Contents

Introduction
I. PRACTICAL OPTIONS IN AGRICULTURE TO MITIGATE GLOBAL WARMING
  1. General remarks
  2. Main agriculture practical actions
     2.1. Adoption of no-till management system
     2.2. Improve nutrient use (fertilizers)
     2.3. Improve management of liming
     2.4. Optimize mechanization and transport
  3. Reduction of GHG emission by biofuel production
     3.1. Lower bioethanol carbon footprint
     3.2. Lower biodiesel carbon footprint
  4. Use of idle lands for food agriculture

II. LIVESTOCK OPTIONS TO MITIGATE GLOBAL WARMING
  1. General remarks
  2. Main grazing land management and pasture improvement practical actions
     2.1. Enhance grazing intensity
     2.2. Increase productivity (including fertilization)
     2.3. Optimize nutrient management
     2.4. Introduce new species
     2.5. Improve feeding practices
     2.6. Adopt longer-term management changes and animal breeding
     2.7. Use specific agents and dietary additives
  3. Reduce emissions from cattle feedlot manure
4. Use of beef tallow for biodiesel production

III. FORESTRY OPTIONS TO MITIGATE GLOBAL WARMING

1. General remarks

2. Main forestry practical actions
   2.1. Maintain or increase forest area: reduce deforestation and degradation
   2.2. Maintain or increase forest area: afforestation/reforestation
   2.3. Increase stand- and landscape-level carbon density
   2.4. Increase off-site carbon stocks in wood products and enhance product and fuel substitution

3. Mitigation by the expansion of reforested areas

IV. AGRICULTURE/LIVESTOCK/FORESTRY CROSSCUTTING

1. Adoption of integrated crop/livestock system
2. Adoption of agroforestry system

Final considerations

References
Introduction

It is widely recognized that the Land Use, Land-Use Change and Forestry (LULUCF) is a key sector of Climate Change, being at the same time i) responsible for important amount of greenhouse gases (GHGs) released but also (ii) representing an important role and potential in climate change mitigation. The agricultural sector alone (i.e. Land Use) is responsible for about 14% of total global anthropogenic GHGs emissions and is expected to have high emission growth rates, driven mainly by population and income increases. Deforestation is responsible for an additional 17%, setting the total contribution of the LULUCF sector to nearly one third of the current total global emissions (IPCC, 2007).

Brazil is one of the top world greenhouse gas emitters and it is well known that a large majority of Brazil's GHG emissions, which contribute to global warming, come from burning linked to deforestation of the Amazon biome, and not from fossil fuels which are the main culprit in most countries. Brazil suffered and still regularly suffers pressure to curb destruction of the Amazon rainforest. The latest official Brazilian data on GHG emissions and sinks were published in 2004 in the report entitled “Brazil’s Initial National Communication to the United Nation Framework Convention on Climate Change” (Brazil, 2004). The second part of this report included the first GHG inventory but comprehended only the period from 1990 to 1994. This report showed that the sub-sector “Forest conversion” (known as the Land-Use Change and Forestry LUCF sector) from the bulk LULUCF Sector was the main contributor in 1994, representing 55% of the total GHG sources, which totalised 1728 Mt CO$_2$-eq (CO$_2$ equivalent), and nearly 82% of the sole emissions of CO$_2$. This last percentage is reduced to 75% when considering the net result, which includes a CO$_2$ sink of 251 Mt.

The agricultural sector is now facing a crossroads of issues linked with food security, rural livelihoods, environmental sustainability, bioenergy, climate change adaptation and mitigation, in a context of important and difficult negotiations for a future regime for LULUCF under the United Nation Framework Convention on Climate Change in a post-2012 international agreement.

According to the Climate Analysis Indicators Tool (CAIT) from the World Resources Institute (WRI, 2009), Brazil ranked 6$^{th}$ for the year 2005 with total GHG emissions of 1005 Mt CO$_2$-eq, including CH$_4$ and N$_2$O emissions, but excluding LUCF (deforestation). No recent data are provided for the LULUCF sector in Brazil. In the last 10 years LULUCF activities in Brazil undergone important changes, therefore in this
new context where the agricultural sector is more than ever central in the international agenda of negotiations, it is important to identify the actual share of GHG emissions and potential sinks.

Our understanding is that the main focus of the majority of the National Inventories is on GHG emissions. However, in Brazil we do include sinks in our net GHG emissions. The sinks are mainly due to carbon fixation in soils and phytomass resulting from advanced agricultural management practices, reforestation and land abandonment.

The Brazilian National Communication reported that in 1994, net anthropogenic greenhouse gas emissions were estimated at 1030 Tg CO$_2$, 13.2 Tg CH$_4$, and 0.55 Tg N$_2$O. It also reported other minor GHG emissions (CF$_4$, C$_2$F$_6$, SF$_6$, HFC-23 and HFC-134a) but these emissions corresponded to less than 0.7% of the total emissions in CO$_2$-eq, and thus will not be considered throughout this paper. It was also reported that between 1990 and 1994, total emissions of CO$_2$, CH$_4$ and N$_2$O increased by 5%, 6% and 12%, respectively. This net amount included a sink (only concerning CO$_2$ emissions) of 251 Mt CO$_2$ mainly due to Abandonment of Managed Lands (204 Mt CO$_2$-eq) and secondarily to Changes in Forest and Other Woody Biomass Stocks (47 Mt CO$_2$). Considering only sources, CO$_2$ emissions amounted to a total of 1280.8 Mt CO$_2$, and the corresponding total for all GHG is 1728 Mt CO$_2$-eq.

It appears that in 1994, CO$_2$ was responsible for 74% of the total amount in CO$_2$-eq, followed by CH$_4$ representing an additional 16%. Nitrous oxide emissions were the less important among these three gases representing circa 10% of the total. An analysis of the main contributors revealed that, as it was already largely reported and discussed by the civil society and scientists, deforestation was the first individual contributor, being alone responsible for more than half of the total Brazilian GHG emissions.

However, if sinks due to reforestation and land abandonment are also considered in the calculations, the net emissions for Forest and Grassland Conversion would be 742.4 Mt CO$_2$-eq, which corresponds to 48.8% of the total emissions. In this case, the relative contribution of Fossil Fuel Combustion, Enteric Fermentation and Agricultural Soil would be 15.8%, 13% and 9.8%, respectively, evidencing the present tendency to reduce emissions from deforestation in relation to the other sectors.

Enteric Fermentation was the third contributor in CO$_2$-eq, but it is also by far the first contributor for CH$_4$ emissions. Among the different components, the non-dairy
cattle is responsible for 82.2% of total enteric fermentation. The agricultural soil sub-sector includes different sources of nitrous oxide emissions, but one is dominant, namely “Grazing Animals”, which corresponds to direct manure deposition on field by animals. The grazing animals contribution is 46% of the sub-sector emissions, with non-dairy cattle accounting for 34% of emissions. Other direct N$_2$O emission for the Agricultural soils sub-sectors are attributed to various individual sources, e.g. synthetic fertilizer, animal manure produced off-field, biological fixation, crop residues, etc.

Cerri et al. (2009) report not only updated estimates of the GHG emissions for the Brazilian territory, but also calculations of the actual and estimated share of agriculture and livestock in Brazil. The authors show that the Agriculture sector increased in 21% and 24% the emissions of CH$_4$ and N$_2$O for the years 2000 and 2005, respectively. For CH$_4$, the main contributor for this increase was the sub-sector Enteric Fermentation, which was responsible for more than 93% of CH$_4$ released in both years. Therefore, it represents the most important source of CH$_4$ to the atmosphere. In terms of N$_2$O emissions, we found that the sub-sector Agricultural Soils represented more than 95% of N$_2$O emissions for the years 2000 and 2005. The Agricultural Soils sub-sector includes direct N$_2$O emissions sources such as grazing animals, synthetic fertilizer, animal manure produced off-field, biological fixation, crop residue etc, and also indirect N$_2$O emissions sources such as leaching, runoff, and atmospheric deposition. However, grazing animals is still the main contributor, accounting for about 40% of the sub-sector, similarly of what occurred in the 1990-1994 period.

