Growing sugarcane for bioenergy – effects on the soil

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Abstract

An increasing area of sugarcane is being growing for the production of bioenergy. Sugarcane puts a high demands on the soil due to the use of heavy machinery and because large amounts of nutrients are removed with the harvest. Biocides and inorganic fertilizers introduces risks of groundwater contamination, eutrophication of surface waters, soil pollution and acidification. This paper reviews the effect of commercial sugarcane production on soil chemical, physical and biological properties using data from the main producing areas. Although variation is considerable, soil organic C decreased in most soils under sugarcane and, also, soil acidification is common as a result of the use of N fertilizers. Increased bulk densities, lower water infiltration rates and lower aggregate stability occur in mechanized systems. There is some evidence for high leaching losses of fertilizer nutrients as well as herbicides and pesticides. Eutrophication of surface waters occurs in high-input systems. Sugarcane cultivation can substantially contribute to the supply of renewable energy, but that improved crop husbandry and precision farming principles are needed to sustain and improve the resource base on which production depends.

Introduction

Sugarcane as a biofuel crop has much expanded in the past decade, yielding anhydrous ethanol (gasoline additive) and hydrated ethanol by fermentation and distillation of sugarcane juice and molasses. Byproducts are bagasse and vinasse (stillage or dunder) which is the liquid waste sometimes used for fertigation purposes. Bagasse, a by-product of both sugar and ethanol production, can be burned to generate electricity or be used for the production of biodegradable plastic. It provides most of the fuel for steam and electricity for sugar mills in Australia and Brazil. One ha of sugarcane land with a yield of 82 t/ha produces about 7,000 L of ethanol. Brazil currently produces about 31% of the global production and it is the largest producer, consumer, and exporter of ethanol for fuel (Andrietta *et al.* 2007). Between 1990 and 2005, global average sugarcane yields increased from 61 to 65 Mg/ha (http://faostat.fao.org). In some countries sugarcane is the main source of revenue and in Mauritius sugarcane occupies 90% of the arable land (Ng Kee Kwong *et al.* 1999). Globally, the area harvested increased by 2.6 million ha in the period 1990-2005; the largest expansion was in India and Brazil. It is expected that the area under sugarcane in Brazil will expand by 3 million ha over the next five years whereas the area under sugarcane in China is forecast to rise by 5% or more than 100,000 ha/y. Traditionally, sugarcane was harvested manually; the senescent leaves (trash) and stalks were removed by people using big knives. In the past two decades, pre-harvest burning has been replaced by mechanical green- or trash-harvesting by cutter-chopper-loader harvesters that leave the trash on the field. Irrigation and large amounts of inorganic fertilizers are often required for high yields. As a consequence, soil properties are likely to change under sugarcane cultivation and the high biocide inputs may affect the environment. Environmental concerns and policies are key factors affecting the future of sugarcane production. There is a also risk that the sugar industry is expanding on marginal lands where the costs or preventing or repairing environmental damage may be high. This paper reviews the main soil and environmental issues under continuous sugarcane cultivation. Most of this work pre-dates the surge of sugarcane production for bioethanol but the results are very relevant for the new situation.

Data Sources and Types

There is fair a body of literature on changes in soil properties under sugarcane cultivation (Table 1). Changes in soil properties under continuous sugarcane have been investigated in two ways. Firstly, soil properties are monitored over time at the same site (Type I data). In the second approach, soils under adjacent different land-use systems are sampled at the same time (Type II data).

Discussion and conclusions

Sugarcane is an ideal crop for renewable energy because of its rapid growth and high energy production per ha. Fossil energy is needed for growing of the crop and the production of bioethanol, which partly offsets the energy produced. In Brazil, fossil energy costs are minimized by use of processing products like bagasse for energy. The energy balance (yield over fossil energy) of such systems may range from 9 to 11

Table 1. Studies focusing on changes in soil chemical, physical and biological properties under sugarcane cultivation.

