

CHAPTER 2

THEORIES AND LITERATURE REVIEW

2.1 Introduction

The concentration of atmospheric CO₂ has increased over the past (IPCC, 2001; Kirstin and Thomas, 2007). Most of the increase has resulted from fossil fuel combustion and land use activities. However, as it has already well known, managing land use activities could also provide the opportunity for greenhouse gas emission reductions. This Chapter gives some relevant reviews of backgrounds and previous research works that are relevant to these issues and current status of research findings.

2.2 Greenhouse Gases, Greenhouse Effect, Climate Change and Global Warming

Global warming arises because of the additional greenhouse effect induced by rising concentration of greenhouse gases in the atmosphere (Figure 2.1). The important greenhouse gases are water vapors, CO₂, CH₄, N₂O, SF₆, O₃ and CFCs. The greenhouse effect occurs when the atmospheric components absorb solar radiation and trap the remaining heat energy in the lower atmosphere for warming the Earth. In the present, greenhouse gases concentrations are increasing rapidly. Because of the amount of absorbed infrared radiation increases, this leads to increased atmospheric temperature. Consequently, large and consistent climate variability from the past climatic conditions may be resulted. Climate changes, therefore, is used to describe such phenomena. There are concerns such climate change would adversely effects to various environments. For example, mean sea level, human health, terrestrial ecosystems, aquatic ecosystems, plants, and water availability would be adversely affected (Wellburn, 1994).

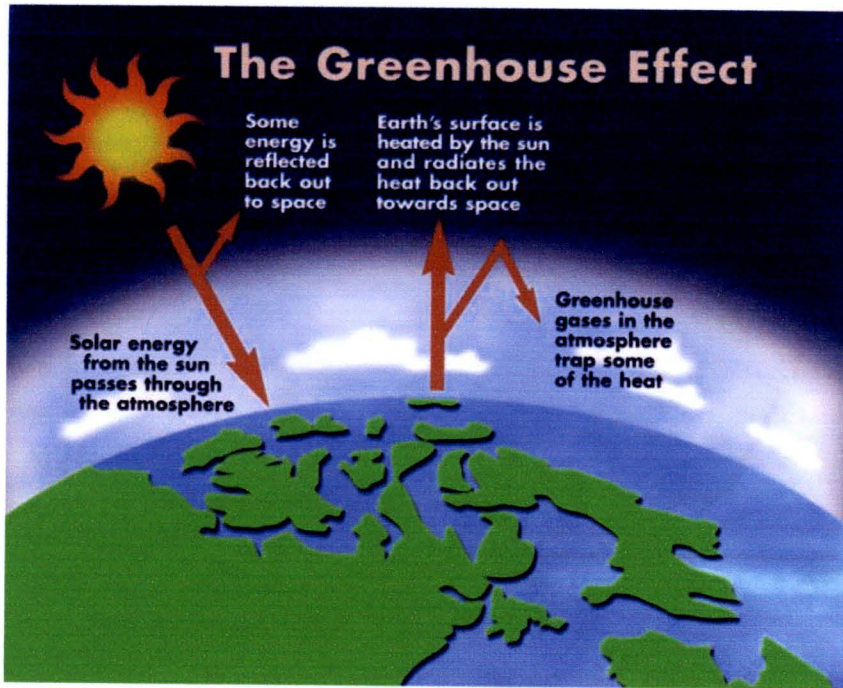


Figure 2.1 The Origin of global warming and the greenhouse effect (Jeremy, 2002)

During the last hundred years, the carbon dioxide concentration of the atmosphere has risen from about 280 to about 360 ppmv and is currently increasing to 381 ppmv in 2005 (Figure 2.2) (Houghton *et al.*, 1997; Kirstin and Thomas, 2007). This is consistent with the data on global emission of greenhouse gases. From 1750 to 1990, the burning of fossil fuels and the clearing of forests has released approximately 160 Gt C as CO₂ into the atmosphere. CO₂ was absorbed by the oceans and terrestrial ecosystems approximately 160 Gt C (Sundquist, 1993 a; Buringh *et al.*, 1984) suggested that before the spread of civilization soils contain about three-quarters of the soil organic matter (Sundquist, 1993b).

Numerical climate model predictions indicate that increased warming by greenhouse gases (mainly CO₂) may add about 1 °C to the global mean temperature by the year 2025, and about 3 °C by the end of the twenty-first century (Jeremy, 2002). Several evidences for such warming have been published, and that shown in Figure 2.3 is one of the examples. An increase over the period since 1860, compared to its average value, has been about 0.6 °C (Haughton, 2004; The UK Meteorological Office, 2007).

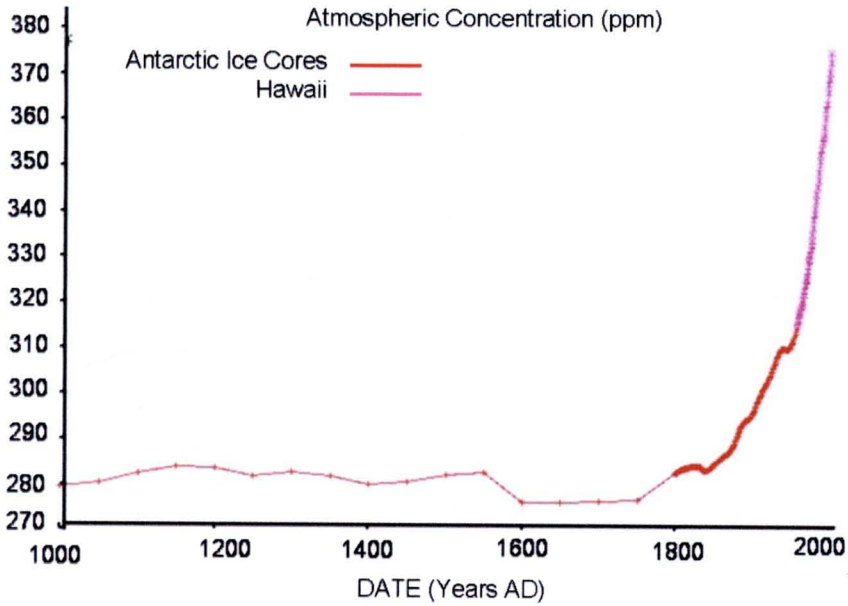


Figure 2.2 Atmospheric CO₂ concentrations during the past 1000 years (Houghton *et al.*, 1997)

**Global near-surface temperatures:
Annual anomalies 1850-2006**

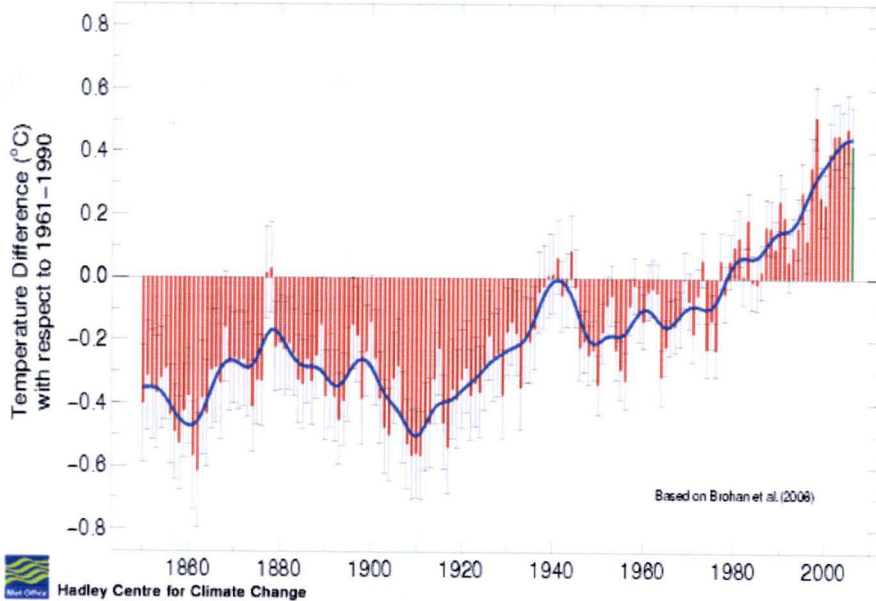


Figure 2.3 Variations of the globally averaged Earth's surface temperature over the last 150 years, the red bars represent the global temperature value for each year, the blue line is the 10-year running average and the green bar is the 2006 value (Haughton, 2004; The UK Meteorological Office, 2007)

2.3 Carbon Cycle

2.3.1 Carbon Cycle in general

Interest in the carbon cycle has increased because of the observed increase in levels of atmospheric CO₂. It is also because of the signing of the UN Framework Convention on Climate Change and Kyoto Protocol that have forced nations to assess their contributions to sources and sinks of CO₂ and to evaluate the process that control CO₂ accumulation in the atmosphere. Over the last few years, our knowledge of the carbon cycle has increased, particularly in the quantification and identification of mechanisms for terrestrial exchanges, and in the preliminary quantification of feedbacks. Atmospheric CO₂ provides a linkage between biological, physical, and anthropogenic process. Carbon is exchanged between the atmosphere, the oceans, the terrestrial biosphere, and more, slowly with sediments and sedimentary (Kreger, 2004).

The global carbon budget is the balance of exchanges (incomes and losses) of carbon between the carbon reservoirs (as know as carbon pools) or within one specific loop of the carbon cycle. The carbon budget of a reservoir can provide information, for example, about whether the reservoir is functioning as a source or sink for carbon dioxide. Carbon is exchanged among pools. The details of carbon pools represented in the diagram as show in Figure 2.4. The main carbon pools are;

- (a) the atmosphere with 70 Gt of carbon
- (b) the upper ocean with about 1,000 Gt
- (c) the deep ocean with some 40,000 Gt
- (d) soil and organic matter with roughly 1,600 Gt
- (e) vegetation with about 600 Gt and
- (f) marine sediments and sedimentary rocks with between 66,000,000 and 100,000,000 Gt (Royal Society, 2005).

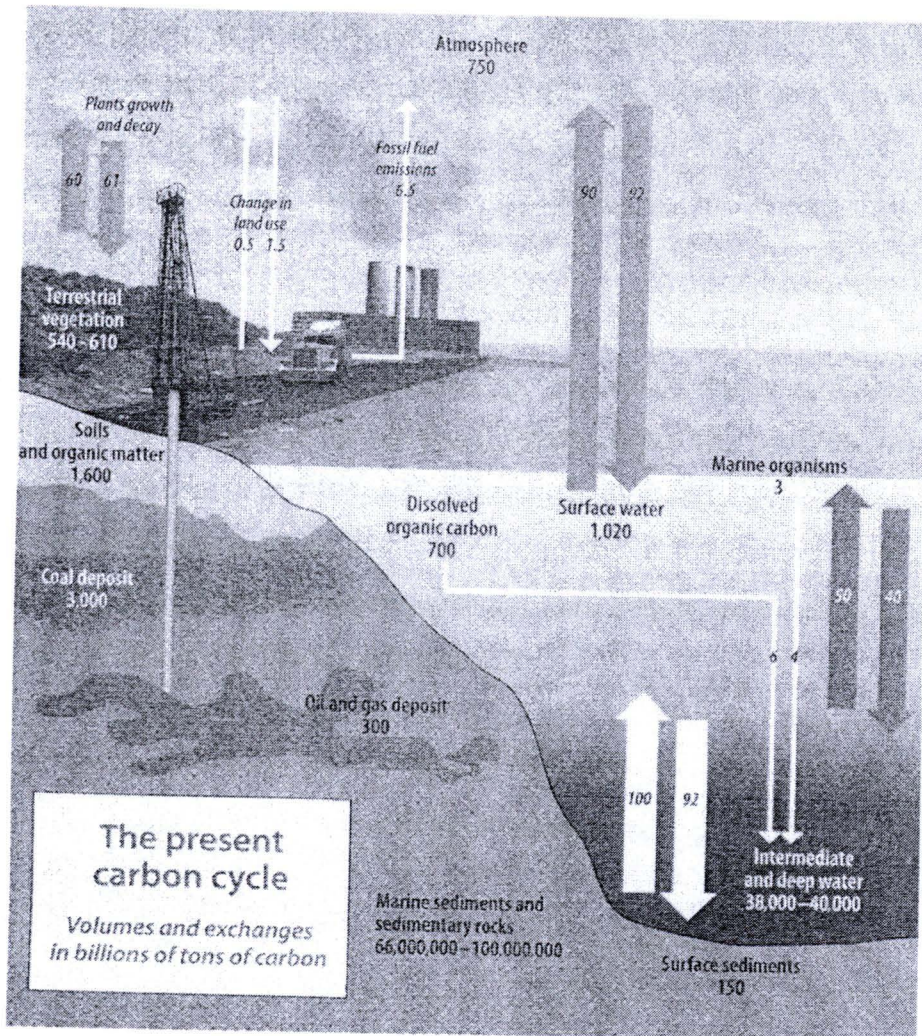


Figure 2.4 The global carbon cycle, including the amount of carbon in every reservoir (unit Gt; gigatons), (Gautier, 2008)

In the cycle, there are various sinks, or sources of carbon and processes. The sink exchanges of carbon are shown by the arrows (Figure 2.4). The process of carbon exchange between the atmosphere and vegetation is by firstly, plants absorb CO_2 from the atmosphere during photosynthesis, also called primary production and release CO_2 back into the atmosphere during respiration. Secondly, major exchanges of CO_2 occur between the ocean and the atmosphere. The dissolved CO_2 in the oceans is used by marine biota in photosynthesis (Gautier, 2008; Kreger, (2004).

The concentration of carbon in living matter (approximately 18% of atmospheric pool) is almost 100 times greater than its concentrations in the earth (approximately 0.19 % of atmosphere). Therefore, living things extract carbon from their nonliving environment. Carbon in the nonliving environment exists in forms of carbon dioxide (CO_2) in the

atmosphere and dissolved in water (forming HCO_3^-), carbonate rocks (limestone and coral, CaCO_3), deposit of coal, petroleum, and natural gas derived from once-living things, dead organic matter and humus in the soil. Carbon returns to the atmosphere and water by respiration (as CO_2), burning and decay (producing CO_2 if oxygen is in present) (Thinkquest, 2008).

The uptake and return of CO_2 are not in balance. The carbon dioxide content of the atmosphere is gradually and steadily increasing. Figure 2.5 shows the CO_2 concentration at the summit of Mauna Loa in Hawaii from 1958 to 2008. The trend increased from 310 ppmv in 1958 to 370 ppmv in 1999 and 380 in 2008 ppmv (IPCC, 1994; Tans, 2008). The seasonal fluctuation is caused by the increased uptake of CO_2 by plants in the summer. The increase in CO_2 probably began with the start of the industrial revolution at the beginning of 19th century as shown in Figure 2.2.