Cerri et al. (2009) present the total emission in CO$_2$-eq and the evolution for the periods 2005-1990 and 2005-1994 for the Agriculture and Land Use Change and Forestry sectors. It was found that within the Agriculture sector, enteric fermentation and agricultural soils were the most important CO$_2$-eq sources. They were responsible on average for 53.3% and 41%, respectively, of the total emission, while the others sources accounted for the remaining 5.7% (i.e. these values represent the average for 2000 and 2005). Additionally, it could be noted that the emission in the 2005-1990 period was higher than in 2005-1994. These results are associated exclusively with the increase in the livestock population, which was higher between 2005 and 1990 than between 2005 and 1994.

The aim of this report is to present some management practices which not only reduce CO$_2$, N$_2$O and CH$_4$ emission, but also enhance atmospheric CO$_2$ fixation into vegetation and soil through Brazilian agriculture, livestock and forestry sectors.
I. PRACTICAL OPTIONS IN AGRICULTURE TO MITIGATE GLOBAL WARMING

1. General remarks

According to the IPCC (2007), opportunities for mitigating GHGs in agriculture fall into three broad categories, based on the underlying mechanism: i) Reducing emissions, ii) Enhancing removals and iii) Avoiding or displacing emissions.

Reducing emissions: Agriculture releases to the atmosphere significant amounts of CO$_2$, CH$_4$, or N$_2$O. The fluxes of these gases can be reduced by more efficient management of carbon and nitrogen flows in agricultural ecosystems. For example, practices that deliver added N more efficiently to crops often reduce N$_2$O emissions, as well as managing livestock to make most efficient use of feeds reduces CH$_4$ emission. The approaches that best reduce emissions depend on local conditions, and therefore, vary from region to region.

Enhancing removals: Agricultural ecosystems hold large carbon reserves, mostly in soil organic matter. Historically, these systems have lost more than 50 Pg C (IPCC, 2007), but some of this lost carbon can be recovered through improved management, thereby withdrawing atmospheric CO$_2$. Any practice that increases the photosynthetic input of carbon and/or slows the return of stored carbon to CO$_2$ via respiration, fire or erosion will increase carbon reserves, thereby ‘sequestering’ carbon or building carbon ‘sinks’. Many studies, worldwide, have now shown that significant amounts of soil carbon can be stored in this way, through a range of practices, suited to local conditions. Significant amounts of vegetative carbon can also be stored in agro-forestry systems or other perennial plantings on agricultural lands. Agricultural lands also remove CH$_4$ from the atmosphere by oxidation, but this effect is small compared to other GHG fluxes.

Avoiding or displacing emissions: Crops and residues from agricultural lands can be used as a source of fuel, either directly or after conversion to fuels such as ethanol or diesel. These bio-energy feedstocks still release CO$_2$ upon combustion, but then the carbon is of recent atmospheric origin (via photosynthesis), rather than from fossil carbon. The net benefit of these bio-energy sources to the atmosphere is equal to the fossil-derived emissions displaced, less any emissions from producing, transporting, and
processing. GHG emissions, notably CO₂, can also be avoided by agricultural management practices that forestall the cultivation of new lands now under forest, grassland, or other non-agricultural vegetation (IPCC, 2007).

2. Main agriculture practical actions

2.1. Adoption of no-till management system

No-tillage is presumed to be the oldest system of soil management. In some parts of the tropics, no-tillage is still practiced as part of slash-and-burn agriculture. After clearing an area of forest by controlled burning, seed is placed directly into the soil. However, as mankind developed more systematic agricultural systems, cultivation of the soil became an accepted practice as a means of preparing a more suitable environment for plant growth. Paintings in ancient Egyptian tombs portray farmers tilling their fields using a swing-plough and oxen, prior to planting. Indeed, tillage as symbolized by the mouldboard plough became almost synonymous with agriculture (Dick & Durkalski, 1997). No-tillage can be defined as a crop production system where soil is left undisturbed from harvest to planting except for fertilizer application.

Conversion of native vegetation to cultivated cropland under conventional tillage system has resulted in a significant decline in soil organic matter content (Paustian et al., 2000; Lal, 2002). Farming methods that use mechanical tillage, such as the mouldboard plough for seedbed preparation or disking for weed control, can promote soil C loss by several mechanisms: they disrupt soil aggregates, which protect soil organic matter from decomposition (Karlen & Cambardella, 1996; Six et al., 1999; Soares et al., 2005), stimulate short-term microbial activity through enhanced aeration, resulting in increased levels of CO₂ and other gases released to the atmosphere (Bayer et al., 2000a,b; Kladivko, 2001), and mix fresh residues into the soil where conditions for decomposition are often more favourable than on the surface (Karlen & Cambardella 1996; Plataforma Plantio Direto, 2006). Furthermore, tillage can leave soils more prone to erosion, resulting in further loss of soil C (Bertol et al., 2005; Lal, 2006).

No-tillage practices, on the other hand, cause less soil disturbance, often resulting in significant accumulation of soil C (Sá et al., 2001; Schuman et al., 2002) and consequent reduction of gas emissions, especially CO₂, to the atmosphere (Lal, 1998; Paustian et al., 2000) compared to conventional tillage. There is considerable evidence that the main effect is in the topsoil layers with little overall effect on C storage in deeper layers (Six et al., 2002).
Globally, at present, approximately 63 million ha are under no-tillage systems with the USA having the largest area (Lal, 2006). In Brazil the no-tillage system started in the south region (Paraná State) in 1972 as an alternative to the misuse of land causing erosion (Denardin & Kochhann, 1993). The underlying land management principles that led to the development of no-tillage systems in Brazil were prevention of surface sealing caused by rainfall impact, achievement and maintenance of an open soil structure and reduction of the volume and velocity of surface runoff. Consequently, the no-tillage strategy was based on two essential farm practices: (i) not tilling and (ii) keeping the soil covered at all times. This alternative strategy quickly expanded to different states and the planted area under no-tillage has since increased exponentially.

In the early 90’s the area covered by the system was 1 million ha increasing 10 times by 1997. Now, the approximately 20 million ha covered by no-tillage practice (Febrapdp, 2006) make Brazil the second largest adopter in the world. This expansion is taking place not only as result of the conversion from conventional tillage in the southern region (72%) but also after clearing natural savannah in centre-west area (28%). More recently, due to the high profits, ranchers in the Amazon region are converting old pastures to soybean/millet under no-tillage.

Changes in soil C stocks under no-tillage have been estimated in earlier studies for temperate and tropical regions. Cambardella & Elliott (1992) showed an increase of 6.7 t C ha\(^{-1}\) in the top 20 cm in a wheat fall rotation system after 20 years of no-tillage in comparison to conventional tillage. Reicosky et al. (1995) reviewed various publications and found that organic matter increased under conservation management systems with rates ranging from 0 to 1.15 t C ha\(^{-1}\) yr\(^{-1}\), with highest accumulation rates generally occurring in temperate conditions. Lal et al. (1998) calculated a C sequestration rate of 0.1 to 0.5 t C ha\(^{-1}\) yr\(^{-1}\) in temperate regions. In tropical western Nigeria, Lal (1997) observed a 1.33 t C ha\(^{-1}\) increment during 8 years under no-tillage as compared to the conventional tillage of maize, which represents an accumulation rate of 0.17 t C ha\(^{-1}\) yr\(^{-1}\).

