# MONITORING AND PREDICTING RESTORATION OF QUALITY ATTRIBUTES OF DEGRADED LAND USING AN ORGANIC MATTER SIMULATION MODEL

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***Abstract***

*Intensification of agricultural production by means of high-input technologies and agroecosystem simplification leads to unsustainable food production and farm livelihood in many areas of the world. Agroecology offers alternatives to develop stable systems that can be taken up also by small scale farmers, normally farming on readily degraded land. One such alternative relies on increasing spatial-temporal diversity of agroecosystems. However, experimentation to evaluate the impact of agrodiversity is costly and time-consuming. A methodology to overcome this is discussed here, based on preliminary results of experiences in central Argentina, an area of strong biophysical and socio-economic gradients. Soil organic matter is proposed as an overall indicator of soil health and system sustainability; the widely used soil organic matter model CENTURY is validated under local conditions and used as a monitoring tool. The impact of an increased agrodiversity on soils with contrasting inherent properties is exemplified by running land use scenarios for the next 50 years and evaluating trends in soil organic matter contents.*

**Key words:** Century model, agrobiodiversity, soil health, sustainability, Argentina.

## INTRODUCTION

'Intensified' agricultural systems based on large-scale, commercial production of commodities, and relying on high-input technologies, are currently displacing traditional, diversified and smaller scale systems in many areas of the world. Such intensification processes lead to an important loss of agrodiversity, affecting the productivity and stability of the resulting systems, which in turn have environmental and socio-economic consequences. That constitutes a common picture in many agroecological zones of Argentina, as e.g. described for the semi-arid *pampas* by Alessandría et al. (2001). The mid- and long-term consequences of the intensification included various forms of physical and chemical soil degradation (e.g. soil erosion, compaction, acidification-depletion, etc.) and important losses of soil bio-diversity.

Agroecology offers conceptual as well as technological alternatives for the development of sustainable agricultural production systems by increasing their agro-biodiversity in space and time (Vandermeer et al., 1998). In that respect, Altieri (2003) has recently shown how the agroecological principles may contribute to enhance natural resource management for poor farmers in marginal environments, by presenting several examples from successful NGO-led projects around the world. Production diversification in time by rotating crops and livestock activities in a certain field - with a concomitantly increased spatial diversity at farm scale – proved a key principle for the development of sustainable systems.

As demonstrated by many studies, it is possible to rehabilitate land that underwent a varying degree of either physical or chemical soil degradation processes, by accomplishing an increased diversity of agricultural production with minimum tillage, crop-livestock rotation or crop residue management (e.g. Gómez et al., 1996). However, the benefits of an increased spatial-temporal diversity would depend on the biophysical characteristics of the system under rehabilitation. This leads us to the concept of resilience (i.e. the capacity of a system to restore its life support processes, or its ability to rebound or heal itself following a perturbation – Lal, 1997) and/or 'rehabilitation potential' of a certain land class, for which the health and quality attributes of the soils play a preponderant role (Doran, 2001).

Is there a limit or threshold to the intensity of soil degradation beyond which the land cannot be rehabilitated by adopting a set of agroecological principles? Such hypothetical threshold will certainly vary depending on the type of degradation and, presumably, on the inherent properties of the soil type considered. How can we know/define such thresholds and which soil property(ies) would be the most sensitive to show them, for each particular soil type? Is there a somewhat universal soil health and quality indicator that can be used to monitor the sustainability of the system, its degree of degradation and its potential for rehabilitation?

### *Monitoring soil organic matter dynamics in central Argentina*

The central region of Argentina (ca. 10 million ha) offers interesting gradients of biophysical conditions and land use systems. They range from intensive cropping in the sub-humid flat and gently undulating lands on loessoid soils, to several crop-livestock combinations on sandy plains and/or on the foothills of the Comechingones mountain range, to a virtually pure livestock system in the lower wetlands and in the higher mountain grasslands. However, the climate is quite homogeneous all over the region, despite the local variability associated with the mountains. Almost similar rainfall and temperature regimes can be observed across areas including widely different, contrasting soil types. This situation allows for the study of the inherent potential of soils for land rehabilitation, when an agroecological alternative such as increasing the spatial-temporal agrodiversity is evaluated as a means to restore the levels of soil C that had been lost by continuous cropping.

