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Sustainable land management in the tropics : the case of sugarcane plantations
Gestion durable du sol dans les pays tropicaux : le cas des plantations de canne à sucre

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Introduction

Land degradation in the tropics has mainly resulted from poor soil management practices. This has been recognised for many years but it is only since the late 1980s that the term sustainable land management is widely used. Although it has different meanings to different people, in essence, sustainable land management refers to practices that do not degrade the soil or contaminate the environment while providing support to human life (Greenland, 1994). Assessing sustainable land management is as difficult as defining it. Key problems are the spatial and temporal borders which need to be chosen for its assessment as well as the selection of indicators to evaluate sustainability in a given locality. Despite these problems considerable achievements have been made in the assessment of sustainable land management in the tropics but most studies refer to subsistence agriculture where low yields and soil degradation form a vicious cycle.

Relatively little has been written on sustainable land management under high-external input or plantation agriculture in the tropics. An important plantation crop in many tropical countries is sugarcane. Its production has dramatically increased in the past few decades. In the 1960s, sugar production in the world was about 64*106 t of which half was produced in developing countries (FAO, 1996). By the mid 1990s, production had increased to 119*106 t. Between the mid 1960s and 1990s the largest expansion of sugar production occurred in India (from about 3 to 15*106 t) and Brazil (from 5 to 10*106 t). Part of the increase in sugar production has resulted from improved agronomic practices, but in many countries, increased production has resulted from a larger area under sugarcane. Most commercial sugarcane is grown intensively at a large scale and many of the husbandry practices are similar to intensive agricultural systems in temperate regions. Heavy machinery is used for land preparation, planting, spraying and harvesting. Biocides are widely used to control pests and diseases, herbicides to control weeds, and inorganic fertilizer applications to sustain yields. Sugarcane also makes heavy demands on soil nutrient reserves as large amounts of nutrients are removed with the harvest. In summary, commercial sugarcane cultivation is likely to affect soil conditions and in this paper, the effects of commercial sugarcane cultivation on soil properties are reviewed.

Data

In general, two methods can be used to study changes in soil properties.

Firstly, soil dynamics can be monitored over time on the same site. This is called chronosequential sampling (Tan, 1996) or Type I data (Sanchez et al., 1985). Although type I data are extremely useful to assess the sustainability of land management practices, few such data sets exist for tropical regions. In the second method, soils under adjacent different land-use systems are sampled at the same time and compared. These are called Type II data Sanchez et al., 1985), biosequential sampling (Tan, 1996), or 'sampling from paired sites' in the literature from Australia (e.g. Garside et al., 1997). The main underlying assumption is that the soils of the cultivated and uncultivated land are similar and that differences observed in soil properties are attributed to the cultivation. Obviously, this is not always the case as the uncultivated land may have been of inferior quality. When carefully taken, however, biosequential samples provide useful information and such a sampling strategy has been followed in much of the literature reviewed on soil changes under sugarcane cultivation.

It was found that in much of the literature on sugarcane, methods for data collection were different and site description was inadequate. In addition, soil management systems were often different which seriously hampered the comparison of rates of change in soil properties. We therefore selected commonly measured soil properties to assess the sustainability of land management practices under sugarcane, and properties inlcuded were: pH, organic matter, soil nutrient status, bulk density, infiltration, soil resistance and microbial biomass.

Soil Chemical Properties

Most of the data on changes in soil pHw (pH water) under sugarcane are type II data. A type I data study was conducted in Fiji where soil fertility properties were monitored between 1978 and 1983 on highly weathered soils (Haplic Acrustox). In one-third of the Oxisols the pHw had declined from 5.5 to 4.6 but in other soils the pHw trend was less obvious or absent (Masilaca et al., 1985). Schroeder et al. (1994) measured soil pHw in 1988/89 and 1992/93 on South African sugarcane farms. A pH (in KCl) decline of 0.4 units was found during this period. In the Philippines, Alaban et al. (1990) found that soil pH had declined on average from 5.0 in 1969/70 to 4.7 in 1988/89. Hartemink and Kuniata (1996) found that the pHw in young alluvial soils under sugar cane in Papua New Guinea had decreased from 6.3 in 1983 to 5.9 in 1994. Maclean (1975) found a small (0.2 pH units) but significant difference in topsoil pHw between sugar cane and uncultivated land. Wood (1985) found a significant decrease in the subsoil pH from cropped land as compared to uncultivated land. Bramley et al. (1996) also found a decline in soil pH under sugarcane but results were inconsistent and there was little relation with the soil type sampled.