In the tropics, specifically in Brazil, the rate of C accumulation has been estimated in the two main regions under no-tillage systems (south and centre-west regions). In the southern region Sá (2001) and Sá et al. (2001) estimated sequestration rates of 0.8 t C ha\(^{-1}\) yr\(^{-1}\) in the 0-20 cm layer and 1.0 t C ha\(^{-1}\) yr\(^{-1}\) in the 0-40 cm soil depth after 22 years under no-tillage compared to the same period under conventional practice. The authors mentioned that the accumulated C was generally greater in the
coarse (> 20 µm) than in the fine (< 20 µm) particle-size-fraction indicating that most of this additional C is weakly stable.

Bayer et al. (2000a,b) found a C accumulation rate of 1.6 t ha\(^{-1}\) yr\(^{-1}\) for a 9 year no-tillage system compared with 0.10 t ha\(^{-1}\) yr\(^{-1}\) for the conventional system in the first 30 cm layer of an Acrisol in the southern part of Brazil. Corazza et al. (1999) reported an additional accumulation of approximately 0.75 t C ha\(^{-1}\) yr\(^{-1}\) in the 0-40 cm soil layer due to no-tillage in the savannah region located in the centre-west (Table 1). Estimates by Amado et al. (1998) and Amado et al. (1999) indicated an accumulation rate of 2.2 t ha\(^{-1}\) yr\(^{-1}\) of soil organic C in the first 10 cm layer. Other studies considering the no-till system carried out in the centre-west part of Brazil (Lima et al., 1994; Castro-Filho et al., 1998; Riezebos & Loerts, 1998; Vasconcellos, 1998; Peixoto et al., 1999; Spagnollo et al., 1999; Resck et al., 2000) reported soil C sequestration rates due to no-tillage varying from 0 up to 1.2 t C ha\(^{-1}\) yr\(^{-1}\) for the 0-10 cm layer.

Bernoux et al. (2006) reported that most studies of Brazilian soils report rates of carbon storage in the top 40cm of the soil of 0.4 to 1.7 t C ha\(^{-1}\) per year, with the highest rates in the Cerrado region. However, the authors stressed that caution must be taken when analyzing no-till systems in terms of carbon sequestration. Comparisons should include changes in trace gas fluxes and should not be limited to a consideration of carbon storage in the soil alone if the full implications for global warming are to be assessed.

As mentioned before, the no-tillage system in Brazil can vary significantly between regions. Therefore, we have used in our calculations of additional soil C accumulation due to non-tillage a weighted average value of 0.5 t C ha\(^{-1}\) yr\(^{-1}\) in the first 10 cm depth. This weighted average value was calculated using soil C sequestration rates for the southern region (72% of the no-till area) and also for the centre-west region (28% of the cultivated area under no-till system) as data shown in Table 1.

Table 1. Top sub-sector emission contributors for the year 1994.

<table>
<thead>
<tr>
<th>Subsector</th>
<th>Sector</th>
<th>Greenhouse Gas Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Main GHG</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Source</th>
<th>Activity Type</th>
<th>GHG</th>
<th>Emissions (Gt/year)</th>
<th>Mitigation Effect (Gt/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest and Grassland Conversion</td>
<td>LUCF</td>
<td>CO₂</td>
<td>993.5</td>
<td>56.3</td>
</tr>
<tr>
<td>Fossil Fuel Combustion</td>
<td>Energy</td>
<td>CO₂</td>
<td>240.4</td>
<td>13.6</td>
</tr>
<tr>
<td>Enteric Fermentation</td>
<td>Agriculture</td>
<td>CH₄</td>
<td>196.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Agricultural Soils</td>
<td>Agriculture</td>
<td>N₂O</td>
<td>147.6</td>
<td>8.4</td>
</tr>
<tr>
<td>Others</td>
<td>All sectors</td>
<td>-</td>
<td>191.3</td>
<td>10.4</td>
</tr>
</tbody>
</table>

The total area in Brazil under the no-tillage system is about 20 million ha, and the weighted average soil C accumulation rate due to no-tillage adoption is 0.5 t C ha⁻¹ yr⁻¹ in the first 10 cm depth, giving an estimated change in total soil C of about 10 Mt yr⁻¹. In addition we should include a C offset due to a significant reduction in fuel consumption (60 to 70%) in the no-tillage system compared to the conventional tillage (Plataforma Plantio Direto 2006).

It is important to mention that there is a lot of controversy regarding whether no-till really does sequester much soil C, especially when the whole soil profile is considered (Smith et al., 1998). Most studies that have looked at the whole profile have shown insignificant soil C gains. The quantity of residues returned, variations in the practices implemented and perhaps the type of climate are factors likely to influence the outcome. According to Smith et al. (1998) only certain fixed amounts of soil C can be gained, up to a new equilibrium limit, which is reversible if management reverts to conventional tillage.

2.2. Improve nutrient use (fertilizers)

Nitrogen applied as fertilizers, manures, biosolids, and other N sources is not always used efficiently by crops. The surplus N is particularly susceptible to N₂O emissions. Consequently, improving N use efficiency can reduce N₂O emissions and indirectly reduce GHG emissions from N fertilizer manufacture. By reducing leaching and volatilization losses, improved efficiency of N use can also reduce off-site N₂O emissions. Practices that improve N use efficiency include: adjusting application rates based on precise estimation of crop needs (e.g., precision farming); using slow- or controlled-release fertilizer forms or nitrification inhibitors (which slow the microbial processes leading to N₂O formation); applying N when least susceptible to loss, often just prior to plant uptake (improved timing); placing the N more precisely into the soil
to make it more accessible to crops roots; or avoiding N applications in excess of immediate plant requirements (IPCC 2007).

2.3. Improve management of liming
Because of the large extent of acidic soils in Brazil, liming is commonly used to correct soil acidity and may represent an important source of CO$_2$. Bernoux et al. (2003) presented a first estimation of net CO$_2$ fluxes from liming of agricultural soils in Brazil for the period of 1990-2000. The summarized annual CO$_2$ emissions for Brazil varied from 4.9 to 9.4 Tg CO$_2$ yr$^{-1}$ with a mean CO$_2$ emission of about 7.2 Tg CO$_2$ yr$^{-1}$. The south, southeast and center regions accounted for at least 92% of total emission. Therefore, it is necessary to apply the adequate amount of lime for specific soil types and climatic conditions in Brazil, in order to avoid large CO$_2$ emissions without jeopardizing its primary function of soil acidity correction.

2.4. Optimize mechanization and transport
The growing demand for clean fuels has led the sugarcane sector to increment ethanol production. However, in order for the country to increase production while minimizing greenhouse gas emissions, it is necessary to invest in new machinery and systems, and to improve the efficiency of the following agricultural activities: a) mechanized harvest of sugarcane without burning for all types of farmers; b) real time monitoring and management of truck and harvester fleets in order to reduce GHG emissions related to harvesting and transportation of sugarcane in the plants, and c) the adoption of precision agriculture techniques, such as applying the correct amount of fertilizers - thus reducing losses and minimizing the emissions of nitrous oxide (N$_2$O), a greenhouse gas – and of liming, reducing CO$_2$ emissions.

3. Reduction of GHG emissions by biofuel production

3.1. Lower bioethanol carbon footprint
The sugar cane crop offers one of the most cost-effective renewable energy sources that are readily available in developing countries (Macedo, 1998). It is a highly efficient converter of solar energy and, in fact, has the highest energy-to-volume ratio of all energy crops (Johnson, 2000). Sugar cane is a perennial crop that is harvested on an annual cycle. There may be up to six cycles before re-planting. There is generally only a short fallow between ploughing out the old cane and re-planting. On the majority of
farms in Brazil sugar cane is grown as a monoculture (Macedo, 1997; Simões et al., 2005). It is a highly flexible resource, offering alternatives for production of food, feed, fibre and energy. Such flexibility is valuable in the developing world where fluctuations in commodity prices and weather conditions can cause severe economic hardships.

