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Changes in an Inceptisol of Mauritius after rock removal for sugar cane production

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ABSTRACT

Sugar cane (*Saccharum hybrid* sp.) cropping in the rocky soils of Mauritius requires the prior removal of rocks to enable the implementation of mechanized operations, particularly harvesting. The effects of such operations on the soil are unknown, particularly the extent to which soil properties could be affected. A study was conducted at a sugar estate on the sub-humid western coast of Mauritius to determine whether the properties of an Inceptisol had been degraded on account of rock removal and land preparation. Pristine uncultivated soils were compared to sugar cane soils from which rocks had been removed, either recently, *i.e.* about 2 years ago, or earlier, *i.e.* about 10 years ago. A number of biological, chemical and physical properties were studied. These comprised organic matter and microbial biomass; pH, cation exchange capacity and exchangeable bases; particle size distribution, aggregate stability, bulk density, plant available water and infiltration rate. The results indicate that biological properties have degraded in the topsoil but improved in the subsoil, chemical properties have generally improved, whereas physical properties were both positively and negatively affected. Thus, organic carbon concentration decreased from about 3.9% to 3.2% in the 0–5 cm layer following rock removal, but increased from about 1.8% to 2.3% in the 15–30 cm layer. Soil pH increased significantly, from 6.9 to 7.5 in the topsoil and from 7.0 to 7.7 in the subsoil. The concentration of exchangeable bases also tended to increase. Stabilized water infiltration rate increased from 133 to 185 mm/h and plant available water increased from 42 to 58 mm. However, bulk density also increased from 0.96 to 1.02 g/cm^3 in the 0–5 cm layer and from 1.09 to 1.23 g/cm^3 in the 15–30 cm layer. While rock removal can explain some of these changes, it is also quite likely that other practices linked to sugar cane production, such as tillage, irrigation and the addition of organic waste material, played a decisive role in this respect. The greatest cause for concern stemmed from soil compaction. Remedial action that was identified to address the issues of declining topsoil organic matter content included trash blanketing, addition of organic wastes and green manuring, whereas soil compaction could be managed through the use of controlled traffic and minimum tillage and *in situ* rock crushing.

1. Introduction

Sugar cane (*Saccharum hybrid* sp.) has been cropped in Mauritius for the last three and a half centuries on soils with very different rock contents, ranging from rock-free to very rocky. Rocky or stony soils represent about 69% of sugar cane land in Mauritius (Jhoty and Ramasamy, 2003a). Land preparation in these soils has required the prior removal of surface and sub-surface rocks, by hand in the early days, and thereafter using mechanized practices. Such mechanized rock removal has gained impetus in recent times, to improve the soil medium for sugar cane cropping and to facilitate the mechanization of operations such as fertilizer and herbicide applications, irrigation, cane loading and harvesting. Given that the presence of rocks leads to harvester blade damage, rock removal has turned out to be an absolute pre-requisite for mechanized harvesting.

Jhoty and Ramasamy (2003a) have summarized the historical trend of events with respect to rock removal and land preparation in Mauritius from the pre-machinery period to the present day. In the pre-machinery period, rocks and stones were manually removed and piled in the fields, either as rock walls in between cane rows or in small mounds or pyramids. As from the early 1950s, rocks were mostly piled into huge rounded mounds in the field using bulldozers. As described by Coombes (1957), rock removal was carried out even in the worst terrain using bulldozers and rippers to reclaim rocky land for sugar cane cropping. However, under these extreme conditions, the land surface had subsided by some 45–60 cm at the end of the operation. Further rock removal later took place to allow the introduction of new irrigation systems and mechanized sugar cane loading. An

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additional boost was given to these operations with the increasing demand for rocks as construction material, which led to stone-crusher companies paying a premium for the rocks that were removed from sugar cane fields. In more recent times, priority has been given to mechanization of all cultural operations to reduce production costs. In this context, it was essential to undertake rock removal to a fine level to improve machine efficiency, reduce the risk of harvester blade breakage, and avoid bringing rocks to the mill. To this end, rocks with diameter exceeding 8 cm were removed from the surface and the subsoil was tilled to a depth of 25–50 cm (Nicolin and Siegmund, 1992). Thereafter, land preparation was undertaken to level the fields, through cut and fill, redesign of drains and realignment of roads.

It is expected that rock removal from sugar cane land will remain an essential activity in the coming years, the more so as mechanization of sugar cane cropping is a top priority in reducing production costs. Until recently, about 35% of the land still required intensive rock removal to achieve the target of complete mechanization (Jhoty and Ramasamy, 2003a). It has been estimated that anything between 58 and 101 million t of rocks can still be raked out of those soils (Jhoty and Ramsamy, 2003b). However, the long-term effects of such large-scale disruption remain unknown, particularly with respect to soil properties. While the adoption of such measures is undoubtedly essential to achieve the goal of complete mechanization of cultural operations, and hence lowering of production costs, their effects on soil have yet to be determined. For the industry to maintain its production in the long-term, it is essential that the effects of all these new practices on soil properties be known, with particular attention to soil quality, *i.e.* to the ability of the soil to meet its various functions, such as supplying a medium for plant growth, controlling water flow in the environment and acting as an environmental filter. To ascertain that soil properties had not been excessively degraded by these practices, a number of soil parameters were measured in sugar cane fields with different cropping histories.