Soil acidification based on type II data were also reported from sugarcane areas in Hawaii (Humbert, 1959), Puerto Rico (Abruña-Rodriguez and Vicente-Chandler, 1967) and Florida (Coale, 1993). It is generally agreed that the decline in pH under sugarcane cultivation is the result of enhanced acidity through acid input and alkali removal. Acid input occurs with the addition of ammonium-N fertilizers followed by nitrification and thedirect uptake of ammonium-N by plants. Furthermore, the high rainfall in many sugarcane areas, the substantial removal of bases with the harvested sugarcane, and the leaching of cations are important causes of soil acidification under sugarcane (Moody and Aitken, 1995).

Changes in soil organic matter content under sugarcane are less well documented than changes in pH. In the Philippines, Alaban et al. (1990) found a significant decrease in organic matter from 23 to 17 g kg-1 between 1969/70 and 1988/89. Masilaca et al. (1985) found a significant decrease in organic carbon of 15 to 25 g kg-1 five years after Oxisols under natural vegetation had been brought into sugarcane production. In Oxisols in Swaziland, the difference between cropped land under sugarcane since 1977 and uncultivated land was about 2 g C kg-1 soil (Henry and Ellis, 1995). In young alluvial soils in Papua New Guinea organic carbon levels had declined from 50 to 35 g kg-1 between 1985 and 1994 (Hartemink and Kuniata, 1996). Whilst most reports indicate a decline in soil organic matter under long-term sugarcane cultivation, some such as Bramley et al. (1996), have shown little or no differences in soil organic matter between cropped and uncultivated land. The absence of such a difference may be partly explained by the existence of trash retention in northern Australia which has the potential to maintain or increase soil organic carbon contents (Vallis et al., 1996; Wood, 1991). A decline in soil organic carbon is probably the clearest indicator of unsustainable land management (Greenland, 1994).

Large amounts of biomass and nutrients are removed from the field with the harvest of the sugarcane. Although estimates differ, the amounts of nutrients removed yearly with a yield of 100 t ha-1 is about 120 kg N ha-1, 33 kg P ha-1 and 125 kg K ha-1 (De Geus, 1973). It is therefore likely that nutrient levels decline under continuous sugarcane cultivation. In the Philippines, Alaban et al. (1990) found a decline in available P from 27 to 17 mg kg-1 between 1969/70 and 1988/89. Exchangeable K declined over the same period from 145 to 134 mg kg-1. In Oxisols in Fiji, Masilaca et al. (1985) found a decrease in exchangeable K from 2.6 to 1.8 mmolc kg-1 five years after they had been brought into production for sugarcaneHenry and Ellis (1995) found a difference in exchangeable K between cropped and uncultivated Oxisols of 206 mg kg-1. On Alfisols in India, soil available K declined by 180 kg ha-1 after plant cane and the 1st ratoon (Sundara and Subramanian, 1990). Wood (1985) compared cropped and uncultivated land in northern Australia and found significantly lower K levels under sugarcane but significantly higher P levels which suggests that excessive P-fertilizer had been applied. In Vertisols in Papua New Guinea, both available P (-12 mg kg-1) and exchangeable K (-4.1 mmolc kg-1) had declined between the mid 1980s and 1990s (Hartemink, 1998). In summary, a decline in plant nutrients commonly occurs under sugarcane cropping and is the result of high nutrient removal by the cane sent to the mill and the lack of a nutrient replenishment. Some of the decline is possibly a secondary effect. For example, the decline in exchangeable Ca and Mg may be caused by increased leaching rates resulting from topsoil acidification. Similarly, the decline in N and P levels is possibly linked to a decrease in organic matter which is commonly found in soils of the tropics.