The model CENTURY has been validated in the region, using data from sampling points that included soils under ‘natural’ conditions and soils with a different degree of degradation by agricultural use. The land use history of each site (i.e. sampling point) has been re-constructed from the interviews held with farmers and other key informants, and simulated with the model. The ‘natural’ conditions where those in which the original vegetation was still present. In some cases, the vegetation had been cleared away in the past, but the land was later abandoned and a semi-spontaneous vegetation grew instead. The accuracy of the model to predict the current level of soil organic matter in the sampled soils is illustrated by Figure 1.

Once the model has been validated and its accuracy is known to be acceptably high, it can be used to simulate the potential evolution of the soil organic matter levels under different land use and management systems. In the following example, two soil types were considered: the silt loam “Las Selvas” soil and the loamy sand “Sarmiento” soil, which main properties are presented in Table 1. The model was first run with the historical land use and management system for each site, yielding an estimation of the present status of the different soil properties. Then, these values were used as starting points to run the ‘scenarios’. In this case, the climate was assumed to remain unchanged for the next 50 years. For both sites, the data from the nearest meteorological station was used to feed in the model (average values in Table 1).

Three land use and management scenarios were selected. The ‘current’ scenario simulates the continuation of the historical management system for the next 50 years, assuming no technological changes. The ‘improved’ scenario assumes an increased agrodiversity in time by rotating crop and livestock activities suited for each particular site (e.g. five cropping seasons including alternated maize-fallow with soybean-fallow and sunflower-fallow for four years and forage rye followed by the implantation of a pasture, and five years of grazing with a stocking rate of 1.2 grazing units per hectare). Finally, the ‘untouched’ scenario simulates a situation in which the land is abandoned and wild vegetation re-colonises the land.

Figure 2 shows the results of the modelling exercise for the two sites selected. The natural savannah-like vegetation was cleared and agriculture started at the beginning and at the middle of the 20$^{th}$ century for Las Selvas (black) and Sarmiento (white), respectively. The original amount of soil organic C was higher in Las Selvas, though the difference was not very important. However, when agriculture started, the coarser soils of Sarmiento lost organic C at a notably faster rate, showing an important difference for the year 2000. If the current land use and management continues for the next 50 years (square markers), the amount of soil C remains somewhat steady for Sarmiento whereas it keeps on decreasing for Las Selvas until it reaches its lower limit. The limit to land degradation, in terms of the amount of organic C in the topsoil, varied with soil type. Note in figure 2 that the rate of decrease in soil C for Las Selvas was accelerated during the 90’s, due to the ‘intensification’ process described in the introductory paragraphs, dominated by mono-crops of soybean.

If agriculture stops and the land remains ‘untouched’ (circles), the amount of organic C in the topsoil recovers at a faster relative rate for the coarser soil. A similar trend can be observed for the ‘improved’ scenario (triangles). However, the amount of organic C continues to increase under both scenarios for Las Selvas (black) whereas it reaches a new equilibrium and it does not increase during the last 10 years of the simulation for Sarmiento (white). The absolute amount of atmospheric $CO_2$ fixed into soil organic C is obviously much higher for Las Selvas. Since this constitutes a simple example, the performance of the ‘improved’ agroecological technology to rehabilitate soils proposed here (i.e. increasing agrodiversity in time) should be considered with caution; it could be further refined to suit the actual conditions of each site and to include new technological options.

This simplified example was designed to illustrate the potential of organic matter models as a tool to monitor and/or predict the success of an agroecological alternative to achieve the rehabilitation of degraded lands. Although other complementary natural processes and technological options were not fully considered in this example (e.g. soil erosion, fertiliser use, no-till systems, etc.), their effect can be readily simulated with the model used here. On the other hand, there are other considerations regarding soil organic matter quality: e.g. the organic C accumulated in the sandy soil under the ‘untouched’ scenario is mainly active C, easily decomposable and therefore non-stable. These quality aspects were not shown in the example but they can be studied with the model as well.

**Integrating the use of models and experiments in agroecological research, education and extension**

The example above showed the potential of the simulation models to save time and resources in agroecological research; an initial step using models may help in directing and designing the experimental phase. Preferably, their use should be always combined with experimentation to continually refine their validity and to feed in new data for their eventual re-parameterisation. Soil organic matter appears as an integrated indicator of soil health and quality, which can be used to monitor land degradation and rehabilitation processes. The example also showed the didactic potential of the organic matter models to illustrate possible outcomes in terms of achieving the rehabilitation of soils and lands from alternative technology adoptions. They can be used during discussion meetings when collective decisions on land use and management are to be made for a given region – in multi-stakeholder decision making. They may also offer multiple possibilities for their use in knowledge and information transfer processes.