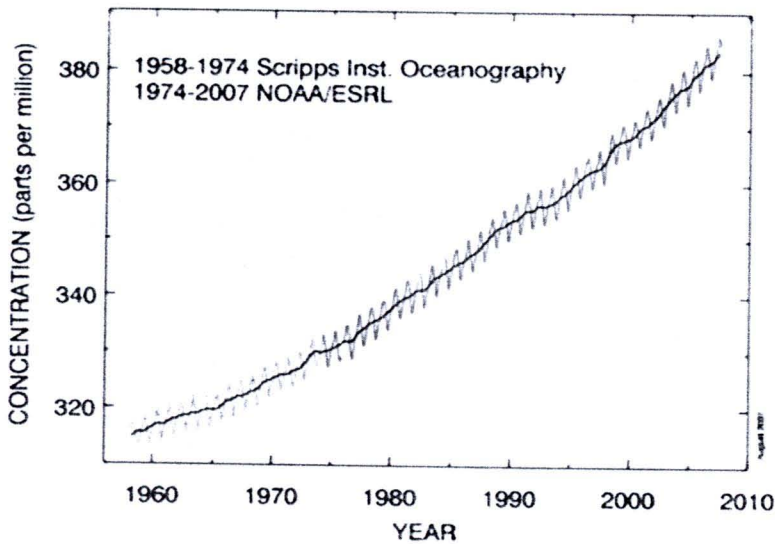


Figure 2.5 Carbon dioxide concentrations (in ppmv) of the air at the Mauna Loa, Hawaii, from 1958 to 2008. In the graph above, the dashed red line represents the monthly mean values, centered on the middle of each month. The black line represents the same, after correction for the average seasonal cycle (Tans, 2008)

Since the measurements of atmospheric CO_2 have begun in the nineteenth century, its concentration has risen over 20%. This increase is mainly caused by human activities such as burning fossil fuels (coal, oil, natural gas, benzyl, diesel and etc.) which returns CO_2 to the atmosphere. This alters CO_2 concentration and exchange rate that has been

locked within the earth for millions of years by clearing and burning of forests, especially in the tropics (Justin *et al.*, 1999).

2.3.1.1 Sources and sinks of anthropogenic CO₂

The main sources of CO₂ emissions are fossil fuels, industrial processes, land use changes, crop and livestock, solid and wastewater. The details are described below.

1. Fossil Carbon Emissions

The main anthropogenic CO₂ sources include those that are generated by fossil fuels use and production of cement. The total emissions of CO₂ from the use of fossil carbon can be estimated based on documented statistics of fossil fuel and cement production (Keeling *et al.*, 1989; Marland and Rotty, 1984; World Energy Council, 1993; Andres *et al.*, 1994).

The trend of used fossil fuels increases rapidly because the growth of industry and population in the world. Emissions of CO₂ by fossil combustion have been increased drastically during the 20th century (Table 2.1). Combustions of fuels were the main CO₂ emitted into the atmosphere.

Table 2.1 Global, U.S. and Indian emissions of CO₂ by fossil fuel combustion (Marland *et al.*, 1999)

Year	Emission (million tons C/year)		
	Global	India	U.S.
1750	3	-	-
1800	8	-	0.07
1850	54	0.03	5
1900	534	3	180
1950	1630	5	692
1970	4075	14	1152
1980	5297	26	1263
1990	6096	50	1314
1998	6608	79	1487

2. Land use changes

Land use changes depend upon human activities, such as clearing forest and converting it to cropland. When human destroyed the forest for agriculture the area or the process that uptakes CO₂ is decreased. Land use change and forestry can be both emissions source and sink of CO₂ depending on management of land use or forestry

(Ministry of Natural Resources and Environment, 2004). CO₂ is stored when trees absorb CO₂ from the atmosphere through the process of photosynthesis. CO₂ emissions were the results of the harvesting, deforestation and utilization of woody biomass. CO₂ sequestration may be achieved by reforestation, tree planting and the natural regeneration of abandoned land. Therefore, the amounts of CO₂ emitted and sequestered from forests are very difficult to estimate because of complex biological factors and the lack of reliable data, especially with regards to the rate of land use changes, the use of converted forest land, and the biomass density of forests (Houghton, 2000). IPCC estimates put carbon dioxide emissions from deforestation, including decomposition following logging operations, to be between 7 and 16 % of the world's contribution in 2004. Carbon dioxide is removed from the atmosphere and stored in plants and soils approximately 100 billion metric tons per year. This means conversion of natural forest to agriculture ecosystem contributes to a net emission of CO₂ and other greenhouse gases.

Table 2.2 was shown land use change contribution to carbon sources and sink into the atmosphere in 1990s. The highest rates for carbon sinks occurred by deforestation in the tropical regions and carbon sources occurred by harvest management on re-growth (Haughton, 2003).

Table 2.2 Estimates of the associated sources (+) and sink (-) of carbon (Pg C yr⁻¹ for the 1990s) from different types of land use change and management (Haughton, 2003)

Activity	Tropical regions	Temperate and boreal zones	Globe
1. Deforestation	2.110*	0.130	2.240
2. Afforestation	-0.100	-0.080	-0.180
3. Reforestation (agricultural abandonment)	0*	-0.060	-0.060
4. Harvest/management	0.190	0.120	0.310
a. Products	0.200	0.390	0.590
b. Slash	0.420	0.420	0.840
c. Re-growth	-0.430	-0.690	-1.120
5. Fire suppression	0	-0.030	-0.030
6. Non-forests			
a. Agriculture soils	0	0.020	0.020
b. Woody encroachment**	0	-0.060	-0.060
Total	2.200	0.040	2.240

*Only the net effect of shifting cultivation is included. The gross fluxes from repeated clearing of follow lands and temporary abandonment are not included.

** Probably an underestimate. The estimate is for the US only, and similar values may apply in South America, Australia, and elsewhere.



3. Agriculture

Emissions in agriculture were from three major sub-sectors: rice, livestock and agricultural soils. The main CO₂ released in this sector come from biomass burning such as rice field, sugarcane biomass and etc. (Ministry of Natural Resources and Environment, 2004). Agricultural soil emits CO₂ at various rates and quantity, depending on field management such as tillage, transportation, farm operation, water and fertilization managements. Therefore agriculture activities release CO₂ and also deplete the soil C pool. West and Marland (2002) analyzed the full carbon cycle for agriculture ecosystems in the United States the results show the difference CO₂ emission contribution from farm management. For example difference tillage practice results in a difference net carbon flux. By these, reduced tillage can significantly reduce CO₂ emission to the atmosphere.

4. Soil

Soil is the largest near-surface pool of global carbon (William *et al.*, 2000). It stores carbon approximately 1550 Pg C in the organic form and 950 Pg C in inorganic form. Totally, the soil carbon pool of 2500 Pg and this is 3.3 times the atmospheric pool of 760 Pg and 4.0 times the biotic pool of 2500 Pg (Bahtti *et al.*, 2006). Since the carbon pool was large and dynamic, the increase and decrease of carbon in the soils could effect the concentration of CO₂ in the atmosphere. Soil C sequestration process removes the atmospheric CO₂ by plants storage CO₂ and fixed C as soil organic matter. The mechanisms of protection of soil organic carbon sequestration in soil include physical, chemical, and biological processes. C sequestration in agriculture soil is an important strategy of reducing the net emissions of CO₂ into the atmosphere. The rates of C sequestration reported from many researchers depended on many factor, for example; soil, climate, land use, management and method of assessment. The rate of soil organic carbon sequestration ranges from 300 to 500 kg C/ha/yr upon conversion from plow tillage to no-till and 100 to 400 kg C/ha/yr by input of N and integrated nutrient management (Bahtti *et al.*, 2006).

5. Industrial Process

Industrial production processes also emit GHG. The most significant GHG from industrial process is CO₂. Industries processes that emit CO₂ include cement production, lime manufacturing, glass production, pulping process, iron and steel production, other

chemical production, food and drink, bread production and fermentation process. Cement production was the largest contributions of CO₂ from industrial process by emitting nearly 93 %, followed by lime production (6 %). The remaining industrial process produces a marginal amount of CO₂ (Ministry of Science, Technology and Environment Thailand, 1994).

2.3.2 Global Carbon Budget

Carbon budget is defined as the balances between sources and sinks of CO₂ in the atmosphere. It is usually referred to as the balance between anthropogenic emissions and fluxes between the main reservoirs; the oceans, the atmosphere, the terrestrials' carbon pool, and build-up of CO₂ in the atmosphere. Because of the relatively stable of atmospheric CO₂ concentration over several thousand years prior to AD 1800, it is assumed that the net fluxes among carbon reservoir were close to zero prior to anthropogenic disturbance.

The major components of the anthropogenic distribution to the atmospheric carbon budget, with estimates of their magnitudes over the 1980s, were emissions from fossil fuel combustion and cement production, atmospheric increase, carbon uptake, tropical land use changes and forest re-growth (Wgley and Schimel, 2000). Table 2.3 shows CO₂ sources and partitioning among reservoirs of CO₂ in the atmosphere and other places.

Table 2.3 Average annual budget of CO₂ perturbations for 1980 to 1989. Fluxes and reservoir changes of carbon are expressed in Gt C/yr, error limits correspond to an estimated 90% confidence interval (Wgley and Schimel, 2000)

Descriptions	IPCC 1995
CO₂ sources	
(1) Emissions from fossil fuel combustion and cement production	5.5±0.5
(2) Net emission from changes in tropical land use	1.6±1.0
(3) Total anthropogenic emissions =(1)+(2)	7.1±1.1
Partitioning among reservoirs	
(4) Storage in the atmosphere	3.3±0.2
(5) Ocean uptake	2.0±0.8
(6) Uptake by Northern Hemisphere forest re-growth	0.5±0.5
(7) Other terrestrial sinks = (3) +((4)+(5)+(6)) (CO ₂ fertilizations, nitrogen fertilizations, climatic effects)	1.3±1.5

Table 2.4 shows fluxes of CO₂ in terms of emissions to the atmosphere and absorption by sinks. The data show the net atmospheric CO₂ increase of 3.2 Gt C/ha during 1990-1999.

Table 2.4 Annual global budgets of carbon dioxide (Jeremy, 2002)

Component	Flux/ Gt C/ha
Emission to atmosphere from fossil fuel combustion and cement manufacture	6.3
Flux from atmosphere to ocean	-1.7
Flux from atmosphere to land	-1.4
Net atmospheric increase	3.2

The terrestrial sources and sink of carbon in 1980s and 1990s was represented in Table 2.5. The budgets were fluctuated from 1980s to 1990s. In the part of fossil fuel utilization was increased from 1980s to 1990s. In addition, the global terrestrials were net sinks for carbon between 1980s and 1990s. The reason for a large increase in the terrestrial sink is unknown. Unexplained is in the decrease of carbon sink in the oceans may be in the large emissions of fossil fuel and higher in the atmospheric concentration of CO₂ in the second decade (Haughton, 2003).

Table 2.5 Global carbon budget for the 1980s and 1990s (Pg C/yr), (Haughton, 2003)

	1980s	1990s
Fossil fuel emissions	5.4 ± 0.3	6.3 ± 0.4
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.2
Oceanic uptake	-1.7 ± 0.6	-2.4 ± 0.7
Net terrestrial flux	-0.4 ± 0.7	-0.7 ± 0.8
Land use change	2.0 ± 0.8	2.2 ± 0.8
Residual terrestrial flux	-2.4 ± 1.1	-2.9 ± 1.1

Negatives values indicate a sink of CO₂ from the atmosphere.

2.3.3 Sugarcane plantation and carbon flow

The main part of sugarcane plants consists of stems, roots, leaves and inflorescence.

Stems: The stem, also the cane or culm, is divided into a series of joined, each consisting of a node and internode. The buds are alternate on the stem and the leaf sheath envelopes the stem for a considerable time. By harvest time there are 20-30 internodes on

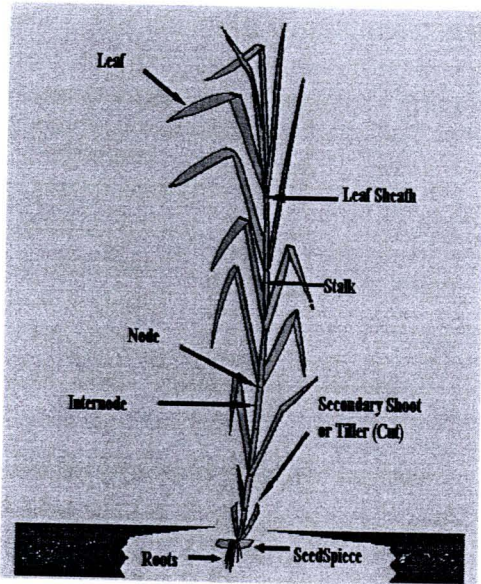
a single stem, each internode being 10-20 cm long, depending on climate and plant nutrition. Stems vary in length from 1.5-4.0 m – typically 2.0-3.0 m and are normally 2.0-4.0 cm in diameter. Individual stems weight between 500 g and 2.0 kg. Cane color depends on the variety and on exposure to the sun, which has a darkening effect. The most commonly found colors of cane are yellowing green and purple. As a result of tillering, a clump of stool 5-20 stems usually develops. Theses, when fully grown, will be of different ages, lengths and diameters, with a growth habit that can, according, to variety, be erect open, spreading or tangled. By this stage they will be more or less free of dried leaves or trash. Stem sugar content is variable from stem to stem with large, late-formed watery tillers having very low sugar content. In an individual stem, the amount of sugar is usually highest near the base decreasing towards the tip (Figure 2.6 a) (Fauconnier, 1993).

Roots: The plant develops a number of different rooting systems at different stages of its growth. The initial roots, those of the sett, are thin, branched, superficial and transitory. They are succeeded by stem roots which are straighter, longer and more permanent. The root have two functions that of supplying nutrients and moisture and that of physically supporting the plant. Evans, Smith *et al.* (2005) classified sugarcane roots into two groups. The first are superficial, branched and have a supplying role. The next are the last is a rope-like system growing downwards of as much 6 m in favorable soil conditions. Half the plant roots are in the top 25 cm of the soil and 90% are within 60 cm of the soil surface. It is often stated that the ratio between stem weight and root weight is significant. However, a good crop of cane cannot be grown without a well-developed root system. Soil moisture, aeration and temperature all affect root development (Figure 2.7 a and b), (Fauconnier, 1993). The root system of a young sugarcane plant were showing sett root growing from the nodes of the sett and shoot roots emerging from the base of the young shoot. The root system of an established sugarcane stool shows three functional types of roots, the superficial, buttress and rope roots (Smith *et al.*, 2005).