Soil order	Country	Soil property investigated			Data[A]	
		Chemical	Physical	Biological	Type I	Type II
Alfisols	Australia	✓	✓	✓		✓
	Brazil	✓	✓			✓
	India	✓				✓
	Swaziland	✓	✓	✓		✓
Andosols	USA Hawaii	✓		✓		✓
Fluvents	Australia	✓	✓	✓		✓
	Brazil	✓				✓
	Fiji		✓			✓
	USA Hawaii		✓			✓
	Iran		✓			✓
	Mexico	✓				✓
	Papua New Guinea	✓	✓		✓	✓
Inceptisols	Australia	✓		✓		✓
	India	✓	✓	✓		✓
	Iran		✓			✓
	South Africa	✓	✓			
						✓
Oxisols	Brazil	✓	✓	✓		✓
	Fiji	✓	✓		✓	
	USA Hawaii		✓			✓
	South Africa	✓	✓	✓		✓
	Swaziland	✓	✓	✓		✓
Spodosols	Australia		✓	✓		✓
	USA	✓				✓
Ultisols	Australia			✓		✓
	Brazil		✓			✓
	Indonesia	✓			✓	
Vertisols	Mexico	✓	✓			✓
	Papua New Guinea	✓	✓		✓	✓
	South Africa	✓	✓	✓		✓
	Zimbabwe	✓		✓		✓
not specified	Australia	✓	✓	✓		✓
	India	✓	✓			✓
	Mexico	✓				✓
	Philippines	✓			✓	
	South Africa	✓	✓			✓
	Trinidad		✓			✓

[A]Type I are data whereby soil dynamics are followed with time on the same site; Type II are data whereby different land-use was sampled simultaneously – see Hartemink (2006)

(Macedo 1998), which compares very favorably to many other biofuel crops. In part, this favorable balance is explained by the relatively low N application rates to sugarcane in Brazil, because of the high rates of biological nitrogen fixation. In many agricultural systems, inorganic fertilizers are a major budget line. Overall, biological nitrogen fixation can be considered one of the principal reasons for the success of the bioethanol program in Brazil (Medeiros *et al.* 2006). Most studies have shown that soil acidification takes place under sugarcane, principally due to the use of N fertilizers containing or producing NH_4^+. All ammoniacal N fertilizers release protons when NH_4^+ is oxidized to NO_3^- by nitrifying micro-organisms. Also, mineralisation of organic matter can contribute to soil acidity by the oxidation of N and S to HNO_3 and H_2SO_4 (Sumner 1997). Since organic matter declined in most soils under sugarcane, it may have contributed to the increase in soil acidity. Acidity is reversible; liming readily restores productivity but if acidification has also taken place in the subsoil, amelioration is much more difficult. There is only a small response of sugarcane to lime on moderately acid soils (Turner *et al.* 1992) whereas in other studies a decrease in the sugar content was found after lime applications (Kingston *et al.* 1996). Sugarcane is fairly tolerant of acidity and high concentrations of exchangeable and soluble Al (Hetherington *et al.* 1988); avoiding strong soil acidification might be a better option than the use of lime to correct for high acidity inputs.

Soil organic C dynamics have received much attention in sugarcane, but there are some conflicting reports. Part of the problem is that total soil organic C determined by the Walkley & Black or the dry combustion method is not very sensitive to short-term changes in land-use. Long-term observations are required to pick up statistically significant differences in soil organic C levels. It is also related to the spatial variability in total soil organic C. Notwithstanding these methodological problems, total soil organic C decreased in most topsoils and in most soil types. This may be the effect of tillage which causes increased soil organic matter decomposition compared to soils under natural ecosystems, but, also, because of lower inputs of organic matter in sugarcane systems. Soil texture plays an important role in the rate of change in soil organic C and this change also differs for different size fractions. An equilibrium is reached after many years, but it is generally lower than the initial level in the soil under forest. In a number of soils, it was found that levels of soil organic C increased in the subsoil. The decrease in soil organic matter under continuous sugarcane reduces soil biological activity and increases the susceptibility of the soils to physical degradation.
Soil compaction is a common problem in mechanized systems, mainly due to the heavy machinery used for field operations at the wrong soil moisture levels. Erosion losses up to 505 Mg soil ha^{-1}/y have been reported under sugarcane. Erosion can be high after the harvest and with replanting, especially on sloping land (Blackburn 1984).

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