For biomass energy production, sugar cane is an excellent feedstock in terms of efficiency and flexibility, providing gaseous, liquid and solid fuels (Ripoli et al., 2000). It offers the potential for climate change mitigation through substitution of fossil fuels without the need for excessive subsidies or expensive infrastructure development (Oliveira et al., 2005).

The Brazilian ethanol programme remains the world’s largest CO$_2$ mitigation programme (Johnson, 2000; Oliveira et al., 2005). At present in Brazil, sugar cane is cultivated on about 8 million ha, with an average annual production of approximately 600 million tonnes (CONAB, 2009). In 2008/2009, 31 million tonnes of sugar and 27.5 million m$^3$ of alcohol were produced (UNICA, 2009).

There are two procedures adopted for sugar cane harvesting. Traditionally, sugar cane has been burnt in the field a few days before harvesting in order to facilitate manual cutting by removing leaves and insects (Thorburn et al., 2001). However, since May 2000 this common practice has been progressively prohibited by law in some areas in Brazil. In addition to CO$_2$ emission, other pollutant gases are emitted during the burning period causing respiratory problems and ash fall over urban areas (Andreae & Merlet, 2001). Even though the law will not be fully implemented before 2030, the adoption of mechanical harvesting has increased exponentially in Brazil during the last decade. In 1997 about 20% of the Brazilian sugar cane area was harvested by machines (Silva, 1997) and it is estimated that about 80% of the planted area in the most productive sugar cane region in Brazil will use mechanical harvesting in the next 20 years (CENBIO 2002).

The current mechanical approach is only adapted for slopes of less than 12% (Luca, 2002) and it seems likely that when the burning ban is fully implemented steeply sloping land will go out of sugar cane production unless new harvesting methods are developed (Simões et al., 2005). By the return of crop residues to the soil surface, the mechanized harvest has indirectly favoured soil organic matter accumulation (Thorburn et al., 2001; Luca, 2002) and gas emission reduction when compared to the burning system (Andreae & Merlet, 2001).
The net contribution of the Brazilian sugar cane industry to the evolution of atmospheric CO$_2$ is a combination of three activities, two industrial and one agricultural. The first activity is the substitution of gasoline as a fuel by alcohol. Since the early 1930’s the Brazilian government has given incentives for alcohol production from sugar cane to be added to gasoline in the transportation sector (Sociedade Nacional de Agricultura, 2000). Due to oil crises in 1973-74, Brazilian authorities created new incentives through the Brazilian alcohol program (Proalcool) to increase the production of alcohol to 10.7 billion litres per year (Coelho et al., 2000). During 1975 to 2000, 156 million m$^3$ of hydrated alcohol and 71 million m$^3$ of anhydrous alcohol were produced. Considering that 1 m$^3$ of gasoline is substituted by 1.04 m$^3$ anhydrous alcohol and 0.8 m$^3$ hydrated alcohol and that gasoline contains on average 86.5 % C (American Petroleum Institute, 1988) we calculate that during the 1975-2000 period, 172 Mt C were offset and consequently not emitted to the atmosphere, which gives an average annual offset of 6.8 Mt C. However, the alcohol production and consumption are increasing every year in Brazil. If data just for the last 10 years were used, the offset would be about 10 Mt C yr$^{-1}$.

The second associated mitigation factor in the sugar cane system is related to the use of plant residues as fuel. At the mill, the cane stalks are shredded and crushed to extract the cane juice while the fibrous residue, known as bagasse, is burnt to provide steam and electricity for the mill (Luca, 2002). For instance, in 1998 approximately 45 Mt dry matter of sugar cane residues were produced in Brazil (Balâncio Energético Brasileiro, 1999). Assuming that 2.35 t of residues substitute 1 t of fossil fuel (Macedo, 1997) we estimate that 8 Mt C were offset in 1998 due to use of sugar cane residues at the mill instead of fossil fuel. This renewable energy resource, found mainly in developing countries, has obvious appeal for international efforts to reduce carbon dioxide emissions. Moreover, the organic wastewater stream from alcohol production, known as vinasse, can be used as fertilizer or can be converted to methane gas through anaerobic digestion. The transportation fleets used in sugar factories and ethanol distilleries in Brazil have in some cases been powered by methane gas (Johnson, 2000). The production of alcohol has been viewed as a valuable means of saving foreign exchange in developing countries while at the same time providing local and global environmental benefits (Oliveira et al., 2005). In addition to climate mitigation and reduction of local pollutants, it can serve as an octane enhancer that might speed the phasing-out of leaded gasoline. The economic and environmental attractiveness of sugar
cane as a renewable energy resource and the variety of options for increasing use of cane by-products and co-products could one day lead to sugar becoming the by-product rather than the main product.

Finally, the third activity associated with CO₂ mitigation in the sugar cane system is the conversion harvesting without prior burning. At present there are 8 Mha of sugar cane grown in Brazil (CONAB, 2009) of which approximately 20% (1.5 Mha) is harvested without burning (Silva, 1997; Oliveira et al., 2005). In the absence of burning, sugar cane residues are returned to the soil surface with litter and this factor is significant because it contrasts with the alternative system where cane is burnt before harvest removing dead and green leaves, so there is very little C returned to the soil from the above ground vegetation. For instance, Blair et al. (1998) found significant increases in the labile C fraction in green trash treatments compared to the trash burnt treatments in the surface soils of two green trash management trials in Australia. In Southern Brazil, Feller (2001) reported that an average of 0.32 t C ha⁻¹ yr⁻¹ was accumulated in 12 years in the first 20 cm depth of an Oxisol due to omitting burning. Other estimates exist, but for shorter period of no-burning. For instance, Luca (2002) reported increases ranging from 2 to 3.1 and 4.8 to 7.8 t C ha⁻¹ respectively for the top 5 cm and 40 cm depth during the first 4 years following no-burning. The corresponding annual increase ranges from 0.5 to 0.78 t C ha⁻¹ yr⁻¹ for the 0-5 cm layer and 1.2 to 1.9 t C ha⁻¹ yr⁻¹ for the 0-40 cm layer. However, sugar cane is typically replanted each 6-7 years and tillage practices are commonly used. This procedure would probably reduce the high rates presented by Luca (2002) if the study had been for a longer period. In our estimate of C sequestration we have used the value found by Feller (2001) because it represents the longest period of harvest without burning in Brazil and incorporates cane replanting. Thus, considering the area under this management system and the mean annual C accumulation rate, a total of 0.48 Mt C yr⁻¹ is sequestered in Brazil.

When sugar cane is burnt other greenhouse gases like CH₄ and N₂O are emitted to the atmosphere. Results from Macedo (1998) show that 6.5 kg CH₄ ha⁻¹ are released from the burning of sugar cane. Considering the total area with sugar cane under no burning harvesting system (1.5 Mha) and that the methane has the global warming potential of 21, we have calculated that 0.2 Mt CO₂-equivalent (0.05 Mt C) that are not emitted annually to the atmosphere due to the adoption of mechanized harvest without burning. The same calculation is required for N₂O emission; however, currently there are no adequate measurements of this gas in sugar cane.
In summary, when sugar cane is harvested mechanically without burning in Brazil, 0.48 Mt C yr\(^{-1}\) is sequestered in soil and methane emission equivalent to 0.05 Mt C yr\(^{-1}\) is avoided. This total of 0.53 Mt C yr\(^{-1}\) is the contribution of the agricultural sector. Moreover, the industrial sector contributes not only the 10 Mt C yr\(^{-1}\) offset due to substitution of fossil fuel by alcohol for transportation but also the 8 Mt C yr\(^{-1}\) by substituting fossil fuel for power generation at the mill. Combining the agricultural and industrial sectors, sugar cane produced without burning is responsible for a total of 18.5 Mt C yr\(^{-1}\) removed from the atmosphere.