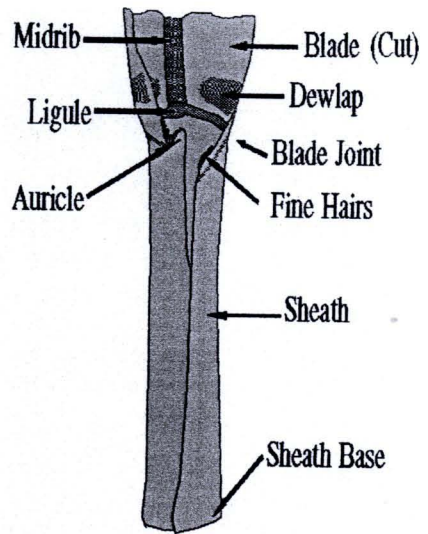
Leaves: The leaves are borne alternately. Each leaf consists of sheath and a blade, with a ligule, a memebrous appendage sheath of the separating the two parts. The ligule can be used as a distinguishing characteristic between varieties of cultivars. The blade is 2-10 and across 60-150 cm long. The color, growth habit, size etc. of the blade can also be used to distinguish between cultivars. A good crop of cane in full growth can have a leaf area times grater than the area of soil on which the crop is growing (Figure 2.6 b), (Fauconnier, 1993). The mature sugarcane plant has an average total upper leaf surface of

about 0.5 square meters and the number of green leaves per stalk is around ten, depending on variety and growing conditions.

Inflorescence: The inflorescence, arrow or tassel consists of a branched panicle with a vertical axis. The size, shape and color of the arrow are also used to identify cultivars. Sugarcane seed is minute and is in fact a fruit or caryopsis. The development of the arrow and the amount of arrowing and growth habit etc. are all of importance to agronomists and plant breeders (Fauconnier, 1993).

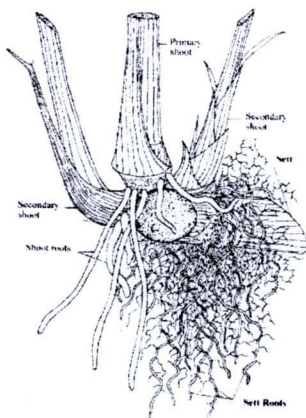


(a) Sugarcane plant part

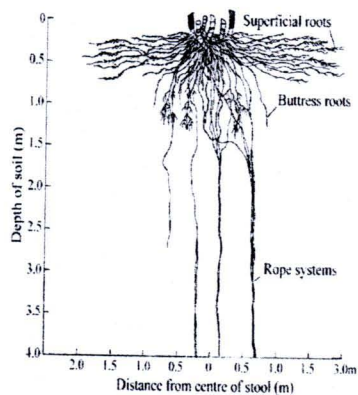


(b) Sugarcane leaf

Figure 2.6 Sugarcane plant part



(a) The root system of a young sugarcane plant, showing sett root growing from the nodes of the sett and shoot roots emerging from the base of the young shoot (Smith *et al.*, 2005)



(b) The root system of an established sugarcane stool, showing three functional types of roots, the superficial, buttress and rope roots (Smith *et al.*, 2005)

Figure 2.7 Sugarcane root system

The chemical of sugarcane plant part were separated to sugars, cellulose, hemicellulose, holo-cellulose and lignin as describe in table 2.6. These chemicals play the important roles to the rate of decomposition in each sugarcane components. The approximate distribution of these together with other components generally are as follows; cellulose (15-60%), hemicellulose (10-30%), lignin (5-30%), soluble waste (5-30%), organic solvents, proteins, and other (ash 1-13 %).

Table 2.6 The chemical compound components of sugarcane parts (Hawai, (2002).

Biomass source	Sugars	Cellulose	Hemi-cellulose	Holo-Cellulose	Lignin	Others
Sugarcane (prepared cane)	43	22	15	37	11	9
Sugarcane leaves	-	36	21	57	16	27
Sugarcane (whole plant)	33	25	17	42	12	13
Bagasse	3	38	27	65	20	12

Prepared cane: Cane after washing off mud and rocks; still has some leaves and water.

2.3.4 Sugarcane soil organic carbon

There are some studies have been made on the soil organic carbon in sugarcane area. The study results were as follow:

First, Osher *et al.* (2003) was studied the effect of land use change on soil carbon in Hawaii. There were estimated changes in soil carbon storage after approximately a century of each land use by using stable carbon isotope values and carbon contents. A result of conversion of tropical forest to pasture and sugarcane cropland were represented total organic carbon stored in soils varied as a result of management, with pasture soils showing net carbon gain (12-15%) and sugarcane soil showing net carbon loss (7-25%). The proportional carbon gains and losses were significantly grater, relative to forest soil carbon contents, difference in rainfall in 2500 mm/yr sites than in 4000 mm/yr sites. In addition the results of this studied conclude that carbon contents of soil (kg/m to 1 meter depth) under pasture and sugarcane management was significantly different from soils under forests in both higher rainfall ($p < 0.05$) and lower rainfall sites ($p < 0.001$).

Second, Naranjo *et al.* (2006) was studied and valuated the change in the fertility in Maxican Fluvisols under continuous cultivation of sugarcane (30 years of cultivation). Three representative plots under monoculture for 5, 10, 20 and 30 years, were selected under on-farm conditions. The soil samples were collected at 0-30 cm soil depth and

composite sample. The results show that there were significant changes in the soil chemical properties due to 30 years of monoculture. Total soil organic C, total N and P were declined by 17, 21 and 37%, respectively. These losses mainly occurred during the first 20 years of cultivation (Figure 2.8). However, the effect of decline in soil fertility was not reflected in the sugarcane yields. The 67 % increase in yields observed between 5 and 30 years of monoculture may be attributed to the adoption of recommended cultural practices and to farmer's experience. Soil physical properties; soil bulk density were not affected by the intensive sugarcane cultivation. There were no significant differences in soil bulk density but a declining trend is occurred with the duration of sugarcane monoculture (bulk density is 1.12 g/cm). This non-significant decline differs slightly from the relatively constant bulk density value of a Fluvisol (1.17 g/cm).

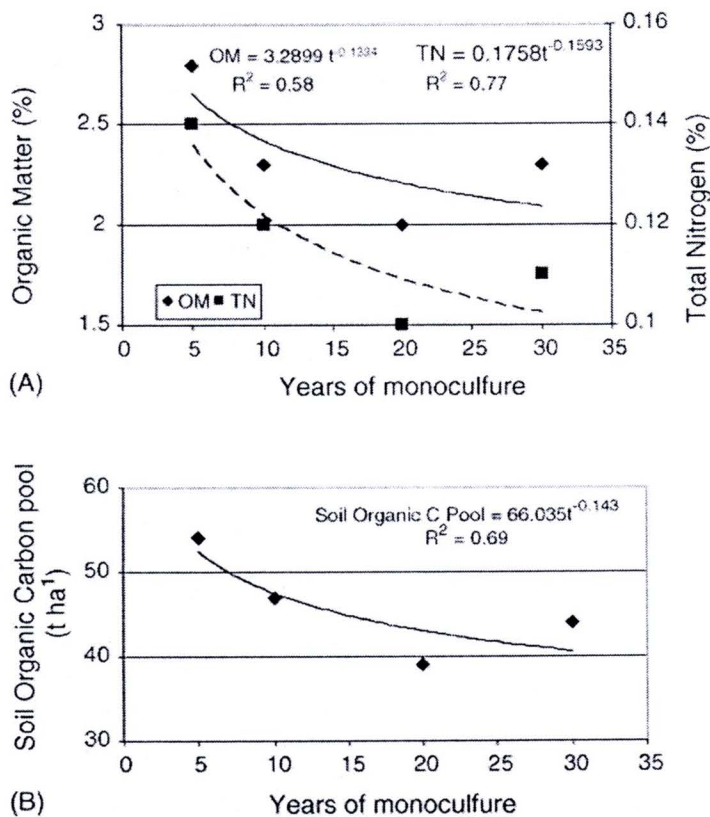


Figure 2.8 Changes with time of soil organic matter, total nitrogen and organic carbon content under sugarcane monoculture from 30 years, (Naranjo *et al.*, 2006)

Third, Mubarak *et al.* (2005) was studied on long-term (> 40 years) and short-term (<10 years) effects of cultivation on properties of a Vertisol under sugarcane Plantation in Blue Nile. There were compared to native vegetation; the area was from a zone of open

grassland receiving no fertilization, irrigation, nor grazing, in the semi-arid tropical region of Sudan. Under short- and long-term cultivation, about 400 m³ of irrigation water was added every 10 days in summer and 14 days in winter to cane plants (for a period of 14–16 months) and ratoon (for a period of 12–14 months). Fertilization was applied by applying 4 months after planting with 220 kg N/ha (annually) and 100 TSP/ha (every 3–5 years). The tillage practices were carried out for land preparation at the end of the fifth ratoon. The results show that particulate organic matter (POM is the organic material recently added to the soil, in initial stages of decomposition and with particles larger than μm) with long-term (8.2 g/kg) and short-term cultivation (6.6 g/kg) were significantly ($P \leq 0.007$) higher than for native vegetation (2.1 g/kg). In the 0–10 cm soil depth, cultivation had no effect on total nitrogen (TN), organic carbon (OC) and bulk density (Bd). However, in the 10–20 cm soil depth, significantly ($P \leq 0.03$) greater N was present under the long-term cultivation (0.46 g/kg) than under native vegetation and short-term cultivation (0.26– 0.33 g kg⁻¹). At 10–20 cm, soil bulk density under long-term cultivation (1.5 mg/m³) was lower ($P \leq 0.01$) than under short-term cultivation (1.8 mg/m³) and native vegetation (1.7 mg/m³). At 20–30 cm, TN and bulk density were not affected, but OC was significantly ($P \leq 0.009$) higher under native vegetation (4.9 g/kg) than under short-term cultivation (1.7 g/kg). It could be concluded that, long-term production of sugarcane in fine textured soils (>52% clay) improved soil properties relative to native vegetation (grassland) in the semi-arid tropics. Moreover, application of fertilizer N in the long term and short term cultivation probably increased N content of POM compared to that native vegetation (grassland).

Fourth, Galdos *et al.* (2009) was studied soil carbon stocks under burned and unburned sugarcane in Brazil. The objective of this study was to evaluate the effect of trash management on carbon dynamics of the sugarcane crop. In the plots sugarcane had been replanted 2, 6 and 8 years before the soil samplings, with and without pre-harvest burning. An area of native vegetation (tropical semi deciduous forest) was also sampled, as a reference. The soil samples were analyzed for bulk density, sand, silt and clay content, total carbon, carbon in the particulate organic matter and microbial biomass carbon. The studied show that the soil microbial biomass carbon and the particulate organic matter carbon were more sensitive to residue management changes than total carbon. The area with the longest period of adoption of the unburned management, 8 years, had higher contents of total carbon (30% higher than the area where the residues

were burned). The total carbon stocks were also higher in the unburned treatment, mainly in the area with 8 years of green cane management. There was a decrease in soil total carbon concentration after long term sugarcane cropping converted from forest, on the surface layer. The carbon concentration for the 0-10 cm layer in the native forest was 30.12 g/kg. The carbon concentration was 36% lower than in the native forest area. In the sugarcane fields, the total carbon concentration was 30% higher in the unburned management in the 0–10 cm layer, in the area with 8 years after replanting. There was no significant difference, though, between treatments in the 10–20 cm layer. There was a statistical difference between treatments in the area with 8 years after replanting. In the area with 8 years after replanting, the unburned area had higher stocks than the burned area. Figure 2.9 was represented carbon stocks between burned and unburned areas were also compared down to 100 cm. There was higher C stocks in the areas with 2 and 8 years after replanting with density correction in the 0–100 cm depth.

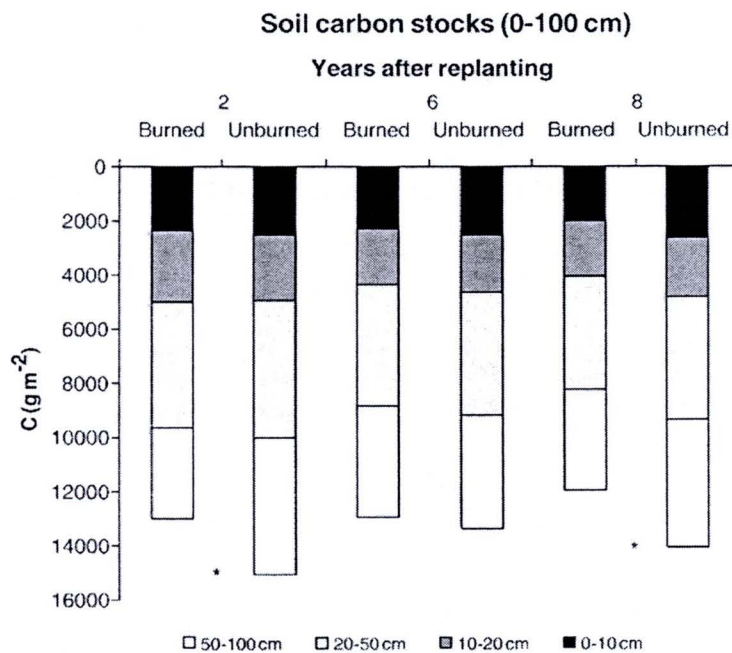


Figure 2.9 Soil carbon stocks in the 0–10, 0–20, 0–50 and 0–100 cm depths in sugarcane areas with 2, 6 and 8 years after replanting, compared to the same soil mass. The star indicates statistical difference at 5% of significance between burned and unburned treatments (Galdos *et al.*, 2009).

The next, Silva *et al.* (2007) was studied the impact of sugarcane cultivation on soil carbon fractions, consistence limits and aggregate stability of a Yellow Latosol in

Northeast Brazil. The studied was located in four areas; this included a native forest and sugarcane fields cultivated for periods of 2 years, 18 years and 25 years. The samples were collected from each area at 0–0.2 and 0.2–0.4 m depth, to determine total organic C, physical fractionation of soil organic matter and consistence limits. The results show that in relation to the soil under native forest, total organic C and particulate organic matter contents were reduced after 2 years of cultivation. Sugarcane cropping for a longer period promoted a recuperation of soil organic matter content. The decrease of total organic C and reduction in aggregate stability after 2 years of sugarcane cultivation rendered the soil more susceptible to compaction. Figure 2.10 was show the results of total organic carbon (TOC) associated with minerals (MOM) as function of the time of sugarcane cultivation in the layers of 0–0.2 and 0.2–0.4 m depth.