2. Materials and methods

The study was carried out at Médine Sugar Estate, on the western coast of Mauritius, an island of volcanic origin situated between the parallels of 19°58′ and 20°32′ south latitude and the meridians of 57°17′ and 57°46′ east longitude in the South West Indian Ocean, with a total land area of about 1860 km^2. It has an elliptical shape, with a major axis running North North East–South South West over a distance of 61 km and perpendicular to this a minor axis of 46 km. The island consists essentially of a ring of peaks about 600–900 m high, enclosing a central plateau rising from about 300 m in the north to 600 m in the South West. Médine Sugar Estate is situated on the coastal plain to the West, with a general slope of about 2%.

The soils at the sugar estate where this study had been undertaken have developed under climatic conditions that are classified as sub-humid megathermal (Halais and Davy, 1969). The experimental site is situated at an altitude of 85 m. Historical mean annual rainfall for the 30-year period between 1951 and 1980 amounted to 776 mm (Padya, 1984), with a monthly maximum of 148 mm in March and a monthly minimum of 14 mm in September. Historical mean monthly maximum temperature varied between 25.6 °C in August and 31.2 °C in February, while mean monthly minimum temperature was in the range of 16.9 °C in July to 22.8 °C in January. The parent material of the soils at the sugar estate has been derived from the older Intermediate Lavas and the younger Late Lavas. As a result, two major soil groups occur in the region: the relatively stone-free Low Humic Latosol from the Intermediate Lavas and the rocky Latosolic Reddish Prairie soil from the Late Lavas (Parish and Feillafé, 1965), respectively equivalent to an Oxisol and an Inceptisol in Soil Taxonomy (Soil Survey Staff, 1999).

The sugar cane fields that were monitored for changes in soil properties were all under the Inceptisol great group. As described by Parish and Feillafé (1965), these soils are derived from a relatively thin layer of moderately weathered lava overlying an older soil. They are reddish-brown to brown silty clay loams over a reddish silty clay to clay subsoil. The solum contains many gravels and boulders and bedrock exposures are common. These soils are neutral to slightly acid, have a relatively high cation exchange capacity (CEC), usually >25 $cmol_c$/kg, throughout the solum and organic matter (OM) contents in excess of 6%.

At the sugar estate, some 83% of the arable land is either very rocky or stony. Some 10 years ago, the estate embarked on a comprehensive long-term plan of rock and stone removal, including three levels of "derocking" (coarse, medium and fine), accompanied by a complete upgrading of irrigation systems and field layout (Jacquin and d'Arifat, 1998). Rock removal and land preparation entail a whole set of operations (Fig. 1), with bulldozers raking and piling boulders prior to loading and carting away in lorries, before the land is graded and tilled, ready for planting.

Fields with three different histories, namely (1) pristine uncropped conditions (treatment P), (2) having undergone recent rock removal (treatment RRR) and (3) having undergone early rock removal (treatment ERR), were studied with respect to their biological, chemical and physical soil properties (Table 1). In this study, pristine conditions refer to fields where no sugar cane had been grown previously, with a natural sparse vegetation of shrubs and grass, and where no rock removal or land preparation had been undertaken. Land slope was similar for all the fields and was generally of the order of 3%.

Biological parameters consisted of organic carbon (OC), total nitrogen and microbial biomass carbon and nitrogen. Chemical parameters included pH, CEC and concentration of exchangeable bases. Physical parameters consisted of particle size distribution, aggregate size and stability, bulk density, stabilized water infiltration rate and plant available water. Bulk density and stabilized water infiltration rate were measured *in situ*. The other parameters were measured in the laboratory. All these measurements were done on three fields with the same history. On every field the measurements were repeated at four randomly selected representative areas, thus giving twelve replicates per treatment. Soil was sampled from two trenches that had been dug within each plot and samples from the same depth for each pair of trenches were bulked to give a representative sample for each plot. Each trench was 150 cm long, 30 cm wide and 50 cm deep. Since cane rows are spaced about 150 cm apart, this procedure ensured that each sample consisted of soil taken from underneath both the cane row and the inter-row. Soil samples were taken from each trench in four layers, namely 0–5, 5–15, 15–30 and 30–50 cm for all laboratory analyses, except microbial biomass and aggregate size determinations. For each layer, two sub-samples were taken from both faces of the trench and the four sub-samples obtained were mixed to give a composite sample representative of the trench. Thereafter, samples were air-dried in the shade and prepared for analysis by passing the soil through 2-mm diameter sieves. For microbial biomass determination, soil samples were taken from the upper 15 cm and passed through 2-mm sieves without air-drying prior to analysis. For aggregate size determination, the soil sampling proceeded as for all the other determinations, but the samples were passed through 8-mm sieves instead of 2-mm sieves before analysis.

Organic carbon content was determined by the modified Walkley–Black procedure (Anderson and Ingram, 1993), total