**REFERENCES**

ALESSANDRÍA E., LEGUÍA H., PIETRARELLI L., SÁNCHEZ J., LUQUE S., ARBORNO M., ZAMAR J.L., RUBIN D., (2001) : La agrodiversidad en sistemas extensivos. El caso de Córdoba. LEISA, 16: 10-11.

ALTIERI M. (2003) : Agroecology: the science of natural resource management for poor farmers in marginal environments. Department of Environmental Science Policy and Management, University of California, Berkeley, US, 28 pp.

DORAN J.W. (2001) : Soil health and global sustainability: translating science into practice. Agriculture, Ecosystems and Environment, 88(2): 119–127.

GÓMEZ A.A., SWETE D.E., SYERS J.K., COUGLAN K.L. (1996) : Measuring sustainability of agricultural systems at the farm level. En: Methods for Assessing Soil Quality. SSSA Special Pub. 49, Madison, Wisconsin, US, pp. 401-410.

LAL R. (1997) : Sustainable Land Use Systems and Soil Resilience. In: Greenland, D.J., Szabolcs, L., (eds.). Soil Resilience and Sustainable Land Use, pp. 41–67.

VANDERMEER J., VAN NOORDWIJK M., ANDERSON J., ONG C., PERFECTO I. (1998) : Global change and multi-species agroecosystems: concepts and issues. Agriculture, Ecosystems and Environment, 67: 1-22.

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**Tab. 1. : Main biophysical characteristics of the sites selected for the development of land use and management scenarios.**

| Site attributes | Units | Las Selvas | Sarmiento |
|---|---|---|---|
| Clay content | % | 13 | 6 |
| Sand content | % | 48 | 79 |
| Topsoil depth | cm | 21 | 19 |
| Current SOM* | % | 2.1 | 1.0 |
| Rainfall** | mm | 762 | 693 |
| Max. Av. Temperature | °C | 24.7 | 25.8 |
| Min. Av. Temperature | °C | 9.7 | 8.8 |

*Current soil organic matter content in the topsoil.
**Average values over 30 years.

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**Fig. 1. : Relationship between the soil C level predicted with the simulation model and the observed by soil sampling and laboratory analysis, for 45 topsoil (0 – 15 cm) samples from undisturbed or minimally disturbed soils of central Argentina**.

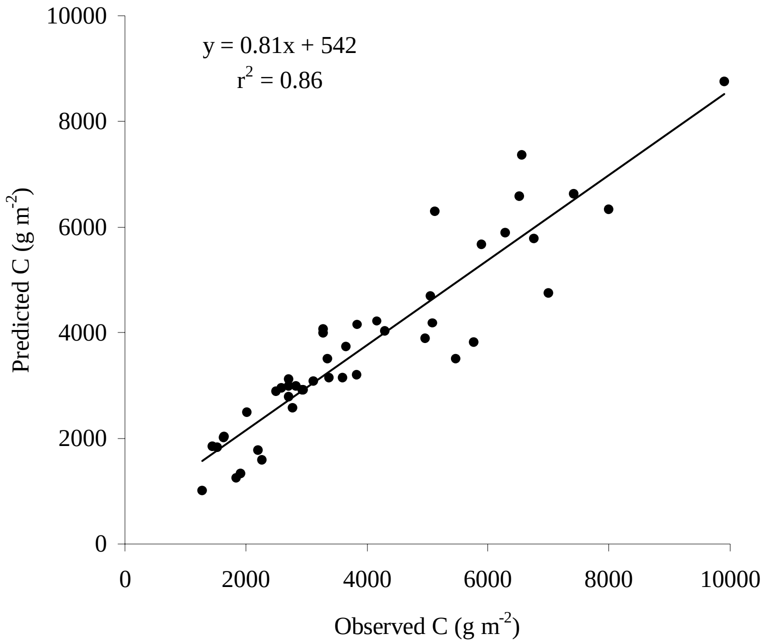


**Fig. 2. : Simulation of the soil organic matter dynamics for two soils of central Argentina under different land use and management situations.** Square markers indicate the evolution under the historical system and the continuation of the current situation. Triangular markers indicate the 'improved' management scenario and circular markers indicate the 'untouched' situation, both from the year 2000 onwards. The black markers correspond to Las Selvas (silty loam) whereas the white ones correspond to Sarmiento (sandy loam).