The results concluded that there was a reduction of TOC at the beginning of cultivation with sugarcane (2 years), compared with the soil under native forest (cultivation time = 0), in the 0–0.2 and 0.2–0.4 m layers (Figure 2.10). The decrease of TOC in the first years of sugarcane cultivation has been observed previously (Masilaca *et al.*, 1986; Silva and Ribeiro, 1998). This reduction was likely a consequence of the mechanical removal of the natural vegetation and of the fast decomposition of organic matter, resulting in disturbance of the equilibrium of the natural ecosystem. At 18 and 25 years of cultivation, the TOC content in the layers of 0–0.2 and 0.2–0.4 m was similar to those under native forest (Figure 2.10). There are suggesting a recovery of the soil organic matter content with longer time of sugarcane cultivation with organic matter input from filter cake and other fertilizer.

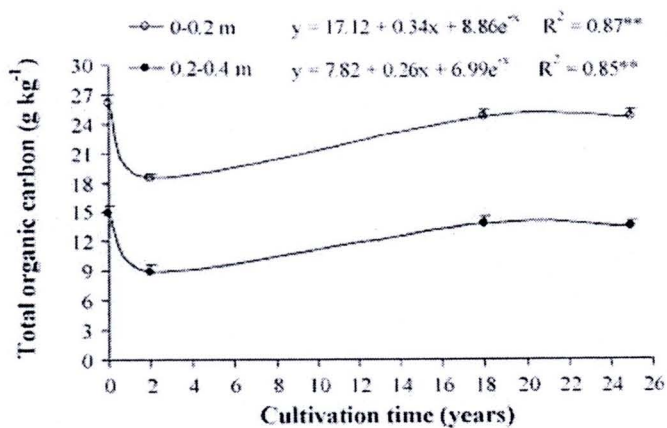


Figure 2.10 Total organic carbon (TOC) associated with minerals (MOM) as function of the time of sugarcane cultivation in the layers of 0–0.2 and 0.2–0.4 m (Silva *et al.*, 2007)

Finally, Yoneyama *et al.* (2006) studied the effects of vegetation and cultivation on $\delta^{13}\text{C}$ values of soil organic carbon and estimation of its turnover a case study in Thailand. Soil samples were collected from two natural forests located at Khon Kaen and Kanchanaburi in October 1997, rice fields located at Suphan Buri, where lowland rice (50 years of continuous cultivation) and sugarcane fields (40 years of continuous cultivation) with located at Song Phi Nong were collected in November 1998. They also collected soil samples from natural forests and sugarcane fields in the Northeastern Region in October 1997 and from fields with two vegetation types in the Central Plain Region in November 1998. The results show that conversion of forest land to sugarcane field contribute to a rapid decrease in soil organic carbon content and an increase in the soil $\delta^{13}\text{C}$ values. The calculated forest-derived carbon rapidly decreased with a half-life of 0.35 years (in the Northeastern Region) after conversion to sugarcane fields, and sugarcane-derived carbon steadily accumulated (Figure 2.11 and 2.12).

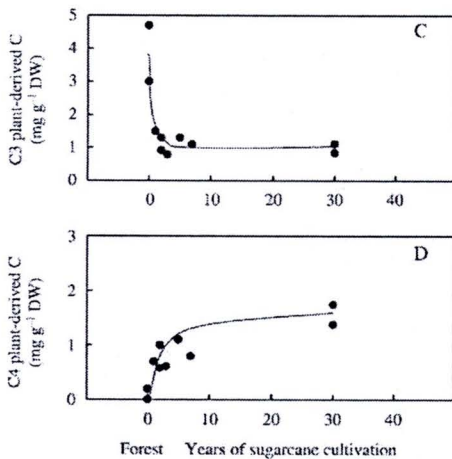


Figure 2.11 (C) C3 plant (forest)-derived carbon content and (D) C4 plant (sugarcane)-derived carbon content in the 0–30 cm soil layer of forests (0 year) and sugarcane fields cultivated for 1 to 30 years in the Northeastern Region of Thailand. Sampling sites were as follows: d Khon Kaen; c, Namphoy. Data correspond to three replicates (Yoneyama *et al.*, 2006)

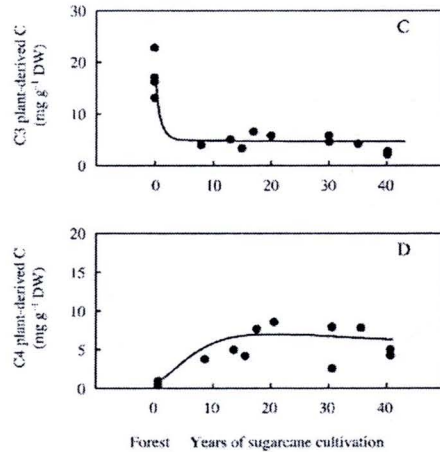


Figure 2.12 (C) C3 plant (forest) derived carbon content and (D) C4 plant (sugarcane)-derived carbon content in the 0–30 cm soil layer of forests (0 year) and sugarcane fields cultivated for 8 to 40 years in the Central Plain Region of Thailand. Sampling sites were as follows: c, d, Kanchanaburi forests (Yoneyama *et al.*, 2006).

2.4 Full carbon accounting in sugarcane production system

The frameworks of CO_2 and other greenhouse gas emissions in sugarcane production are shown in Figure 2.13. The flow of carbon in sugarcane production is

important because of the potential of sugarcane as source of renewable energy. The C flow in sugarcane production can be divided into two parts. First, in sugarcane plantation including C-fossil fuels utilized for agriculture production and carbon emitted during sugarcane plantation. The second part includes the portion of C that is cycled in sugarcane processing such as industries or sugarcane bioenergy system (Figure 2.13).

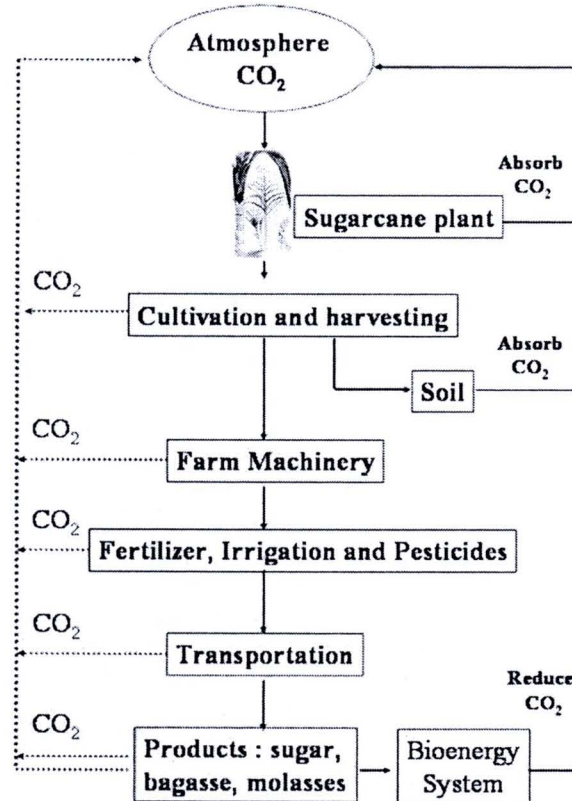


Figure 2.13 C flow in the sugarcane production, solid line indicates carbon uptake while dot line indicates carbon release or emission

2.4.1 Carbon flow in sugarcane agricultural part

West and Marland (2002) proposed the concept of carbon flow and accounting in an agricultural system. An application of this concept is demonstrated in Figure 2.14 and Figure 2.15. Carbon is emitted from agriculture by various processes including (1) decomposition of crop residues (2) production and application of crop inputs, (3) direct use of fossil fuels from farm machinery, and (4) burning or other oxidation of biomass. The process of CO₂ uptake is photosynthesis and carbon sequestration in soil (West and

Marland, 2002). The net contribution of the sugarcane production to atmospheric CO₂ can be described in the details as follow.

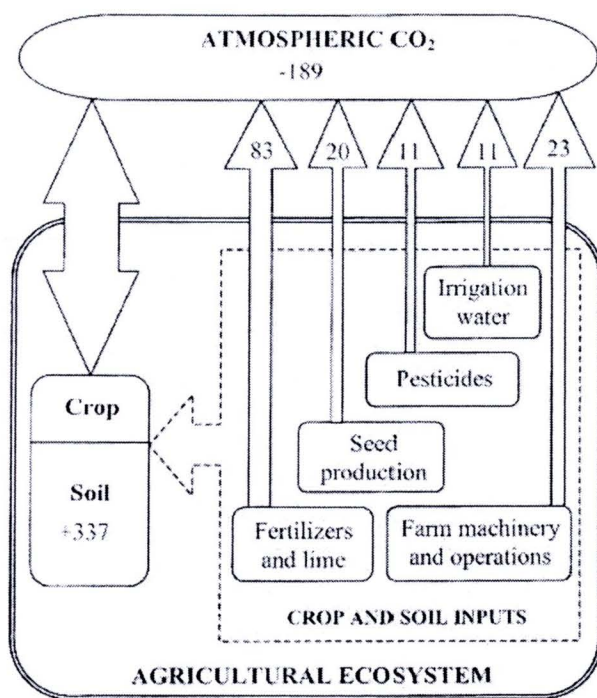


Figure 2.14 Example of annual carbon fluxes in agriculture ecosystems for the early years following a change from conventional tillage to no-till based on average US crop inputs. Values embedded in arrows measure rates of flow; other values measure changes in stocks. Rates of flow between the atmospheres and biosphere (crop/soil pool) are inherent in the change in soil carbon stock. Units in kg C/ha/yr based on data in West and Marland, (2001), West and Marland (2002).

2.4.1.1 Carbon sequestration in the soil

Soil can act as both atmospheric carbon sinks and sources, depending on the amount of the input organic matter such as crop residues and land management. Carbon sequestration is defined as an increase in long-term terrestrial carbon stocks, and thus results in reducing the atmospheric CO₂ concentration (West and Marland, 2001).

Carbon sequestration in soil depends significantly on soil management (Table 2.7). Such includes zero tillage, reduced tillage, permanent crops, and conversion of cropland to grassland. Freibauer *et al.* (2004) showed the good example of carbon sequestration potential in cropland soil in EU countries. This estimation was based on available of land, biological resources and land suitability and the potentials estimated to be realistically

achievable by 2012 adapted from figures in Freibauer *et al.* (2004), as given in Table 2.7 (Smith, 2004). The emergence of soil C sequestration as an issue has resulted in a large effort to compile database of SOC stocks at scale ranging from the plot to the globe.

Table 2.7 Carbon sequestration potentials limited only by availability of land, biological resources and land-suitability, and the potential estimated to be realistically achievable by 2012 adapted from figures in (Freibauer *et al.*, 2004; Smith, 2004)

Practice	Soil carbon Sequestration potential (t C/ha/yr)	Total soil carbon Sequestration potential for EU15 (Mt C/yr) ^a	Realistic soil carbon Sequestration potential for EU15 (Mt C/yr) by 2012
Zero tillage	0.38 (0.29)*	24.4	2.4
Reduced tillage	<0.38	<24.4	<2.4
Set-aside	<0.38	2.4 (maximum)	0
Permanent crops	0.62	-	-
Deep-rooting crops	0.62	-	-
Animal manure	0.38 (1.47)*	23.7	-
Cereal straw	0.69 (0.21)*	5.5	-
Sewage sludge	0.26	2.1	-
Composting	0.38	3	3
Improved rotations	>0	0	-
Fertilization	0	0	0
Irrigation	0	0	0
Bioenergy crops	0.62	4.5	0.9
Extensification	0.54	11	-
Organic farming	0-0.54	3.9	3.9
Convert cropland to grassland	1.2-1.69 (1.92)*	8.7-12.3	0
Convert cropland to woodland	0.62	4.5	4.5

All estimates are based on extrapolation from Smith *et al.* (2000) except those marked by asterisk (*).

For full list of assumptions, limitations and sources, see Freibauer *et al.* (2004).

^a Carbon sequestration potentials limited only by available of land, biological resources and land-suitability.

An important technique for creating a database of large scale SOC stocks is GIS, technique which can be used to study soil carbon. Generally, the data needed for processing and predicting soil organic carbon include; soil types, soil properties (soil organic matter), soil physics, soil chemical, soil texture, soil deep, soil moisture regimes; land cover such as vegetation types, precipitation, temperature, climate and elevation. This study were applying such method, we are able to estimated soil carbon in sugarcane area in Eastern Thailand. Therefore, the example from the previous studied on soil organic carbon in semi-arid Sudan using GIS and the CENTURY model. The aim was to predict soil organic carbon related with GIS techniques and data such as climate, soils, vegetation, land use, precipitation, temperature, soil texture, land cover and land management. By integrating the database with the CENTURY ecosystem model, they were able to estimate historical, current and future pools of soil organic carbon as a function of land management and climate. Model predictions were compared with field data for validation of the

model's performance. Possible errors and suggested improvements were discussed. The results suggested the requirement of the input data of high quality and details to produce reliable estimates. Modeling was a helpful tool when assessing the future C sequestration potential, impacts on climate, management and land use on soil organic carbon dynamics on a regional level (Jonas and Lennart, 2003; Falloon *et al.*, 1998).

2.4.1.2 CO₂ uptake by photosynthesis

Photosynthesis is the only process that uptake CO₂ from the atmosphere. The photosynthesis process is the conversion of carbon dioxide and water into a sugar called glucose using sunlight energy. Oxygen is produced as a waste product. The best known form photosynthesis is the one carried out by higher plants and algae as well as by cyanobacteria and their relatives, which are responsible for a major part of photosynthesis in oceans. All these organisms convert CO₂ to organic material by reducing this gas to carbohydrates in a rather complex set of reactions (Vermaas, 1998).

2.4.1.3 Decomposition of crop residues

CO₂ is released by the decomposition of crop residue and soil organic carbon (SOC). Therefore, sugarcane produces a large quantity of biomass, leaves and root after harvest which upon decomposition enriches soil fertility. From the process and mechanism of decomposition enhance the CO₂ emission and some of improve soil fertility by store soil organic carbon by decomposition process. Combined with conservation tillage, cover crops have been shown to improve the productivity of degraded soils in the Southeastern USA (Bruce *et al.*, 1995; Sainju *et al.*, 2002). Agriculture management contributed to rate of biomass decomposition; for example tillage practice. If agriculture soil is disturbed by tillage methods, the rate of decomposition and oxidation of soil organic matter increases. The products of decomposition were carbon dioxide, heat, water and the final humus-like material that call compost. Tillage of soils often decreases soil organic matter content and increases the flux of carbon dioxide (CO₂) from soils. Additionally, the microbial-controlled decomposition of soil organic C that affects soil CO₂ flux is dependent on several plant, soil, and climatic conditions that also are affected by tillage. Plant factors include age, amount, and the C:N ratio of plant residue (Parr and Papendick,

1978; Ghidey and Albert 1993). Tillage has both direct and indirect effects on crop establishment and residue decomposition. Tillage directly effects residues fragmentation and distribution as well as seed placement within the seedbed. Tillage indirectly effects environmental conditions which effect residue decomposition, seed germination and seedling emergence. The resulted from the previous studied in sugarcane plantation in Brazil show that intensive land preparation term of conventional tillage gave a highest rate of soil CO₂ emission than reduced tillage and no-tillage as well as no burning of crop residues left on soil surface after harvesting. The resulted was about 0.47- 1.11 g CO₂/m²/h in no-tillage, 0.74-2.41 g CO₂/m²/h in reduced tillage and 1.29-2.90 g CO₂/m²/h in conventional tillage, respectively. Although it is know that crop residues are important for restoring soil carbon, this results indicates that an amount equivalent to approximately 30% of annual crop carbon residues cloud be transferred to that atmosphere after plowing tropical soils, in a period of 4 weeks only, when conventional tillage is applied on no-tilled soils (Scala, *et al.*, 2006). This is similarly results about no-tillage gave a lower soil CO₂ flux than tillage practice in semi-arid soil (Ellert *et al.*, 1999).