3.2. Lower biodiesel carbon footprint

The problems of petroleum supply on the world market during the 1930s, combined with efforts of the European countries to develop alternative sources of energy, culminated in the search for viable solutions for the replacement of fossil fuel. In this research scenario, biodiesel took a place of prominence (Suarez and Maneghetti, 2007).

Biodiesel has been considered one of the most promising alternatives for petroleum diesel, and can be used in cars and other vehicles with diesel engines. Made from renewable energy sources, biodiesel emits fewer pollutants than diesel and is being adopted by many countries, especially in Europe where the main producers are Germany, Italy and France.

In addition to the aspects cited above, the use of petroleum as a main energy source has contributed, over the decades, to the increase of greenhouse gases (GHG) in the atmosphere. The main gases responsible for global warming are CO\(_2\) (carbon dioxide), CH\(_4\) (methane) and N\(_2\)O (nitrous oxide). To prevent or slow the rising concentrations of greenhouse gases, some mitigation decisions need to be adopted (Adler et al., 2007). Among 15 strategies for mitigation of carbon (C) based on the use of new technologies, Pacala and Socolow (2004) identified the use of biofuels as a viable alternative.

Concerns about climate change are growing and have converged to global emission reduction policies, according to which it is necessary to transition to a new energy matrix that can replace petroleum as raw material. Biodiesel is a fuel derived from renewable sources and has virtually the same properties of fossil diesel, but, according to Holanda (2004), can reduce net emissions of carbon dioxide by 78%, smoke emissions by 90%, and eliminate the emissions of sulfur oxide.
Biofuels, especially ethanol and biodiesel, are seen by environmentalists and leaders of government as the most promising alternative to achieve the goal of reducing dependence on fossil fuels, and consequently of CO\textsubscript{2} emissions (Farrell et al., 2006; Ragauskas et al., 2006). Furthermore, in some cases, biofuels can provide agricultural local support and economic development (Goldemberg et al., 2007).

There are three general principles that should guide the viability of policies and practices of the use of biofuels: promote sustainability and low impacts on the supply chain with a low ecological footprint; maintain native systems and essential cultures; and, at least, require a neutral carbon balance from biofuels. With the urgency of reducing the GHG emissions to the atmosphere, biofuels with low CO\textsubscript{2} emissions are likely to be accepted more easily. Clearly, all biofuels proposed until the present moment, with the exception of ethanol derived from corn, have a great potential for reducing air pollution and decreasing CO\textsubscript{2} outputs.

Emphasizing the environmental aspect, an accurate assessment of the productive chain of biodiesel should be conducted. An important issue that should be taken account is the use of fossil fuels throughout the life cycle of biodiesel, which causes the emission of greenhouse effect gases to the atmosphere. In agriculture cultivation, the largest emissions of greenhouse gases are N\textsubscript{2}O, CO\textsubscript{2} and CH\textsubscript{4} from soil, in addition to the CO\textsubscript{2} emissions from agricultural machinery (Del Grosso et al., 2001; West and Marland, 2002). Bioenergy systems vary according to the length of plant life cycle, productivity, efficiency of energy conversion, demand for nutrients, inputs of carbon in the soil, losses of nitrogen, and other characteristics, all of them resultant from management operations. Such factors affect the magnitude of the components that contribute to the net fluxes of GHG and N losses. The N\textsubscript{2}O emissions and leaching of NO\textsubscript{3} vary with the amount of nitrogen fertilizer applied and its interaction with precipitation, temperature and soil texture, and crop rotation (Adler et al., 2007).

From the environmental point of view, the first justification for the use of biodiesel as a substitute for diesel oil is a proposal of having a CO\textsubscript{2}-neutral system. This prerogative of the hypothesis is that all the CO\textsubscript{2} emitted by the burning is absorbed by photosynthesis. But this view fails to consider energy input required to plant, grow, harvest, transport, process, and distribute fuels, and the release of CO\textsubscript{2} on burning of the biodiesel. Consequently, the degree to which any biodiesel may decrease CO\textsubscript{2} emissions relative to diesel oil depends on production and refining methods (Turner et al., 2007).
In summary, currently in the context of climate change, biofuel use as a substitute for fossil fuel can be considered the main mitigation measure adopted. In terms of structure of the biodiesel production chain, soil management takes an important role, mainly under sustainable practices and conservation management. Studies toward land use are required to assess the environmental impact of the biodiesel agricultural chain. Besides a GHG emissions comparative analysis between biodiesel and fossil diesel, is also necessary to consider soil carbon sequestration in the production stage of different oilseeds. Within an environmental context, studies are still needed as well as investments that contribute to the use of raw materials with high yield potential, using a minimum of natural resources such as soil and water. Besides, oil seed crops such as *Jatropha* that can be adapted to low soil fertility and water deficient conditions should be considered. The cultivation of microalgal biomass for production of biodiesel has attracted considerable scientific interest, since it presents the possibility of an environmentally sustainable production of biodiesel for the replacement of the diesel derived from petroleum (about 40 billion liters per year).

4. Use of idle lands for food agriculture

Even within the context of land use, there are areas with low adaptation for production of food crops that could be directed to the production of energy crops using species that are adapted to regional conditions. In Brazil, the northeast semi-arid region deserves considerable attention in this discussion, since it is an ecologically fragile area that does not support production systems based on the traditional models of agriculture. The excessive deforestation followed by techniques that do not recover nor preserve soil structure is the first step that triggers the desertification process, with dangerous impacts in the medium and long terms.

An issue that has been well discussed for the northeast semi-arid region is the use of soil and water conservation practices among the local farmers, in order to guarantee the agricultural productivity of lands. Within the mentioned alternatives to improve the production systems integrated to the conservation of soil environment are the abolition of burnings, planting in level curves, preservation of soil moisture near the plant, and crop rotation with crops that supply and fix nitrogen in the soil.

Castor bean is found in the Northeast semi-arid region and has particular traits such as strong resistance to drought, heat, and light (Amorim Neto et al., 1999). The semi-arid rainfall is one of the main factors that provide the high levels of agricultural
productivity of castor bean (Beltrão, 2004). Castor bean cultivation occupies a prominent place in the program of social inclusion of biodiesel, as it has aroused great interest for family agriculture. Currently Bahia State is the largest national producer of castor bean, responsible for 92% of the Brazilian production.

Besides the economic aspect, castor bean is a major source of biomass and energy and can contribute significantly in sequestering around 10 t ha$^{-1}$ C, thereby assisting in reversing global warming (Beltrão, 2004).

A very promising alternative for low fertility soils in semi-arid regions is the cultivation of *Jatropha*, which is being studied with the aim of helping supply the ever increasing demand of biodiesel (Lima, 2007). This is an oil crop with great potential for oil production due to an essential feature which differentiates it from other oil crops: their production cycle extends for more than 40 years.

The oil yield in *Jatropha* is less than that of castor bean; however, as the farmer does not need to plant the crop again for more than 40 years, the production cost can be greatly reduced (Albuquerque, 2008). Moreover, Jatropha has a hardy root system that makes it resistant to drought. This crop is grown in environments with as little as 200 mm of precipitation annually and can withstand up to three years of consecutive droughts (Saturnino et al., 2005). Based on these characteristics, and being able to develop in soils of low fertility, *Jatropha* becomes a potential crop to integrate into the program to produce biodiesel in the semi-arid region of Northeast Brazil (Arruda et al., 2004).

