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Ecosystem restoration during the long fallow periods in the traditional potato agriculture of the Venezuelan High Andes

In the Venezuelan High Andes (3,300 to 3,800 m), the traditional agricultural system of potato cultivation alternates short periods of production with long fallows (five or more years). During the fallow, a secondary succession occurs, allowing restoration of soil fertility and vegetation. Even though the process has been the subject of a number of studies in the Bolivian "punas" and the Colombian and Venezuelan "paramos", the ecological mechanisms of fertility recovery and the ecosystem impacts of this agriculture are not well understood (Hervé, 1994). The analysis of long-fallow agriculture with an ecosystem perspective has particular importance, since a substantial number of the Andean traditional systems are inside national parks and are suffering a recent process of transformation to more intensive and harmful land-use strategies.

In this study, our initial hypotheses were: (1) cultivation of paramo areas produces a significant decrease of soil microbial biomass; (2) the fallow period allows for the recovery of the diversity and biovolume of the plant community and soil microbial biomass; (3) these changes can be related to the restoration of the effectiveness of N-cycling and the recovery of fertility.

To analyse the dynamics of soil and vegetation restoration, we compared 36 successional fields with different ages (one to nine years, four replicates per year) and four areas of the never-cultivated paramo ecosystem. The study was undertaken during the wet season of 1996 in Gavidia, a valley of glacial origin with about 500 inhabitants, in Venezuela's Sierra Nevada National Park. A composite sample was obtained for each plot, and the following soil parameters were determined: soil total C and N; microbial biomass N (fumigation-extraction method: Brookes *et al.*, 1985); NO_3; NH_4; P; Ca; Mg; Na; K; pH; cation exchange capacity; and texture. The vegetation was characterized using the point quadrat method (100 points per plot), and its total biovolume, species richness and diversity (Shannon-Wiener index) were determined.

The results show a very high heterogeneity between plots for all soil parameters. Principal Component Analysis shows that this heterogeneity can be partially associated with the geomorphological position of the plots. A successional recovery of the soil organic matter or of any of the nutrients evaluated is not observed, a result which has also been obtained in previous studies on traditional fallow agriculture in the tropical Andes (Sarmiento and

Monasterio, 1993; Ferwerda, 1987; Hervé, 1994). We did not observe an increase in microbial biomass, a result which contradicts our original hypothesis and the observations of other studies in temperate agro-ecosystems (Insam and Hasselwandder, 1989; Insam and Domsch, 1988; Sanstruckova, 1992). So, it is possible that processes not considered here, such as N-mineralisation dynamics or nitrification potentials, could explain the unresolved problem of fertility restoration during the fallow. However, our results have to be interpreted in the light of the high spatial heterogeneity, which could be partially obscuring real successional tendencies. We believe that this study shows the paramount importance of considering the high geomorphologic and edaphic heterogeneity which characterises these environments in the study and management of fertility in high mountain agro-ecosystems.

Analyzing vegetation dynamics, we observe that there is no successional increase in plant biovolume. In the case of species richness, there is an initial increase from the first to the second year, and then no apparent change up to the ninth year. Only species diversity increases steadily throughout succession.

Comparing the natural ecosystem with the successional plots, we detect that agricultural use causes a statistically significant decrease in microbial biomass N, which is more than twice as high in the never-cultivated plots, suggesting that this parameter is an excellent indicator of agricultural disturbance on paramo ecosystems. The use of microbial biomass as a disturbance indicator is supported by several authors, such as Gregorich *et al.* (1995); similar results have been obtained by the Tropical Soil Biology and Fertility Program in a number of contrasting savanna and forest sites of the lowland tropics (Woomer *et al.*, 1994). We also detect a statistically significant decrease in plant biovolume, species richness and diversity (Kruskall-Wallis, α=0.05) and decreases in total soil C and N, pH, Ca and Mg which, however, are not statistically significant.

So our results show that agricultural disturbance on the paramo ecosystem causes a series of negative impacts on key soil properties, which are not restored in the fallow period currently used by the farmers. This questions the sustainability and the assumed high conservationist value of these traditional agro-ecosystems. However, the observed successional increase in diversity, and the fact that a good number of the successional species are not present in the original ecosystem, indicate that the fallow allows the maintenance of a higher landscape diversity than an intensive monoculture or the undisturbed ecosystem alone would allow.

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