Duiker and Lal (2000) found that the rate of input residue is related to the rate of CO₂ released from the soil (Table 2.8). Soil CO₂ emission was also depended on environmental conditions. For example, soil surface temperature, moisture and period of time that residues were added to soil. Duiker and Lal (2000) calculated C balance by CO₂-C flux minus crop residue C applied. They found that crop residue input rate of 16 Mg C/ha/yr gives the best results of CO₂ reduction. These mean crop residues store C in terms of soil organic matter. Crop residue returned to the land can increase or maintain SOC content (Paustian, 1997).

Table 2.8 Calculation of annual C budgets in sugarcane production affected by different crop residue application rates (1997) (Duiker and Lal, 2000)

	Annual residue application rate (Mg C/ha/yr)				
	0	2	4	8	16
(A)Total CO ₂ -C flux (Mg C/ha/yr)	3.84	5.64	4.51	5.34	6.63
(B)Total crop residue-C added (Mg C/ha/yr)	0.00	0.83	1.65	3.30	6.61
(B)-(A) (Mg C/ha/yr)	-3.84	-4.81	-2.86	-2.04	-0.02
SOC content (0-10 cm) ((Mg C/ha)	10.1	11.5	10.7	11.2	14.0

Note: Mg = ton

2.4.1.4 CO₂ release as affected by field management and direct use of fossil fuels in farm machinery

Carbon dioxide emissions from crop input include those from fertilizers and pesticides utilization, irrigation for water applies and other production inputs. Carbon emissions from the application of fertilizers, pesticides, lime and irrigation are estimated from their production on a per crop basis. Actually, these were estimated from fossil fuels used in the production of fertilizers include emissions from mineral extraction and fertilizer manufacture. Emissions from post-production can include those from packaging, transportation, and field application of fertilizer (Mudahar and Hignett, 1987). In addition, Lal (2004) has grouped C emissions from agriculture practice into three groups; primary sources of C emissions are either due to mobile operations (e.g., tillage, sowing, harvesting and transport) or stationary operating (e.g., pumping water, grain drying). Secondary sources of C emissions comprise manufacturing, packaging and storing fertilizers and pesticides. Tertiary sources of C emission include acquisition of raw material and fabrication of equipment and farm building, etc. Therefore, repair of the machinery normalized over the lifetime of the equipment contributed to CO₂ emissions (West and Marland, 2001; Brentrup *et al.*, 2004). Moreover, carbon dioxide from pesticides was estimated for specific pesticides classes by calculating average values of energy input for the production and application of individual pesticides (Green, 1987). For Irrigation, carbon emission was estimated from energy expense from fossil fuels used to power pumps and transportation of water to farm, which distribute irrigation water on farm. CO₂ released and fossil fuel utilization from the farm activity depending on how much and methodology for farm operation and management and fuel types which is include for farm machine. Changes in agriculture practice can also affect CO₂ emission associated with these practices. As the mentioned above, reduced tillage cloud minimizes CO₂ emission for example.

The carbon budget can be used to illustrate carbon emission and reduction from farm operation and management. A case study in the United States in 1995 used the full carbon accounting concept estimate the carbon budgets by comparing tillage methods in three crop types: corn, soybean, and wheat. In the part of application of crop inputs it was found that no-till have much more C in soil than the conventional tillage practice. Corn crops generate the largest amount of emissions per unit area cultivated, with soybean

generate the least. The difference between two crops is largely attributed to N fertilizer use. Among tillage practice, conventional tillage (CT) had higher CO₂ emissions from the agriculture inputs than reduced tillage (RT) and no-till (NT). It was caused by fossil fuel use to generate and process them (Figure 2.12) (West and Marland, 2002).

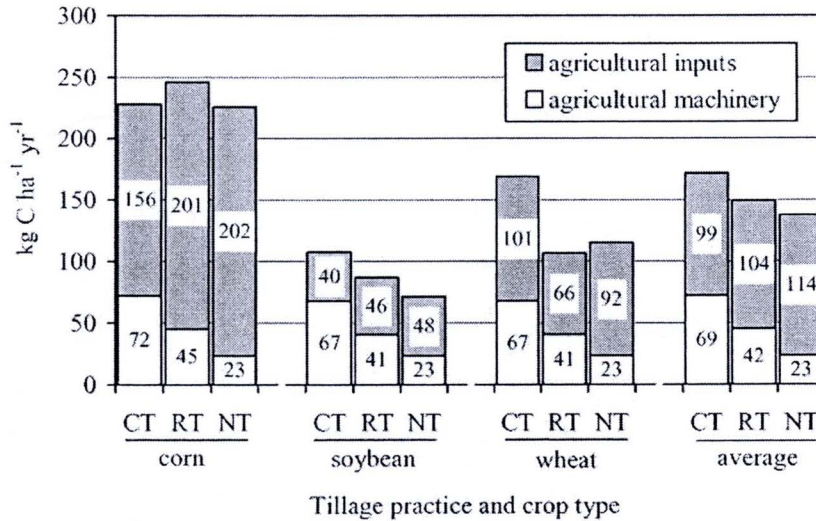


Figure 2.15 Total US average carbon dioxide emissions for three crop types using three different tillage practices. CT, RT, and NT are conventional tillage, reduced tillage, and no-till, respectively. The graph is for non-irrigated areas, which comprise 85% (by area) of US corn crops, 95% of soybean crops, and 93% of wheat crops (West and Marland, 2002)

Lal (2004) commented on the effects of different farm operations on emissions mentioned in other publications. These include direct emission from tillage, fertilizer and pesticides. First, direct emissions from tillage depended on numerous factors including soil properties, tractor size, implement used and depth of tillage. The reported diesel consumption for moldboard plow was ranged from 14.7 to 49.6 liters/ha, chisel plow (6.6 to 14.3 liters/ha) and disk plow (5.6 to 12.2 liters/ha).

Second, chemical fertilizers are principle sources of CO₂ and N₂O emissions. The estimate of carbon emissions were reported Nitrogen (0.9 to 1.8 kg CE/kg), Phosphorus (0.1-0.3 kg CE/kg), Potassium (0.1 to 0.2 kg CE/kg) and lime (0.03 to 0.23 kg CE/kg).

Finally, pesticide was reported in portion of herbicide (1.7 to 12.6 kg CE/kg), insecticide (1.2 to 8.1 kg CE/kg) and fungicides (1.2 to 8.0 kg CE/kg).

2.4.1.5 CO₂ released by burning or other oxidation of biomass

The emissions are mainly from agricultural activities including biomass burning. GHG Emissions from burning sugarcane in field before harvesting (mostly top and green leaves). Normally, farmer burns sugarcane top and leaves in the field before harvesting because this makes the field convenient to harvest. This method usually release methane as well, due to the combustion process is in most cases not complete (ISAIAS, 1997).

Sugarcane biomass burning is the results of soil fertility losses especially on nitrogen and negative effect on soil organic matter (Lefroy *et al.*, 1994). Finally may cause deterioration of soil physical and soil microbiological conditions (Blair, 2000; Collins *et al.*, 1992). Furthermore, residue combustion is a source of particulates and gaseous (CO₂, NO, NO₂, and N₂O) emissions to the atmosphere that may contribute to the greenhouse effect and the associated global warming. A large quantity of nitrogen (N) is lost during burning in sugarcane harvest. Biederbeck *et al.* (1980) found that burning of grassland and wheat residues resulted in losses of 50–70% of the N contained in the residue, while Lefroy *et al.* (1994) recorded losses between 65% and 70% when rice trash was burnt. The harvest of green sugarcane reduces N loss, so nutrients contained in vegetal trash remain on the field and can be recycled in the system.

2.4.1.6 CO₂ fluxes and factors, influence on CO₂ flux in soil

The two most important factors affecting carbon balance of a terrestrial ecosystem are photosynthesis of above-ground vegetation and soil respiration. Soil respiration or CO₂ evolution from the soil surface is important because it represents the sum of soil changing activities. Soil surface CO₂ flux, or soil respiration, is a major component of the biosphere's carbon cycle because of its contribution to about three-quarters of total ecosystems respiration. The CO₂ flux at the soil surface and CO₂ concentration in soil air depend on both of CO₂ production and gas transport in the soil air by the molecule diffusion in the unsaturated soil zone. Soil CO₂ fluxes begin from autotrophic root respiration and heterotrophic microbial respiration in the rhizosphere and bulk soil. The CO₂ flux depends on the environmental conditions such as soil moisture and temperature.

Soil respiration or CO₂ efflux is a major component of C cycle, accounting for about 25% of the global CO₂ exchange (Bouwmann and Germon, 1998). Soil respiration is also intimately associated with nutrient processes such as decomposition and mineralization. Carbon cycle in ecosystem is the processes of plant fix CO₂ from the air

and convert to organic compound by photosynthesis process. CO₂ is released back into the atmosphere by plant respiration. Dead plant materials are decomposed by microorganisms to provide energy or microbial biomass growth and other activities. At the same time, CO₂ is released back into the atmosphere by microbial respiration.

CO₂ is produced by plant respiration (R_p) and microbial respiration (R_m) that occurs during decomposition of litter and soil organic matter. R_p , or autotrophic respiration, can be separated into aboveground plant respiration (R_a) and belowground plant respiration (R_b). The belowground plant respiration is root respiration. In the part of microbial respiration (R_m) during decomposition of litter and soil organic matter is called heterotrophic respiration. The efflux rate measured at the soil surface (R_s) is the sum of root respiration and microbial respiration as show in equation 2.3:

$$R_s = R_b + R_m \quad (2.3)$$

Ecosystem respiration (R_e), the total CO₂ emission from an ecosystem, can be described in the equation 2.4.

$$R_e = R_a + R_s \quad (2.4)$$

The relationship of R_s with R_e , on the average from data collected for aspen-dominated mixed hardwood forest in Michigan from 1999 to 2003, R_s accounts for 71% of R_e , while leaves and aboveground live wood combined (R_a) contribute lower than R_e (Curtis *et al.*, 2005). Normally, R_s contributes 30-80 % of R_e in forests (Luo and Zhou, 2006). In cropland, the researcher who studied on the root respiration represented annual root respiration contributed 41 % of total soil respiration for organic soil croplands in Finland (Makiranta *et al.*, 2008) and 40% for spring wheat (Swinnen *et al.*, 1994). The contribution of root respiration to soil respiration in a C₃/C₄ mixed grassland in Japan ranged from 31% to 51% in August to October of 2004, and from 45% to 49% from April to June 2005 (Wang *et al.*, 2005).

Sources of CO₂ efflux from soil were included first; microbial decomposition of SOM in root free soil without undecomposed plant remains, frequently referred to as 'basal respiration'. Second; microbial decomposition of SOM in root affected or plant residue affected soil (rhizosphere priming effect). Third; microbial decomposition of dead plant remains. Fourth; microbial decomposition of rhizodeposits from living roots, frequently

referred to as ‘rhizomicrobial respiration’ and the last one is root respiration (Figure 2.16, Kuzyakov, 2006).

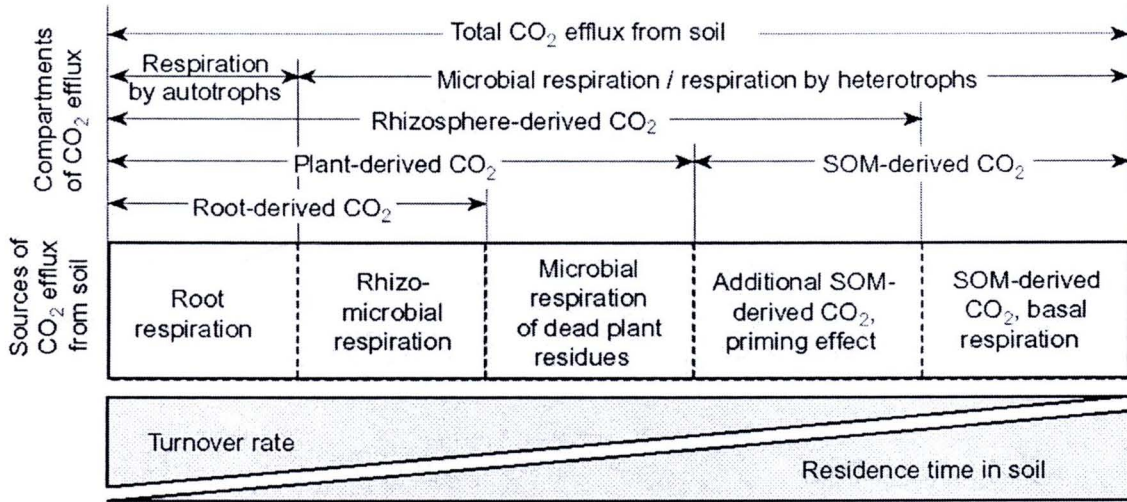


Figure 2.16 Five main sources of biogenic CO₂ efflux from soil, ordered according the turnover rates and mean residence times of C in soil. The sources and compartments of the CO₂ efflux consider C pools with different turnover rates and MRT, the localization of C pools and the agents of CO₂ production (Kuzyakov, 2006).

The chemical reaction of glucose as representative of biomass carbon to carbon dioxide can be described in Equation 2.5.



Biochemically, the overall processes of aerobic respiration are carried out through glycolysis, the pentose phosphate pathway, the TCA cycle, and electron transport pathway (Figure 2.17).