Soil Physical Properties

Sugarcane is usually cultivated on low ridges (rows) with tractors and harvesters passing over the interrow. McGarry et al.(1996) found a topsoil bulk density of 1.55 Mg m-3 in the rows as compared to 1.85 Mg m-3 in the interrow on Spodosols in Australia. An adjoining uncultivated site had a topsoil bulk density of 1.40Mg m-3. Maclean (1975) and Wood (1985) reported significant increases in bulk density of 0.15 to 0.18 Mg m-3 in the top 8 cm as compared to uncultivated land. In Fluvents in Papua New Guinea, a significant increase in bulk density of 0.23 Mg m-3 was found in the interrow whereas no difference was found between adjoining natural grassland and the row (Hartemink and Kuniata, 1996). Masilaca et al. (1985) found an increase in bulk density from 0.85 to 1.03 Mg m-3 in Oxisols under sugarcane cultivation. Soil compaction is generally perceived as a problem in sugarcane cultivation (Yates, 1978) and has also been reported from India (Srivastava, 1984), and South Africa (Swinford and Boevey, 1984).

Increases in bulk density or a decrease in porosity, is commonly caused by wheel traffic. The compaction can occur during one event such as during field operations at moist soil conditions, or can be cumulative during the years of cropping. Trouse and Humbert (1961) have shown that the topsoil bulk density of an Oxisol in Hawaii increased from 1.25 Mg m-3 after 10 tractor passes to 1.43 Mg m-3 after 20 passes, and to 1.53 Mg m-3 after 50 tractor passes.

One common result of compaction is an increase in soil strength. In South Africa, Swinford and Boevey (1984) found a penetrometer resistance of 220 N cm-2 in fully compacted topsoils.

Uncompacted soils had resistance values of about 140 N cm-2McGarry et al.(1997) observed soil resistance values in Spodosols in north Queensland of about 2500 kPa in the top 10 cm of the interrow and values of 800 kPa in the row. In Trinidad, Georges et al. (1985) found an increase in penetration resistance from 21 to 26 kg cm-2 after wheel traffic on a clay soil. The increase was lower on a silty clay loam.

In addition, water intake is commonly lowered by an increase in topsoil bulk density. Hartemink (1998) observed bulk densities causing slow water intake (< 50 mm h-1) to be about 1.20 Mg m-3 in Fluvisols and 1.16 Mg m-3 in Vertisols. For both soil types, an increase of about 0.2 Mg m-3 drastically reduced the water intake.

Soil Biological Properties

Little is known on changes in soil biological properties occurring under sugar cane cultivation. Some microbial biomass measurements have been made in cultivated and uncultivated sites in Australia. Such measurements are an indication of the microbial population in the soil. Garside et al. (1997) observed that soil microbial biomass was significantly lower on old sugarcane land than on new land and concluded that there is a rapid loss of soil microbial biomass when sugarcane is established and a build up of soil pathogens with a sugarcane monoculture. Similar observations were made in Oxisols in Swaziland (Henry and Ellis, 1995).

Conclusions

Although the data are scanty and research methodologies differed, there is evidence that land management is a matter of concern in many sugarcane areas. Soil acidification, nutrient depletion and declining organic matter levels commonly occur under sugarcane cultivation. In addition, interrow compaction with reduced infiltration and topsoil erosion has been reported from some sugarcane areas. The review has shown that soil degradation in the tropics also occurs in high external input agriculture like commercial sugarcane cultivation.

Three main causes can be identified which affect sustainable land management on sugarcane plantations: (i) the use of heavy machinery, (ii) the use of biocides and inorganic fertilizers, and (iii) the large amount of nutrients removed with the harvest. Whilst most changes in soil properties brought about by these management practices are reversible, their remediation is costly. Consequently, soil management systems for sustainable sugarcane production will need to be much more proactive than they have been in the past and accommodate ecological principles to an increasing extent. Strategies based on management by soil type, crop residue retention, nutrient recycling and row/interrow management will help to develop sustainable production systems.

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