Besides encouraging the cultivation of castor bean, there are several private sector and Brazilian government initiatives for gathering information about the production system of *Jatropha* in the conditions of semi-arid Northeast. The research with the oil crop in the region is still very recent, so it is necessary to search for technical information to promote sustainable production systems.

II. LIVESTOCK OPTIONS TO MITIGATE GLOBAL WARMING

1. General remarks

In Brazil, one of the main points to be considered is the land use and occupation of areas that could be used for agriculture. It is possible to report the existence of areas currently used in livestock sector which could be better managed, thus allowing the expansion of agricultural cultivation of grains, fibers and oil seeds.
Livestock farming in Brazil is primarily an extensive activity due to the availability of large areas. Preliminary results released by Instituto Brasileiro de Geografia e Estatística (IBGE, 2006) show that the area of pastures in Brazil is approximately 172 million hectares, covering almost 50% of the total area.

The low potential of land use for pastures leads farmers to the abandonment of lands, and to clear other forest areas for implementation of new pastures, which results to an increase in deforestation. According to the Instituto Nacional de Pesquisas Espaciais, the area deforested in Amazon region was estimated at more than 551,000 km². Of the total land area deforested in the Amazon, 45% is covered by pastures, 28% by secondary forests originated from pastures abandoned after 1970 and 2% by degraded pastures (Fearnside, 1996).

Preliminary results released by IBGE (2006) show that the area of pastures in the North region in Brazil increased from 24.3 million hectares in 1995 to 32.6 million hectares in 2006, representing an increase of 33.8% of lands used for livestock. Considering the total extension of the country, there was a shrinkage of 3% in land use for livestock, with decreases in the South, Southeast and Center-West regions. In the North region, the increase of pasture areas seems to be tied to the increase of almost 14 million heads, representing about 80.7% of the total cattle herd (IBGE, 2008).

The areas subject to agricultural uses in the Amazon region are showing serious problems regarding the conservation of natural resources. Currently, about 60% of the area covered with pastures is in advanced process of degradation. Degraded pastures are characterized by lack of nutrients in the soil, low plant biomass, few seeds of primary forest, presence of weeds in large quantities, lack of forest seeds in seed banks, low rate of germination (Nepstad et al., 1998), compaction and low soil drainage (Eden et al. 1991). The degradation of pastures is due to the inadequate management of cattle herds and lack of corrective fertilization and pasture maintenance (Macedo, 2000).

Within this context, the Brazilian livestock production system needs to be reformed. An appropriate management of cattle and pastures depends on an increase of soil productivity, preventing deforestation and making the system more sustainable. The use of areas occupied with degraded pastures for growing food crops can reduce the competition per area between food crops and crops with potential to produce biofuels, including oil plants. The appropriate management of pastures should include the potential for carbon sequestration, which combined with the use of beef tallow in
biodiesel production, can reduce the GHG emissions to the atmosphere, and contribute to the mitigation of global warming.

2. Main grazing land management and pasture improvement practical actions

Grazing lands occupy much larger areas than croplands and are usually managed less intensively. The following are examples of practices to reduce GHG emissions and to enhance removals suggested by IPCC (2007).

2.1. Enhance grazing intensity

The intensity and timing of grazing can influence the removal, growth, carbon allocation, and flora of grasslands, thereby affecting the amount of carbon accrual in soils. Carbon accrual on optimally grazed lands is often greater than on ungrazed or overgrazed lands. The effects are inconsistent, however, owing to the many types of grazing practices employed and the diversity of plant species, soils, and climates involved. The influence of grazing intensity on emission of non-CO$_2$ gases is not well-established, apart from the direct effects on emissions from adjustments in livestock numbers.

2.2. Increase productivity (including fertilization)

As for croplands, carbon storage in grazing lands can be improved by a variety of measures that promote productivity. For instance, alleviating nutrient deficiencies by fertilizer or organic amendments increases plant litter returns and, hence, soil carbon storage. Adding nitrogen, however, often stimulates N$_2$O emissions thereby offsetting some of the benefits. Irrigating grasslands, similarly, can promote soil carbon gains. The net effect of this practice, however, depends also on emissions from energy use and other activities on the irrigated land.

2.3. Optimize nutrient management

Practices that tailor nutrient additions to plant uptake, such as those described for croplands, can reduce N$_2$O emissions. Management of nutrients on grazing lands, however, may be complicated by deposition of feces and urine from livestock, which are not as easily controlled nor as uniformly applied as amendments in croplands.

2.4. Introduce new species
Introducing grass species with higher productivity, or carbon allocation to deeper roots, has been shown to increase soil carbon. For example, establishing deep-rooted grasses in savannas has been reported to yield very high rates of carbon accrual, although the applicability of these results has not been widely confirmed. In the Brazilian Savannah (Cerrado Biome), integrated crop-livestock systems using Brachiaria grasses and zero tillage are being adopted. Introducing legumes into grazing lands can promote soil carbon storage, through enhanced productivity from the associated N inputs, and perhaps also reduced emissions from fertilizer manufacture if biological N\textsubscript{2} fixation displaces applied fertilizer N. Ecological impacts of species introduction need to be considered.

2.5. Improve feeding practices

Methane emissions can be reduced by feeding more concentrates, normally replacing forages. Although concentrates may increase daily methane emissions per animal, emissions per kg feed intake and per kg-product are almost invariably reduced.

The magnitude of this reduction per kg of product decreases as production increases. The net benefit of concentrates, however, depends on reduced animal numbers or younger age at slaughter for beef animals, and on how the practice affects land use, manure N content and emissions from concentrate production and transportation. Other practices that can reduce CH\textsubscript{4} emissions include: adding certain oils or oilseeds to the diet; improving pasture quality, especially in less developed regions, because this improves animal productivity, and reduces the proportion of energy lost as CH\textsubscript{4}; and optimizing protein intake to reduce N excretion and N\textsubscript{2}O emissions.

2.6. Adopt long-term management changes and animal breeding

Increasing productivity through breeding and better management practices, such as a reduction in the number of replacement heifers, often reduces methane output per unit of animal product. Although selecting cattle directly for reduced methane production has been proposed, it is still impractical due to difficulties in accurately measuring methane emissions at a magnitude suitable for breeding programmes. With improved efficiency, meat-producing animals reach slaughter weight at a younger age, with reduced lifetime emissions. However, the whole-system effects of such practices may not always lead to reduced emissions. For example in dairy cattle, intensive
selection for higher yield may reduce fertility, requiring more replacement heifers in the herd.

2.7. Use specific agents and dietary additives

A wide range of specific agents, mostly aimed at suppressing methanogenesis, has been proposed as dietary additives to reduce CH₄ emissions:

- Ionophores are antibiotics that can reduce methane emissions, but their effect may be transitory; and they have been banned in the EU.
- Halogenated compounds inhibit methanogenic bacteria but their effects, too, are often transitory and can have side-effects such as reduced intake.
- Novel plant compounds such as condensed tannins, saponins or essential oils may have merit in reducing methane emissions, but these responses may often be obtained through reduced digestibility of the diet.
- Probiotics, such as yeast culture, have shown only small, insignificant effects, but selecting strains specifically for methane-reducing ability could improve results.
- Propionate precursors such as fumarate or malate reduce methane formation by acting as alternative hydrogen acceptors. But as response is elicited only at high doses, propionate precursors are, therefore, expensive.
- Vaccines against methanogenic bacteria are being developed but are not yet commercially available.
- Bovine somatotropin (bST) and hormonal growth implants do not specifically suppress CH₄ formation, but by improving animal performance, can reduce emissions per kg of animal product.