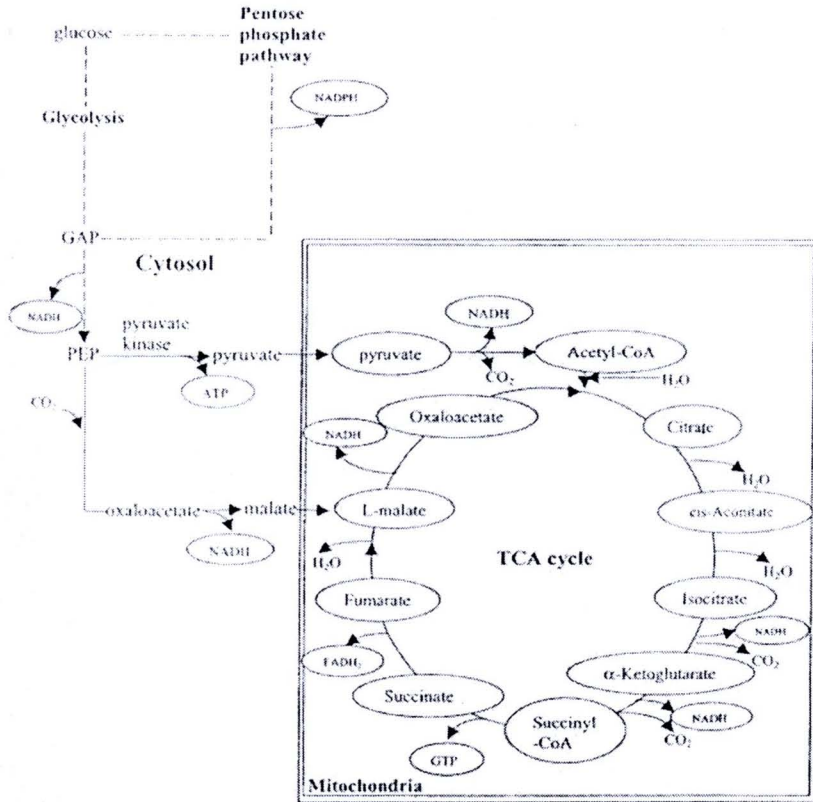


Figure 2.17 The respiratory pathways in living tissues include glycolysis, the pentose phosphate pathways, and the TCA cycle.

Root respiration

Root respiration usually contributes to approximately half of the total soil respiration but varies from 10 to 90% among different studies (Hanson *et al.*, 2000). For example, Raich and Tufekcioglu (2000) reported that root contribution to soil respiration was 33-89% in forests, 17-40% in grassland, 12-38% in croplands, and 50-93% in arctic tundra. Moreover, plants are the most important autotrophs contributing to CO₂ efflux from soil by root respiration.

The amount of CO₂ produced through root respiration is determined by the root biomass and specific root respiration rates. Root biomass in an ecosystem depends on ecosystem production and allocation patterns of plant species, and it varies with growth environments and seasons. Forests and sclerophyllous shrub lands have a root biomass of 5 kg/m², whereas croplands, deserts, tundra, and grasslands have a lower root biomass, less than 1.5 kg/m² (Jackson *et al.*, 1996). The greatest root biomasses that have been reported in the previous studied were found in a Venezuelan catinga rainforest (Klinge and Herrera, 1978) and in the California chaparral (Kummerow and Mangan 1981).

In addition, by comparing about soil respiration in term of soil CO₂ from different crop types, soil management and region it was found that sugarcane plantation had the highest soil respiration rate (Table 2.9).

Table 2.9 Soil respiration rate in different vegetation types from different country

Soil respiration rate (mg CO ₂ /m ² /h)	Vegetation, Location	References
55.83-116.25	Wheat residue amendment, USA	Jacinthe, 2002
63-1006	Corn field, Thailand	Jaiarree, 2008
366.67	Corn, Iowa USA	Tufekcioglu, <i>et al.</i> , 1999
412.5	Soybean, Iowa USA	Tufekcioglu, <i>et al.</i> , 1999
46.02-263.40	Afforested organic soil cropland, Finland	Mäkiranta, <i>et al.</i> , 2008
966	Oil palm plantation, Malaysia	Minako, <i>et al.</i> , 2006
231-444	Tropical bare soil, Brazil	La, <i>et al.</i> , 2000
183-1162	Pasture, Brazil	Fernandes, <i>et al.</i> , 2002
68.75-524.02	No till system	Diuker and Lal, 2000
320.67	Barley, Spain	Sánchez, <i>et al.</i> , 2003
470 – 1110	Sugarcane No tillage, Brazil	Scala Jr., <i>et al.</i> , 2006
940-2410	Sugarcane Reduce tillage, Brazil	Scala Jr., <i>et al.</i> , 2006
1290-2900	Sugarcane Conventional tillage, Brazil	Scala Jr., <i>et al.</i> , 2006

The CO₂ flux depends on environmental conditions, such as soil moisture and temperature, as described below.

(a) Effects of Temperature

Soil temperature is one of the most important factors controlling the CO₂ flux. High soil temperature can stimulate rate of decomposition of soil organic matter and high activity of microorganisms.

Mizue *et al.* (1999) reported that soil respiration rates increased exponentially with soil temperature (Figure 2.18), whereas soil moisture did not have a significant effect ($p < 0.05$). Generally, soil temperature alone was sufficient to explain seasonal variations as soil and root respiration (Mizue *et al.*, 1999).

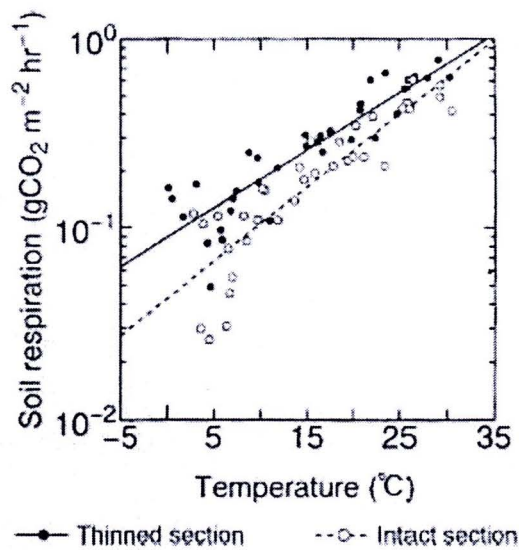


Figure 2.18 Relationship between soil respiration (R_s) and soil surface temperature (T_s). Regression equation for the thinned section was $\ln(R_s) = 0.071(T_s) - 2.10$ ($r^2=0.89$) and for the intact section was $\ln(R_s) = 0.090(T_s) - 3.15$ ($r^2=0.79$) (Mizue *et al.*, 1999)

(b) Effects of Moisture

Soil moisture depends on geographic locations, season, and precipitation. Soil moisture content is an important factor for growing of microorganisms. Soil CO_2 flux rates might change due to a higher soil moisture regime as result of restricted plant water uptake. Alternative, any potential soil moisture effect on soil surface CO_2 flux may be masked by soil temperature differences because the two environmental properties vary simultaneously. Soil temperature trends to be high when soil moisture is low. Extreme soil moisture status inhibits microbial communities and their efficiency, therefore soil surface CO_2 flux tends to be inhibited by anaerobic soil conditions at low soil temperatures and by drought at high temperature (Howard and Howard, 1993).

(c) Effects of pH (Acidity)

The effects of pH contribute to dissolution of minerals and this correlates with microorganism activity. The optimum pH for microorganism is neutral or approximately pH 6 to 8. If the pH is close to acidity, the microorganism will be decrease the rate of growing, and thus, the rate of soil respiration.

(d) Land use

Changes in land use affect input and output fluxes of nutrients and carbon in soils and vegetation. This can lead to changing soil fertility, which in turn affects biomass production and human decisions in land management. Next to a local impact on land quality, changing biogeochemical cycles can also have a global impact through the emission of greenhouse gasses. Recently, increasing attention is paid to global land use change impacts on biogeochemical cycles, especially the emissions and sequestration of carbon (Hoghton *et al.*, 2000).

Land covers conversion and land management interaction with nutrient fluxes and soil nutrient status. Land, conversion, for example from natural vegetation to agriculture land, or from grassland to arable land, can have strong impact on soil chemical properties such as soil carbon and nutrient concentration. Land use changes often alter the soil profile, thereby changing not only carbon stocks, but maybe also carbon fluxes.

2.4.2 Carbon flow in sugar factory or sugarcane bioenergy system

Carbon is emitted during various steps of sugarcane processing. The main processes involved in carbon releases are described below.

2.4.2.1 Sugar mill process and energy utilization

After sugarcane has been harvested it must be processed within less than 24 hours to avoid sugar loss by inversion to glucose and fructose. General sugarcane processing is represented in Figure 2.19. Based on the products, sugar process may be divided into three types of sugar; raw sugar, white sugar and refine sugar. The process goes through the following stages; First process for raw sugar can be divided into 5 parts (Wangkanai Sugar mill, 2008; Sombat, 2003).

1. Juice Extraction

The cane is first washed to remove mud and debris. Then the cane is chopped and shredded in huge roller mills to extract the juice. About 93% of the juice is extracted. Water and weak juice from the last mill is added to help to macerate the cane and to aid in the extraction. The final mill dewateres the residual cane fiber (Bagasse) which is then conveyed to the bagasse bin and the boiler station for use as fuel.

2. Juice Purification

The juice extracted by the milling train contains impurities which are removed by heating the juice and adding lime. The process coagulates the impurities into flocks of mud which are settled in a large clarifier vessel. In the clarifier, the mud settles to the bottom while the clarified juice overflows from the top of the vessel.

3. Evaporation

After purification, the juice is then boiled in multiple evaporation steps to extract 70% water. The last product from this step is syrup. The thin clarified juice is concentrated to heavy syrup by boiling at progressively higher vacuums through the set of evaporators.

4. Crystallization

The heavy syrup, which is about 65% sugar, is concentrated by boiling in a vacuum pan and seeded with small sugar crystals. The sugar crystals are grown to required size by adding more syrup while boiling is continued. When the crystals reach the required size, the mixture of syrup and crystals is discharged from the pan. The product from this step called messecuite. The messecuite is discharged to a crystallizer where the crystallization is completed.

5. Centrifugation

The messecuite is sent to a centrifuge where the syrup is separated from the crystals. The dark syrup surrounding the crystals is thrown off through the perforations and the crystals are washed with hot clean water. The separated syrup is repeatedly boiled again until all possible raw sugar crystals are obtained. After drying of the crystals, the

light brown raw sugar is ready for shipping to a refinery. The by-products of this step is molasses, which is often used for cattle feed, or citric acid, and fermentation products.

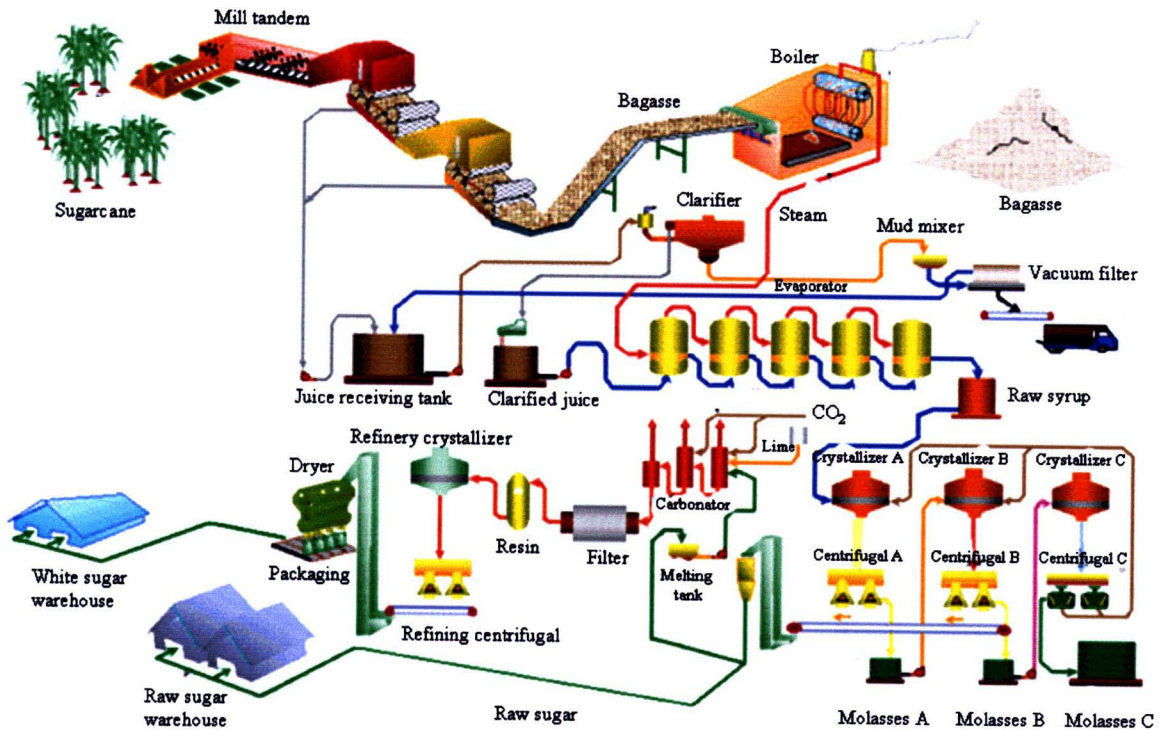


Figure 2.19 Sugar production processes from sugarcane
(Wangkanai Sugar mill, 2008; Sombat, 2003)

The process for white sugar production and refining sugar can be divided into 5 steps:

1. Affinated Centrifugaling

The first step in refining is called affination, where the raw sugar crystals are treated with heavy syrup (typically 60-80 Brix; Degree Brix (symbol °Bx) is a measurement of the dissolved sugar-to-water mass ratio of a liquid. It is measured with a saccharimeter that measures specific gravity of a liquid or more easily with a refractometer) in order to remove the film of adhering molasses. This strong syrup dissolves little or none of the sugar but softens or dissolves the coating impurities. The mixture, called magma, is spun in centrifuges and washed with hot water to remove the adhering molasses film. The washed raw sugar crystals are then dissolved in water and diluted to about 54 Brix.

2. Clarification

During carbonation, the syrup is mixed with milk of lime and reacted with carbon dioxide to produce a precipitate of calcium carbonate (chalk). The chalk precipitate entraps organic non sucrose and inorganic impurities. Pressure filters are used to remove the chalk precipitates and to produce clear light brown syrup. The brown syrup is then passed over a series of acrylic and styrene resin columns and granular activated carbon columns. The resulting low colored syrup (fine liquor) is used for crystallization of white sugar or for the production of bulk liquid sugar.

3. Crystallization

The fine liquor is now concentrated and crystallised in vacuum pans. The liquor is boiled under vacuum in the pans until super saturation and sugar is able to crystallise. Rather than allowing the crystals to simply grow randomly, a large number of very small nucleus crystals are introduced and a controlled number of crystals are allowed to grow using tight control of the process. The resultant product is called massecuite - a mixture of sugar crystals and syrup.

4. Centrifugation

The syrup is then spun off from the massecuite leaving wet refined sugar in high speed centrifuges. The product is refined sugar and white sugar.

5. Drying

The remaining moisture is removed, improving the keeping quality of the sugar.

