes in Brazil, mitigating potential risks of food security (Marris, 2006).

According to Rideg and Smith (2007) Brazil could increase its sugarcane planted area for ethanol by 40% without affecting the area of corn or soybeans or cutting down forests. They claim there are 90 million hectares of cerrado and 100 million hectares of pastureland that is degraded and could be planted. Also Brazil has other options too, with the USA agricultural area now almost fully planted, so any increase in corn production for ethanol will be at the expense of other crops – often soybeans, therefore Brazil could increase its soybean acreage and corn for products other than ethanol.

Hoffmann (2006) claims that poverty is the main cause of food insecurity in Brazil since the country produces a surplus of food, enough to meet all the national demand. The author also argues that the expansion of the ethanol production in Brazil will generate income and new job opportunities, which, in turn will help alleviate poverty and food insecurity. Hence, eventually the impact of food price increases will be less relevant in this context.

Sugarcane can be harvested for either sugar or for ethanol. Since 2000 the production split has been approximately 50:50 (Knapp, 2003). Brazil's Campanhia nacional do Abastecimento forecasts the 2007/08 harvest to be 496 million tonnes (547.2 million tons) up 15% on 2006/07, and is split between 41% sugar manufacturing; 13% specialty sugar products; and 46% ethanol production (Navarro; 2007). The decision on final product destination is determined generally on the financial return to the mill with mills able to easily switch between sugar and ethanol production, depending on the price of each commodity (Constance, 2006). Hence, if demand for and return on ethanol is greater than for food-grade sugar then there will be a swing away from sugar exports and increased availability to locals. However, since sugar accounts for only a small fraction of food consumption, this should only cause a very small direct impact.

An International Energy Agency study cited in Goldemberg et al. (2008) shows that sugarcane growth does not seem to have an impact on the food production area, since the area used for food crops has not decreased. Projections also need to take into account significant opportunities for productivity gains not just in sugarcane production and processing but all Brazilian agriculture. In São Paulo cattle density has increased from 1.3 head/ha in 2004 to 1.4 head/ha in 2005 (Lora et al., 2006, cited in cited in Goldemberg et al., 2008).

Wilson (2007) observes that if crop residues are used for energy generation (as they are in bioethanol production from sugarcane) rather than the crop itself there would be a reduction in conflict between crops for food or energy. This is becoming more realistic with technological advances in cellulosic technology, which includes:

- searches for new enzymes that degrade plant cellulose into sugar
- development of new strains of yeast, along with synergistically acting enzyme mixtures that convert all the sugars in cellulose into ethanol (Knauf, 2004)
- exploring ways to increase the production of higher value co-products (Wermer, 2006)
- introducing Zeachem technology to improve energy efficiency from 46% to 95% (Edye, 2004).

The research is advancing rapidly (Junginger, 2006; Jolly, 2006) and is expected to be economically viable within 5 years (Bullion, 2006).

7.4 Conclusions

Food versus fuel production has become a significant focal point of public interest over the past year. While there is limited information on the specific impacts from increased sugarcane production in Brazil it will not have the same impact as other more staple food crops like soybeans and corn will and are having.

For Brazilian agriculture food availability is closely linked to the level of poverty and if economic benefits flow through from higher sugarcane returns then increased production should have a positive rather than negative impact on food availability.

8.0 SOCIAL IMPACTS

The sugarcane industry is a major industry in Brazil creating an enormous amount of income, jobs, and both substantial foreign savings by avoiding oil imports and generating exports.

8.1 Number of jobs

The sugarcane harvest employed 1.2 million workers in 2005 (Parra, 2005). La Rovere (2004) and Macedo and Nogueira (2005) cited in de Almeida (2007) estimated the industry created 700,000 direct jobs and 200,000 indirect jobs and was one of the key reasons behind the government's support for the ethanol industry.

According to University of São Paulo professor Ariovaldo Umbelino, in the Brazilian countryside 87% of jobs are in small production units, 10% in medium sized units and just 2.5% in large units. As mechanisation of harvesting is adopted especially to reduce the area of cane burnt and associated health risks, seasonal employment will decrease by possibly 11% (Martines-Filho et al., 2006).

8.2 Wages

There is a shortage of semi-skilled workers in the sugarcane industry. Their wages have risen in recent years where they are earning wages substantially higher than those undertaking similar jobs in many cities. On average seasonal agricultural workers have earned slightly above the minimum wage levels, however there are yearly variations and it is unclear whether this rate is sufficiently high enough to avoid poverty (Smeets, et al. 2006).

In 2006 the wage rate for migrant cane harvesters in São Paulo was R$2.36/t (R$2.60/ton) of cut cane where harvesters are expected to cut between 10.9 and 13.6 tonnes per day (12 and 15 tons). The day rate in the 1980s was 5.4 t/day (6 tons/day), rising to 9.1 t/day (10 tons/day) in the 1990s. Day rates are set against mechanised cutting rates. Worse though, if a worker cannot meet these rates, that often means the worker is fired or placed on a list that circulates among factories preventing them from working next season (Mendonça, 2005).