3. Reduce emissions from cattle feedlot manure

Feedlot cattle manure usually returns to soil as organic fertilizer. Organic matter decomposition returns GHG to atmosphere, so this practice does not contribute to mitigate emission or lower the beef carbon footprint. The treatment of cattle feedlot manure promotes reduction of GHG emission and thus lowers the beef carbon footprint. Ultimately, the adequate waste treatment adds value to the meat price.

4. Use of beef tallow for biodiesel production
Apart from oilseeds, animal fat can also be used in biodiesel production. There are some differences in physical properties between biodiesel made from vegetable oils and from animal fat. The main point is related to the cloud and melting points.

The cloud point (CP) occurs from the lowering of temperature and is defined as the temperature in which the formation of liquid crystals becomes visible in biodiesel, indicating solidification. From this point, the continuity in lowering temperature causes the crystals that merge to form larger clusters that may restrict or prevent the free flow of fuel in pipes and filters, causing engine problems. The melting point (MP) is defined as the temperature at which crystal agglomeration is widespread enough to prevent the free flow of fluid (Knothe et al., 2006).

The biodiesel produced from animal fat has higher CP and MP than those derived from vegetable oils. Thus, the formation of crystals in tallow biodiesel is easier, making its use in pure form difficult. However, at the same temperature, there is little difference between the vegetable and tallow biodiesels in terms of pollutant emissions and engine performance (Van Gerpen, 1996).

In Brazil, the most appropriate animal fat to produce biodiesel is bovine tallow. The country has the second largest cattle herd in the world and tallow is presented as an alternative raw material for biodiesel with interesting availability and high potential of production.

Tallow is a greasy residue composed of triglycerides which has in its composition mainly palmitic acid (30%), stearic (20-25%) and oleic (45%) (Graboski and McCormick, 1998).

The Brazilian production potential of biodiesel derived from beef tallow can be easily calculated based on data from the year 2008: each animal slaughtered provides on average 15 kg of tallow serviceable (RBB, 2006). Considering a yield to pure biodiesel equal to 80% and the slaughter of 22 million heads in 2008 (IBGE, 2008), the Brazilian potential to produce biodiesel from beef tallow would be approximately 400 million liters of biodiesel.

Regarding the quality of tallow produced, it begins at slaughter when the decomposition process of fats starts. With animal death, the action of enzymes and bacteria causes changes in color and in content of free fatty acids. Thus, the enzymatic and bacterial control before and during the slaughter process is an essential factor for obtaining a quality tallow. The efficiency of biodiesel production process depends on its quality, and therefore it is necessary to monitor the entire production cycle from the
animal slaughter, through an efficient sanitary control on all production stages, to transport and storage of the finished product.

III. FORESTRY OPTIONS TO MITIGATE GLOBAL WARMING

1. General remarks

Forestry projects are included in the activities classified as LULUCF, and have a prominent place in the Kyoto Protocol and Clean Development Mechanisms (CDMs). Due to their capacity for carbon fixation in the growth period, the production of agro-forestry species is considered a CO₂ sink. Planted forests in Brazil absorb annually, on average, 63 million tons of CO₂, which represents three times as much as the CO₂ emitted in the paper and cellulose industry. Therefore, the paper and cellulose industry, through the planting of forests, compensates its emissions and sequesters emissions from other sources, providing an environmental service.

Due to a combination of climate conditions, biotechnology and forest management practices, eucalyptus and pinus grow 365 days per year, allowing a harvest every 6 or 7 years. The growth rates are five to ten times higher, reaching 20 times, compared to temperate climate managed forests. The carbon sequestration by planted forests in Brazil is, therefore, highly efficient compared to other countries.

The Brazilian territory encompasses 851 million hectares, among which 315 million hectares are arable land (37%). Currently, 72 million hectares are occupied by agriculture and 172 million hectares are used for livestock, with a remain available area of 71 million hectares. Eucalyptus and pinus forests used in the paper and cellulose industry represent less than 1% of the arable land in the country, since this land use has expanded into degraded lands, and has focused on increased productivity per unit area.

Mitigation measures will occur against the background of ongoing change in greenhouse gas emissions and removals. Understanding current trends is critical for evaluation of additional effects from mitigation measures. Moreover, the potential for mitigation depends on the legacy of past and present patterns of change in land-use and associated emissions and removals. The contribution of the forest sector to greenhouse gas emissions and removals from the atmosphere remained the subject of active research, which produced an extensive body of literature (IPCC, 2007).

The design of a forest sector mitigation portfolio should consider the trade-offs between increasing forest ecosystem carbon stocks and increasing the sustainable rate of
harvest and transfer of carbon to meet human needs. The selection of forest sector mitigation strategies should minimize net GHG emissions throughout the forest sector and other sectors affected by these mitigation activities.

2. Main forestry practical actions

For the purpose of this report we are presenting below the IPCC (IPCC, 2007) suggested options available to reduce emissions by sources and/or to increase removals by sinks in the forest sector. They are grouped into four general categories: i) maintaining or increasing forest area: reducing deforestation and degradation, ii) maintaining or increasing forest area: afforestation/reforestation, iii) increasing stand- and landscape-level carbon density, and iv) increasing off-site carbon stocks in wood products and enhancing product and fuel substitution.

2.1. Maintain or increase forest area: reduce deforestation and degradation

Reduced deforestation and degradation is the forest mitigation option with the largest and most immediate carbon stock impact in the short term per ha and per year not only for Brazil but also globally, because large carbon stocks (IPCC, 2007) are not emitted when deforestation is prevented. The mitigation costs of reduced deforestation depend on the cause of deforestation (timber or fuel wood extraction, conversion to agriculture, settlement, or infrastructure), the associated returns from the non-forest land use, the returns from potential alternative forest uses, and on any compensation paid to the individual or institutional landowner to change land-use practices. The present section is not going to discuss such issue since it is the main focus of another report.

2.2. Maintain or increase forest area: afforestation/reforestation

Planted forests for industrial purposes in Brazil implies in the preservation of native forests due to the very strict requirements imposed by environmental legislation, such as the maintenance of Permanent Preservation Areas and Legal Reservations. Currently, 2.8 million hectares of native forests are preserved by the paper and cellulose industry, as legal reservations and permanent preservation areas.

Therefore, there is no opposition between planted forests for industrial purposed and native forests. On the contrary, the Brazilian silviculture contributes for the regeneration of endemic species, and therefore, the preservation of biodiversity. Finally,
it is important to note that silviculture has been integrated to livestock and crop production, providing benefits to both activities.

Afforestation typically leads to increases in biomass and dead organic matter carbon pools, and to a lesser extent, in soil carbon pools, whose small, slow increases are often hard to detect within the uncertainty ranges. Biomass clearing and site preparation prior to afforestation may lead to short-term carbon losses on that site. On sites with low initial soil carbon stocks (e.g., after prolonged cultivation), afforestation can yield considerable soil carbon accumulation rates. Conversely, on sites with high initial soil carbon stocks, (e.g., some grassland ecosystems) soil carbon stocks can decline following afforestation.

2.3. Increase stand- and landscape-level carbon density

Forest management activities to increase stand-level forest carbon stocks include harvest systems that maintain partial forest cover, minimize losses of dead organic matter (including slash) or soil carbon by reducing soil erosion, and by avoiding slash burning and other high-emission activities. Planting after harvest or natural disturbances accelerates tree growth and reduces carbon losses relative to natural regeneration. The potential benefits of carbon sequestration can be diminished where increased use of fertilizer causes greater \( \text{N}_2\text{O} \) emissions.