2.4.2.2 Carbon emissions from by-products and waste material in sugar processing

Carbon stored in plant, plant debris, waste from the process, and soil changes when biomass is removed for energy production. In sugarcane production, carbon storage in plant or biomass includes trash, root system, bagasse, molasses, sugar, filter cake, cane top and leaves (Schlanddingw *et al.*, 1997). Fiber and pith (bagasse) from the stalks are burnt

for power. Sucrose is processed to sugar (and ethanol), and its carbon is also recycled into the atmosphere in a short period (ISAIAS, 1997). Emissions from bagasse boiler and unburnt organics are methane gases. This could occur in transient or uncontrolled disturbed boiler operation. Beeharry (2001) shows data of carbon uptake for 1 ha of sugarcane plantation in each component (sugar, molasses, filter cake, water bagasse, cane top and leaves (CT&L), trash and root system). The data of C content could be applied to estimate carbon store and emission from sugar process (Table 2.10).

Table 2.10, was represented the average produces the following amounts of byproducts for every 66,000 kg cane yield/ha/yr in Mauritius. Since fossil fuel use is the only source of CO₂ that is not counterbalanced by what is absorbed by the biomass, a process that does not use any fossil fuel will have a 100% carbon closure. In other words, all CO₂ produced will be re-absorbed by the system resulting in a zero net carbon system. The total annual CO₂ uptake by 1 ha of sugarcane plantation with an average yield of 66,000 kg (Table 2.10). The computation is based on the CO₂ equivalent to the carbon contained in each component of sugarcane plant. It is estimated that a total of 58.2 ton CO₂ is absorbed annually by growing sugarcane biomass. As a details in Table 2.10, in each components were divided into sugar (10 % of millable cane, 0.42 % of C content), molasses (3%, of millable cane, 0.357 % C content), filter cake (4% % of millable cane, 0.4 % of C content), bagasse (30 % of millable cane, 0.499% of C content), respectively (Beeharry, 2001).

Table 2.10 Total annual carbon uptakes for 1 ha of sugarcane plantation (Beeharry, 2001)

Component	Share of millable cane (%)	Amount ^a (kg)	Moisture (%)	Dry biomass (kg)	C content (dry basis) (%)	C sequestered (kg)	Equivalent CO ₂ uptake (kg)
Sugar	10	6,600	0	6,600	0.420 ^b	2,772	10,164
Molasses	3	1,980	20	1,584	0.357 ^c	565	2,073
Filter cake	4	2,640	80	528	0.400 ^d	211	774
Water	52	34,320	100	0	0.000	0	0
Bagasse	30	19,800	50	9,900	0.499 ^e	4,940	18,114
CT &L	31	20,658	68	6,611	0.493 ^e	3,259	11,950
Trash	10	6,732	19	5,433	0.490 ^e	2,662	9,761
Root system	15	9,900	70	2,970	0.490 ^f	1,455	5,336
					Total	15,865	58,172

^a Cane yield=66,000 kg/ha/yr.

^b Assuming sugar in pure sucrose [C₁₂H₂₂O₁₁]

^c Brix=0.85 (sucrose/dry/solids)

^d From Paturau

^e Based on ultimate analysis

^f Assuming carbon content comparable to the other fibrous components.

Net soil carbon sequestration is assumed to be zero.



2.4.2.3 Carbon emission from fossil fuel and energy input

Energy inputs are used for operating production, processing and transportation facilities in sugarcane industrial bases. In sugarcane production systems, fossil fuel use can be divided into two parts; in sugarcane base system, and bioenergy system. In sugarcane base system, energy use (such as natural gas, gasoline, diesel, coal, electricity and etc.) including energy use for operating the production and processes. In bioenergy system, energy use including energy use for ethanol production (electricity, chemical and lubricants), bagasse surplus electricity and etc. (Beeharry, 2001).

The example for carbon balance and energy utilization in sugar mill process case studied in Mauritius were reported on different byproduct of sugar; bagasse for bioenergy sources. It is show that reference option (based on current practice in Mauritius, only 30% of cane mass bagasse is exploited for power surplus power production, the electricity output is 41 kWh/ton cane) gave a lowest CO₂ emission and highest avoid CO₂ but lowest in electricity output if compared between another option. In the reference option based on 1 ha of sugarcane plantation exploited for 1 year there was used 127 m³ of natural gas, 93 liters of diesel, 84 kg of coal and 750 kWh of electricity. This is based on cane output of 66 tons and surplus electricity output of 41 kWh/ton cane. The CO₂ emissions were 0.035 kg CO₂/kWh (Beeharry, 2001).

The energy input in sugar milling in Thailand, were presented diesel used for transport of 0.11 liter/ton cane. In addition, there were used renewable energy sources; input 7 kg/ton cane of rice husk and 4.4 kg/ton cane of wood waste and bark. Bagasse 282 kg/ton cane can be surplus electricity about 16.94 kWh/ton cane. This is quite lower than that case studied in Mauritius (Nguyen, *et al.*, 2008). Moreover the energy use for ethanol production in Thailand were reported from the previous studied 12.36 MJ/L Ethanol from coal (1150.1 g CO₂ eq/L ethanol), 1.33 MJ/L ethanol for diesel fuel transportation (emitted 96.9 g CO₂ eq/L ethanol), (Nguyen, *et al.*, 2007b).

2.4.2.4 Emission reduction of CO₂

Reduction of CO₂ emission could be achieved by substituting ethanol for gasoline blending and also by substituting sugarcane bagasse for biofuel in sugar production and others industrial sectors (such as food, paper and pulp chemical industries). These can be use by-products of sugar, such as bagasse and molasses, to produce renewable energy.

This is clean energy because emission from this fuel can be recovered by photosynthesis process when biomass plants are re-growth. There were divided into two systems, first, bagasse for bioenergy in sugar mill process can be replaced fossil fuel energy; heat and power in sugar mill processing. Second, molasses can be produced ethanol and blending with gasoline for oil fuel transport.

Bagasse is also used at the sugar mills as a fuel, for either sugar or ethanol production (Beeharry, 2001). Bagasse can be used as biofuel and is a renewable resource. In Mauritius, Beeharry (2001) studied carbon flow in sugarcane bioenergy system compared with fossil fuel coal based in four systems that related CO₂ emission and reduction (Beeharry, 2001). It was found that sugarcane bioenergy systems could help to reduce CO₂ emitted to the atmosphere. It has been show that depending on the degree of cane residue utilization, the avoided CO₂ emissions (compared to the hard coal fuel chain) would range between 1.081 and 1.137 kg CO₂/kWh.

About bioethanol, an emission from burning ethanol in ethanol engine is different to gasoline engine. The analysis shows CO₂ emissions from ethanol engine is lower than gasoline engines. This means if using ethanol from sugarcane industries it can reduce CO₂ emission (ISAIAS, 1997). In the Philippines, Raymond *et al.* (2004) studied carbon balance implications of coconut biodiesel utilization for automotive transport sector. The net CO₂ emissions were estimated at 77-104 g/MJ of diesel displaced by biodiesel (Raymond *et al.*, 2004). Similarly, in China Zhiyuan *et al.* (2004) applied life cycle assessment (LCA) concept to the assessment of automobile fueled by bioethanol blends. It was found that the benefit gains were quite similar to the study in the Philippines. Bioethanol blends fueled automobile in China would be the potential transportation tool and it would be helpful for developing sustainable transport system in China and reduction of CO₂ emissions to the atmosphere. These 20% of reduction cloud gain. By these cassava-based E85 fueled FFV emits lower life cycle CO₂, CO, HC, and PM pollutants, higher NO_x than gasoline fueled car does. And, the combine environment indicator of FFV is about 20% lower than gasoline car (Zhiyuan *et al.*, 2004). The previous studied in India were used life cycle assessment of pollution from alternative transport fuel in Indian condition. It is concluded that bioethanol can play a significant role in reducing life cycle carbon emissions. In comparison, CNG shows a reduction of about a third. Alcohol-fuelled vehicles, by comparison, can how neutral carbon emission (Prakash, *et al.*, 2005). Luo, *et al.* (2009) were reported about a comparative life cycle assessment on gasoline and

ethanol as fuel, and with two types of blends of gasoline with bioethanol, all used in mid size car. The focus is main application in Brazil, sugarcane based ethanol. The results show that in the base case the levels of ADP (Abiotic depletion) and GHG emissions drastically decrease when replacing gasoline by ethanol fuels, about 83 % and 81 % respectively. This is due to the replacement of fossil resources by renewable biological resources.

Nguyen, *et al.* (2007a) were studied the GHG mitigation potentials of ethanol as a gasoline substitute in Thailand. The results show that GHG balance assessment based on the baseline scenario in Thailand shows that emissions are most likely increase with substitution. In addition, another studied in Thailand were used a life cycle analysis of the environmental benefits and limitations of using ethanol as an alternative transportation fuel. The results show that, along its whole life cycle, E10 (the mixed between 10% ethanol with 90 % of gasoline) consumes less fossil oil (6.3 %) and produces lesser amounts of CO₂ (6.4%), CH₄ (15.4%), and NO_x (15.8%) than CG (conventional gasoline), (Nguyen, *et al.*, 2007b). These all about previous research show the potential of renewable energy to GHG mitigation.

2.5 Sugarcane crop and its potential for bioenergy production

2.5.1 Sugarcane crop and sugar production in the world

2.5.1.1 Global situation

Sugarcane is presently grown under a wide range of conditions in tropical and subtropical regions of the world, from 35° in Spain to 35° in South Africa. Sugarcane has long been widely grown. Some commercialization was reported by the mid-nineteenth century, but the crop became of major importance after World War II. In the early 1950s, production averaged 1.6 million tons per year, and in the late 1950s self-sufficiency in sugar was completed. Therefore, in 2004 and 2007 the largest producers is Brazil and Thailand is the fourth producer (Table 2.12; Figure 2.20) (FAOSTAT, 2005; FAOSTAT, 2007).

The annual global production of dry cut sugarcane (sugar content is about 55% dry basis) is about 328 Tg (1 Tg = teragram = 10¹² g). Asia (44%) is the primary production

region, and South America is the second largest production region, producing 110 Tg of sugarcane (34%). The annual yield of dry sugarcane ranges from 14 to 22 Mg/ha with an average of 17 Mg/ha. Brazil is the largest single producer of sugarcane with about 27% of global production and a yield of 18 dry Mg/ha. The highest yield occurs in Peru, which produces more than 32 Mg (1 Mg = megagram = 10^6 g) of dry sugarcane per hectare (Seungdo and Bruce, 2004).

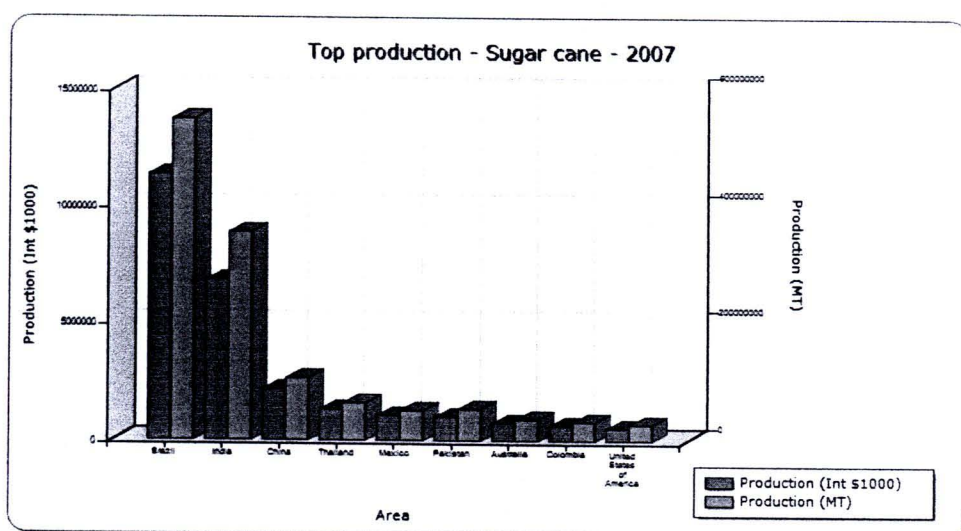
Food manufacturing is the major use of sugarcane, consuming about 97% of sugarcane (a yield of 400 kg of sugar per dry ton of sugarcane). The fraction of other uses such as animal feed, human food, and other, is less than 3%. About 3 Tg of dry sugarcane in the world becomes waste. The uses of sugarcane are illustrated in Table 2.11 (Seungdo and Bruce, 2004).

Table 2.11 Use of sugarcane in the world (Seungdo and Bruce, 2004)

Sources	Feed (%)	Seed (%)	Waste (%)	Food Manufacture (%)	Food (%)	Other uses (%)
Africa	0.14	2.02	2.12	89.43	4.44	1.85
Asia	3.14	4.68	1.13	86.19	4.57	0.30
Europe	0.18	0.00	0.00	87.90	0.00	11.92
North America	0.00	5.37	0.00	94.62	0.00	0.00
Central America	1.80	0.25	1.06	95.40	0.05	1.45
Oceania	0.00	0.00	0.00	99.99	0.01	0.00
South America	0.98	0.00	0.68	97.83	0.27	0.24
World	1.91	2.35	0.97	91.88	2.40	0.48

Table 2.12 World sugarcane producers (FAOSTAT, 2005)

Sugarcane	2004	
	Production (million ton)	Area (1000 ha)
Brazil	416.26	5634.55
India	236.18	4000.00
China	90.98	1392.10
Thailand	64.97	1121.41
Pakistan	53.42	1047.50
Mexico	45.13	639.06
Colombia	40.02	431.74
Australia	36.99	448.00
Philippines	32.50	395.00
United States of America	26.32	379.68
Indonesia	25.60	360.00
Cuba	24.00	700.00
Argentina	19.30	350.00
South Africa	19.09	321.57
Guatemala	18.00	186.34
World	1328	20454

**Figure 2.20** World sugarcane production trend (FAOSTAT, 2007)

More than 100 countries produce sugar, 78% of which is made from sugarcane grown primarily in the tropical and sub-tropical zones of the southern hemisphere and the balance from sugar beet, which is grown mainly in the temperate zones of the northern hemisphere. Generally, the costs of producing sugar from sugarcane are lower than those in respect of processing sugar beets. Currently, 69% of the world's sugar is consumed in the countries of origin, while the balance is traded on world markets. Due to the residual nature of the world market, the free market price is one of the most volatile of all commodity prices. The largest sugar producer is in Brazil following by India, EU, China and Thailand in 2007/08 production year. The largest sugar exporter is Brazil following by Thailand, Australia and India (Table 2.13 and Figure 2.21), (International sugar statistics, 2008).