There appears to be no fair measure of workers' daily cutting quantities for many workers. Mendonça (2005) in her report says:

> *"many denunciations point towards manipulation and fraud of these data by the Mills, who pay less than the workers have the right to earn. The Union of Rural Workers of Dobrada (São Paulo) for example, denounced cases in which workers received the equivalent of 10 cut tons per day, when the quantity was actually 19 tons."*

By contrast the Pernambuco mills do weigh the loads of cane and claim to treat their workers fairly. They will pay workers two minimum wages per month if they achieve

8.2 cut tonnes of sugarcane per day (9 cut tons), but the harvest period is only 3 to 4 months and not much work is available for the rest of the year.

Mechanising the harvesting of crops in many countries has meant loss of many manual jobs but an improvement in the quality of jobs being undertaken. It seems the opposite has happened with sugarcane, with sugarcane now required to be trimmed close to the ground to maximise sucrose concentration and the canes are required to be trimmed cleaner. To achieve this workers have to spend more time making their cuts (Mendonça, 2005).

Goldemberg et al. (2008) states that despite the low wages and these being linked to the quantity harvested the income of people working in sugarcane crops is higher than in most agricultural industries including coffee, citrus, rice banana and corn crops, but lower than in soybean crops. The workers in São Paulo receive, on average, wages that were 80% higher than those of workers holding other agricultural jobs.

In Smeets et al. (2006) review they highlighted that while wages were generally above average the main problems are related to cane cutters, which do most of the low-paid work related to ethanol production.

In contrast to Mendonça (2005) Smeets et al. (2006) review found that sugar mills keep more than 600 schools, 200 daycares units and 300 ambulatory care units. In a sample of 47 São Paulo based units showed that

> ''more than 90% provide health and dental care, transportation and collective life insurance, and over 80% provide meals and pharmaceutical care. More than 84% have profit sharing programs, accommodations and day care units''.

In terms of accessing progress wage levels can be used as a practical and easy to verify criterion and indicator. Smeets et al. (2006) determined that increasing by 50% the wages paid to sugarcane cutters ethanol production costs would increase by just 4%.

8.4 Working Conditions and Worker Rights

Some sugar mills are accused of exploitation of workers, using child labour and repressing rural workers. The producers wield substantial political power and are able to obtain resources through programs, incentives and opportunities offered by the government (Mendonça, 2005).

The majority of São Paulo sugarcane harvesting is undertaken by migrant workers from the North-East, and from the Valley of Jequinhonha in Minas Gerais. There are at least 40,000 migrant workers in the industry. Often they live far from their homes and support networks.

Mendonça is a journalist and director of Social Justice and Human Rights Network. She has documented many poor working conditions in the sugarcane industry, particularly for the cane cutters. Many migrant workers are transported from the North-East to São Paulo for a fee they can not afford, so they start working in debt.

Accommodation and food costs of R$400 per month leaves very little for savings. Often food and accommodation rates are higher for the sugarcane workers than the local population, giving them little chance to get out of this vicious cycle. Harvesting sugarcane is the toughest work available, and unfortunately for many the only employment they are able to secure despite its temporary nature (Mendonça, 2005).

The Migrants' Pastoral of São Paulo registered 13 deaths of sugarcane workers. There are also a number of indirect deaths from illnesses e.g. cancer provoked by the use of poisons and respiratory illnesses and allergies from sugarcane soot (Mendonça, 2005). Goldemberg et al. (2008) also found 19 worker deaths between 2004 and 2007, but noted that conditions were improving and that they were better than in other rural sectors.

Spinal column problems, tendonitis and loosening of digits result from the repetitive cutting movements. Birola spasms - spasms followed by dizziness, headaches and vomiting are provoked by the excessive loss of potassium. These illnesses often go untreated, as workers don't have the financial resources to purchase medicines. Mutilations and wounds are common, but companies rarely report work place accidents and with little control by government organisations, workers have very little assistance. Often sick and mutilated workers don't qualify as disabled, despite not being able to work; therefore they enter a downward spiral (Mendonça, 2005).

Mechanisation is expected to improve working conditions, although at the cost of many jobs. However mechanisation harvesters can only work on flat terrain, forcing the manual cutters to harvest the more difficult crops where terrain is not flat; crop quality is poor or planted irregularly. These factors will make achieving daily cut rates much more difficult (Mendonça, 2005).

Others also acknowledge the poor working conditions and that it remains a controversial subject (Smeets, et al., 2006; Goldemberg et al., 2008; de Almeida et al., 2008) but that strengthened government regulations has resulted in considerable improvements in working conditions in the last decade. Goldemberg et al. (2008) points to the Brazilian Government outlawing child labour, defining the minimum age of 18 years for hard jobs and intensifying inspections on working conditions in the sugarcane sector. Further progress is still needed (Smeets et al., 2006).

One of the big issues according to Smeets et al. (2006) is poor law enforcement. There are some working condition issues which need to be addressed, but it seems that there are laws in place to address them.

8.5 Conclusions

The Brazilian sugarcane industry is responsible for employing between 700,000 and 1.2 million people and so consequently is a major economic driver creating jobs, income, and substantial foreign savings and income. However behind these headline numbers most jobs are unskilled cane cutters that generally have poor working conditions and despite receiving above average wages these may be insufficient to avoid poverty.

There appears to be general agreement that working conditions, particularly for migrant cane cutters, can be poor and need to be improved; however there are starkly differing views on the extent of the problems. Legislation has been put in place to improve conditions, although as has been raised previously enforcement can be weak.

Most report that working conditions have improved in the last decade but that further progress is still needed.

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