2.4. Increase off-site carbon stocks in wood products and enhance product and fuel substitution

Wood products derived from sustainably managed forests address the issue of saturation of forest carbon stocks. The annual harvest can be set equal to or below the annual forest increment, thus allowing forest carbon stocks to be maintained or to increase while providing an annual carbon flow to meet society’s needs of fibre, timber and energy. The duration of carbon storage in wood products ranges from days (biofuels) to centuries (e.g., houses and furniture). Large accumulations of wood products have occurred in landfills. When used to displace fossil fuels, woodfuels can provide sustained carbon benefits, and constitute a large mitigation option. Wood products can displace more fossil-fuel intensive construction materials such as concrete, steel, aluminium, and plastics, which can result in significant emission reductions. The mitigation benefit is greater if wood is first used to replace concrete building material and then after disposal, as biofuel.
3. Mitigation by the expansion of reforested areas

The area to be reforested in Brazil to supply the internal and external markets with cellulose and timber was calculated by the Brazilian Society of Silviculture (…) to be about 3 million hectares. This expansion should be performed mainly in degraded pastures to avoid endanger food production. The adoption of conservative practices like desiccation of pasture vegetation instead of plowing, and minimum till to plant the seedlings will avoid unnecessary GHG emissions.

IV. AGRICULTURE/LIVESTOCK/FORESTRY CROSSCUTTING

1. Adoption of integrated crop/livestock system

The integration of crops and livestock is a technology as old as the domestication of animals and plants. In Brazil, the crop-livestock integration (CLI) has been widely used, but the innovative application has been on the introduction of this practice in the no-till system (Paulino et al., 2006).

The use of the CLI system in no-till leads to land use intensification, strategically incorporating pastures into grain and fiber production systems, benefiting both. This system is capable of supplying the demand for land in Brazil, meeting the economical needs of agriculture and livestock producers without causing deforestation and related environmental problems.

This system can be defined as: “The integration of two activities in order to rationally maximize land use, infra-structure and labor; to diversify and verticalize production; minimize costs; dilute risks and aggregate value to products, though the resources and benefits provided by one activity to the other” (Machado, et al., 1998).

According to Kluthcouski et al. (2006), the use of perennial grasses such as braquiaria in CLI, in consortiation, succession or rotation with annual crops can minimize soil degradation through benefits to soil physical attributes.

The success of CLI is not only related to biomass production by the grasses. Pasture management, or adecquatly animal occupancy to forage supply, is a key factor for optimal Grass productivity, and thus a larger quality of litter produced for the subsequent no-till crop (Salton, 2005).

Studies performed in the cerrado region have demonstrated the increment in soil C stocks in CLI systems under no-tillage when compared to no-tillage areas without
forages in the crop rotation/succession. Salton (2005) evaluated the C accumulation rates under different cerrado land use and management systems, and observed higher C stocks when forages where used, resulting in the following soil C stocks in decreasing order: permanent pasture > CLI under no-tillage > no-tillage cropland > conventional tillage cropland. The author reported soil C accumulation rates of CLI under no-tillage compared to no-tillage areas of 0.60 and 0.43 Mg ha\(^{-1}\) year\(^{-1}\). Preliminary results by Carvalho et al., (in press) in the cerrado region indicate that the C accumulation rates when no-tillage is converted to no-tillage with CLI can be even higher, varying from 0.8 to 1.5 Mg ha\(^{-1}\) year\(^{-1}\), thus reducing GHG emissions to the atmosphere.

2. Adoption of agroforestry system

The Agroforestry System (AFS) is a land use in which trees are produced in association with other perennial or annual crops and/or with cattle, in several spatial and temporal combinations, using appropriate management practices. There are ecological and economic interactions between the trees, crops and animals that result in advantages compared to other agricultural systems (Nair, 1989; Young, 1989; Rao & MacDiken 1991).

The recognition of agroforestry as a greenhouse-gas mitigation strategy under the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) offers an opportunity to agroforestry practitioners to benefit from the global Carbon credit market (Takimoto et al., 2008).

According to Jose (2009) agroforestry systems (AFS) are believed to provide a number of ecosystem services. Agroforestry can be useful in accessing ecosystem services and environmental benefits \textit{i.e.}: (1) carbon sequestration, (2) biodiversity conservation, (3) soil enrichment and (4) air and water quality. There are clear evidences that agroforestry systems, as part of a multifunctional working landscape, can be a viable land-use-system option that, in addition to alleviating poverty, offers a number of ecosystem services and environmental benefits. The perception of agroforestry system as an integrated tool in addressing many problems will help to promote a better land-use system increasing productivity, improving rural livelihood, increasing carbon sequestration in biomass and in the soils, and by avoiding many of the problems of the large scale monoculture – \textit{i.e.}: soil erosion, soil organic matter degradation, etc.
The incorporation of trees or shrubs in agroforestry systems can increase the amount of carbon sequestered compared to a monoculture field of crop plants or pasture (Sharrow and Ismail 2004; Kirby and Potvin 2007). In addition to the significant amount of carbon stored in aboveground biomass, agroforestry systems can also store carbon belowground. The largest amount and most permanent form of carbon may be sequestered by increasing the rotation age of trees and/or shrubs and by manufacturing durable products from them upon harvesting.

The potential of agroforestry systems to sequester carbon varies depending upon the system type, species composition, age of component species, geographic location, environmental factors, and management practices.

The success in the implementing agroforestry projects for GHG mitigation will depend on the farmers’ willingness to participate. Several reasons have been recognized in support of introducing C sequestration benefits into smallholder agroforestry practices in developing countries. First, the sequestration service does not need to be physically transported, thus, it can benefit people in remote areas, most of whom are very poor. Secondly, there are no quality differences: a molecule of C is the same wherever it is located; so the problem often faced by smallholders in not being able to achieve the quality required by international markets in agricultural commodities does not apply here (Cacho et al. 2003). Furthermore, even small amounts of additional income would make a great difference for these subsistence farmers who have very limited alternative employment opportunities to make such additional cash income.

Final considerations

In Brazil, most mitigation efforts focused on the energy and LUCF sectors, with a focus on reduction of deforestation in the Amazon. The later aspect has achieved some success, since deforestation rates decreased. On the other hand, despite the intensification of ethanol use (increasing percentage of flex fuel cars), the energy sector showed the highest level of increase (+44%). However, it must be recognized that the energy-related programs and measures implemented in the 90’s and after have provided a broad range of benefits for the Brazilian economy, and helped lower carbon emissions in relation to what was considered business as usual in the yearly 90’s. Besides efforts to curb emissions from the energy and deforestation sectors, it is now a top priority to implement a national program to encourage mitigation efforts concerning the agricultural sector (+27%). These mitigation options should not be only focused on
emissions reduction, but also on enhancement of the carbon sink. Such a program would be easy to implement, because several mitigation strategies have already proved to be efficient, simple to adopt and economically viable.
References


Amado et al. (1999)


Bayer et al., 2000a,b;


Bertol et al., 2005


Cambardella & Elliott (1992)
Castro-Filho et al., 1998;


Corazza et al. (1999)


Denardin & Kochhann, 1999

Dick & Durkalski, 1997


Febrapdp, 2006


Karlen & Cambardella, 1996;


Kladivko, 2001


Lima et al., 1994;


Lal, 2006
Lal, 2002
Lal et al. (1998
Lal (1997)


Peixoto et al., 1999;
Riezebos & Loerts, 1998;
Reicosky et al. (1995) Resck et al., 2000
Sá (2001)
Six et al., 1999;
Soares et al., 2005
Spagnollo et al., 1999;

UNICA, 2009. **Estatísticas de produção de cana-de-açúcar.** Available at:

**Vasconcellos, 1998;**


**WRI, 2009**