Table 2.13 Sugar production in the world in 2007/08 production year (International sugar statistic, 2008)

Production years 2007/08	Production (10 ⁶ tons)	Export (10 ⁶ tons)	Population (10 ⁶)	Per Capita Consumption (kg)
Brazil	31	21	190	58
India	29	3	1 117	20
EU	18	1	490	34
China	15	-	1 314	11
Thailand	8	5	65	36
United States	8	-	301	29
Mexico	5.978	0.4	107	52
SADC	5.834	2	157	22
Australia	5.013	4	20	47
Pakistan	4.891	-	165	25

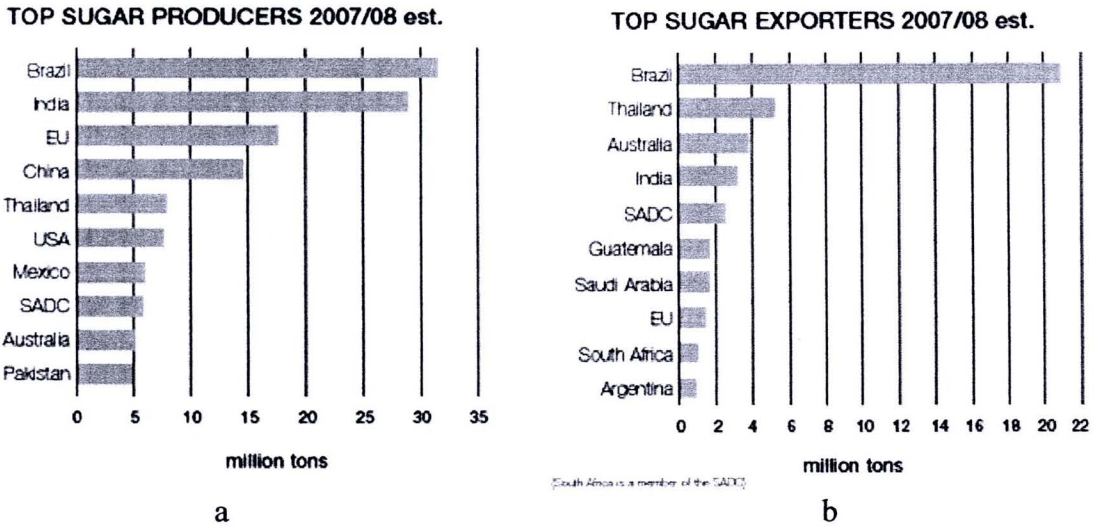


Figure 2.21 Sugar producers 2007/08 (left) and sugar exporters 2007/08 (right) in the world sugar trend (International sugar statistic, 2008)

2.5.1.2 Potential Bioenergy/renewable energy production from sugarcane

The world energy demand is supplied by conventional energy sources such as coal, oil, natural gas, etc. Since the life of these sources is limited by the present and future energy consumption of the world, attention is being turned toward new and renewable sources, such as solar, wind, biogas, biomass, and etc. On the global scale increase in the emissions rates of greenhouse gases and particular CO₂, represented an environmental problem to the world climate. The new alternative ways in energy resources is renewable energy. It is expected to play an increasing role in the energy consumptions and reduce environmental problem such as global warming etc. (Kirstin and Thomas, 2007).

Worldwide, about 4 percent of total primary energy comes from sources which do not produce greenhouse gases. It means renewable energy, the world renewable energy for electricity generation comes from biomass (39 GW), wind (48 GW), small scale hydro (61 GW), geothermal (8.9 GW), solar (4 GW) and tide (0.3 GW) (Kirstin and Thomas, 2007).

In sugar industry, bagasse is a potential alternative energy source. It is produced during the crashing of cane and can be used as a boiler fuel. Each ton of cane yield sending to sugar process is resulted in about 250 - 280 kilograms of bagasse produced (Rammurthi *et al.*, 2000). Globally about 180 Tg of dry sugarcane bagasse is produced and can be utilized. This could produce about 51 GL of bioethanol. Furthermore, lignin-rich fermentation residues from bagasse could generate 103 TWh of electricity and 593 PJ.

These based on the annual global production of dry cut sugarcane is about 328 Tg. (Seungdo and Bruce, 2004).

Furthermore, waste from sugarcane process can be used to produce renewable energy. In Turkey, Brazil, Mauritius, India, USA, and other countries such renewable energy policy is being implemented (Beeharry, 2001). Bagasse is burned to supply heat to the sugar operation and can generate electricity backward to grid (Seungdo and Bruce, 2004).

2.5.1.3 Potential Bioethanol/renewable energy production from sugarcane

Brazil has several projects that use fuel alcohol produced mainly from sugarcane for abating CO₂ emissions. The main objectives of the project are reducing CO₂ emissions and providing new sources of energy. The production of alcohol from sugarcane as an alternative car fuel is more than 20 years old (Suzana and Luiz, 1998). Waste sugarcane, such as bagasse, trash, cane top and leaves, could produce 1.59 GL (calculated from waste sugarcane in bioethanol process in global scale; waste sugarcane is the fraction of other uses such as animal feed, human food, and so on, is less than 3%), (Table 2.14) of bioethanol by bioethanol production process, replacing 1.1 GL of gasoline when ethanol is used in E85 fuel (a mixture of 85% ethanol and 15% of gasoline by volume) (Seungdo and Bruce, 2004).

From the global production of sugarcane, waste sugarcane and sugarcane bagasse could produce globally about 51 GL of bioethanol, replacing 38 GL of gasoline in an E85 midsize passenger vehicle, or about 3.4% of the global gasoline consumption. Asia can produce about 22 GL of bioethanol. The regional potential bioethanol production is shown in Table 2.14 (Seungdo and Bruce, 2004).

Table 2.14 Regional potential bioethanol production from wasted sugarcane and sugarcane bagasse (Seungdo and Bruce, 2004)

Regions	Potential bioethanol production(GL)		Total bioethanol (GL)	Gasoline Equivalent (GL)
	From wasted sugarcane	From bagasse		
Africa	0.23	3.33	3.56	2.56
Asia	0.82	21.3	22.1	15.9
Europe	-	0.004	0.004	0.003
North America	-	1.31	0.31	0.94
Central America	0.18	5.46	5.64	4.05
Oceania	0.0001	1.84	1.84	1.32
South America	0.37	18.1	18.5	13.3
World	1.59	51.3	52.9	38.0

2.5.2 Sugarcane Cropping in Thailand

2.5.2.1 Sugarcane area, Production in Thailand, Eastern Thailand and Chonburi and Rayong provinces

Thailand began its sugar industry in 1825. In 1960, Thailand became an exporter of sugar. Rising world prices led Thailand's market-responded to the farmers to expand cropped areas in the 1970s. Productivity of Thailand's was low if compared with other major sugarcane growing countries (about 53 tons of sugarcane per hectare against in Taiwan's 70 and Indonesia's 80 in the mid-1970s). Introduction of new varieties and improved cultivation and cropping practices were needed to raise output levels in Thailand's. The principal sugarcane growing areas were in and around Kanchana Buri Province and in Chon Buri Province. Sugarcane was also grown in the Northeast and in the North around Chiang Mai, Lampang, and Uttaradit (U.S. Library of Congress; Sombat, (2003), Office of the cane and sugar board, (2008)).

In Thailand sugarcane grows best in deep, well drained soils of medium fertility with loamy to loamy-sand soil textures, a pH range between 6.1-7.7 and organic matter content is about 1.5 percent. Clay-textured soils are unfavorable to sugarcane growth. Optimal temperatures are between 20 and 35 degrees Celsius. Under rainfall conditions, good distribution of rainfall is required. The water requirement is 240-960 liters/ha (Khonkhen University, 2005)

Cane is normally planted either as two-or three-budded crops times, or as whole cane cut into 30 cm lengths and covered on the soil. Most cane is planted manually, but

machine planting is also used. Row and plant space are 1.0-1.3 m × 0.5 m for manual planting. The row space is about 1.4-1.6 m for machine planting. In the case of double row planting, there are about 30 cm spaces between double rows and 1.3 m (1.00-1.40 m) between rows. It is recommended that a variety with high tillage should be planted at the wide row spacing. After planting, farmers should take care of their crops by watering and fertilizing gradually and increased organic matter in the soil. Watering of plants during the first 11 months is more essential for crops (Foodmarket, 2003).

In 2008 there were 46 sugar industries in Thailand. There are 9 sugar factories in the Northern region, 17 sugar factories in the Central region, 5 sugar factories in the Eastern region and 15 sugar factories in the Northeastern region (Office of the cane and sugar board, 2008). Thailand ranks in the fourth as world sugar exporter. In year 2002, Thailand exported sugar about 30,592 millions bath and consumption in Thailand was about 20,000 millions bath (by amount of sugarcane production 59.6 Million tons and the area was about 6 millions Rai, sugar production 6 million tons, and exported 4 millions tons) (Office of Agriculture Economics, 2002).

Sugarcane production over period from 1997/08 to 2007/08 has an average value of about 60.7 million tons per year (Table 2.15). Crop year 2000/01 processed about 99% of the sugarcane produced. Most of residues from sugarcane processing can be found at the mills except the sugarcane tops (stumps and leaves, etc.) that are usually harvesting in the field by farmers (Office of Agricultural Economics, 2004; Office of the cane and sugar board, 2008).

In 2007/08 production year sugarcane area in Chonburi and Rayong provinces was covered 171,913 rai approximately to 43.07 % of the sugarcane area in Eastern region and 2.63 % of Thailand. The sugarcane production produced 1,663,384 tons (Office of the cane and sugar board, 2008).

Table 2.15 National production of sugarcane and harvested area in Thailand (Office of Agricultural Economics, 2004; Office of the cane and sugar board, 2008)

Crop year	Sugarcane (1,000 Tons)	Sugarcane area (1,000 rai*); (1,000 ha)	Sugarcane yield ton/rai; (ton/ ha)
1997/98	46,873	5,893 (943)	7.95 (49.71)
1998/99	50,332	5,735 (918)	8.78 (54.83)
1999/20	52,813	5,862 (938)	9.00 (56.30)
2000/01	49,563	5,481 (877)	9.04 (56.51)
2001/02	60,013	6,320 (1011)	9.50 (59.36)
2002/03	74,263	7,121(1139)	10.43 (65.20)
2003/04	70,101	7,120 (1139)	9.85 (61.55)
2004/05	80,051	7,228 (1156)	11.08 (69.25)
2005/06	46,689	5,890 (942)	7.93 (49.56)
2006/07	63,797	6,556 (1049)	9.73 (60.82)
2007/08	73,588	6,516 (1042)	11.29 (70.62)
Average	60,735	6,338 (1014)	9.58 (59.90)

* 6.25 rai = 1 ha

2.5.2.2 Sugarcane Biomass Burning in Thailand

Burning of cane residues either before or after sugarcane harvest is widely practiced in Thailand as well as in many other tropical countries. Farmers burned sugarcane to reduce the amount of leafy extraneous material, including stalk tops and dead leaves, which are delivered with the cane to the factories for processing, and to control pests. Additionally, sugarcane burning facilitates manual harvesting thus reducing labor and production costs. They caused the problem about labor and sugarcane burning makes it easy to harvest. However, such burning also causes greenhouse gas emissions. This indeed represents an important global source of particles and gases to the atmosphere, especially, in the tropics where biomass burning is widespread. Annually, 7,500-8,600 Tg (teragrams) of dry material is burned and greenhouse gases are emitted to the atmosphere around the world through the process of burning. About 43% of this dry material is derived from savannah burning, 23% from the burning of agricultural waste, 18% from rainforest burning, and 16% from wood burning for fuel (Jose *et al.*, 2008). Estimates show that the annual carbon and PM released to the atmosphere because of biomass fires in the tropics is around 2,000-4,500 Tg and 36-154 Tg, respectively (Jose *et al.*, 2006). In Thailand, more than 60 % of sugarcane sent to sugar mill process is burned (Office of the cane and sugar board, 2008). Additional energy needs to be expensed in order to clean the burned sugarcane before being processed. Moreover burning may cause the lost of nutrient

from soil system. Saowakon *et al.* (2008) suggested that although a change from burning to sugarcane residues retention led to alterations in N cycling and improved soil organic matter it did not significantly affect N₂ fixation due to the uniforming action of ploughing and the extended time gap between sugarcane residue incorporation and legume planting. Therefore, sugarcane biomass gets the benefit to generate fuel and electricity. This way can lead to mitigate greenhouse gases to the atmosphere.

2.5.2.3 Sugarcane biomass for bioenergy systems in Thailand

Bagasse is the residual fiber remaining when sugarcane is pressed to extract of the sugar. Some bagasse is burned to supply heat to the sugar refining operation. Some is returned to the fields, and some finds its way into various board products (Winrock International, 1995). From milling statistics, bagasse constitutes 29% of the cane. Therefore, sugarcane amount of 57.7 million tons in Thailand can produce 16.7 million tons of bagasse. The traditional use of bagasse is as a fuel in the sugar mill, and to produce steam for the process and electricity for mills. At present, sugar mills can sell the excess electricity to the grid. The other usage of bagasse is as a raw material in particleboard and pulp industry. Typically 7% of the cane weight remains as excess because of the large amount of bagasse used for steam and power supply in sugar mills. The annual availability of this resource is estimated at 4.04 million tons (The EC-ASEAN COGEN Programme, 1998; Sutitratana, 2004).

In Thailand, the use of ethanol as alternative fuel was recommended in 1977, but at that time the cost of ethanol was much higher than oil prices. Recently there have been various policies and supports from the government agencies to promote production and utilization of bioethanol as alternative automobile fuels.

Yoosin *et al.* (2003) reported that Thailand has a high potential to produce ethanol. Thailand can produce ethanol from crops that remain from consumption in the country. Sugarcane crops could supply approximately 2,392 million liter ethanol/year or 30% use of gasoline at year 2002. If the government has good planning to support utilization bioethanol, it can reduce energy input from abroad. Recently, Thailand has 8 ethanol factories. Raw material used to produce ethanol by these factories is bagasse, molasses, and cassava (Table 2.16) (Yoosin and Sorapipatana, 2003).

Table 2.16 List of industrial firms that produce ethanol in Thailand (Yoosin and Sorapipatana, 2003)

Name	Locations	Power (liter/day)	Raw materials
Pornwili International Group Trading ,Company	Ayuttaya	25,000	Molasses/cassava
Thai Argo Energy, Company	Nakornsawan	150,000	Molasses
International Gasohol Corporation, Company	Rayong	5,000,000	Cassava
SangSom, Company	Nakornpathom	100,000	Molasses
ThaiNgang Ethanol, Company	Chaiyapum	130,000	Cassava
Sugar Khonkhen , Company	Khonkhen	85,000	Molasses/cassava
Alpha Energy, Company	Nakornsawan	212,000	Cassava
Thai National Tower, Company	Rayong	300,000	Cassava