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SUCCESSION, REGENERATION, AND STABILITY IN HIGH ANDEAN ECOSYSTEMS AND AGROECOSYSTEMS: THE REST-FALLOW STRATEGY IN THE "PARAMO DE GAVIDIA", VENEZUELA*

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Abstract

An agricultural system on the highest level of the Venezuelan Andes (3,300-4,000 m a.s.l.) is analysed. The peasant management is characterized by a two-phase agricultural cycle. The first, cultivation, starts when a plot with natural vegetation is plowed, mixing the biomass and necromass with the soil. Subsequently, the plot lies fallow for four months, after which a second plowing and sowing of potatoes is carried out. After the harvest (six to eight months later), the plot is plowed again and, according to soil conditions, either undergoes a new period of cultivation of potatoes or cereals, or passes over into the second phase. During this, an ecological succession occurs, which, if there is sufficient time, allows the regeneration of natural vegetation. Its duration is very variable (from 2 to more than 20 years) and depends on the characteristics of each plot and the land availability of the peasant.

The purpose of this work is to discuss the probable ecological meaning of this management system through the analysis of processes occurring during the cycle. We analyse results referring to the macronutrients' dynamics, the natural vegetation decomposition, the processes of mineralization and absorption of nutrients, the crop production, and the exportation of nutrients. This approach, based on the comprehension of the ecological processes triggered by the agricultural practices, may allow the implementation of new alternatives of land-use and new forms of resource utilization

1. Introduction

Páramo ecosystems occupy the uppermost levels of the northern Andes from Ecuador to Venezuela, starting at 2,800-3,000 m a.s.l. at the permanent snowline. For a detailed account of these ecosystems we refer to MONASTERIO (1980a, b), MONASTERIO / VUILLEUMIER (1986) and VAN DER HAMMEN / CLEEF (1986).

In the lower belt of Páramos (2,800-3,600 m), which is characterized by a rather extended frost-free period, a traditional system of land-use still persists, although it is undergoing rapid transformations. It consists of two complementary phases succeeding one another in a cyclic way (Figure 1). The cultural phase starts, when land, either under natural- or recovered vegetation, is plowed, and ends, when the soil loses its fertility. Then, the opposite process starts: the succession-restoration phase, leading, through a sequence of changes, to the restoration of natural vegetation and to the recuperation of the soil's aptitude for growing crops (SARMIENTO/MONASTERIO 1989).

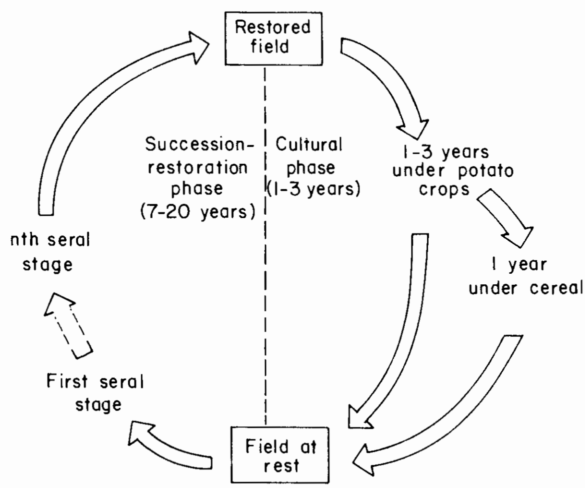

Figure 1: The rest-fallow strategy in the "Páramo de Gavidia", Cordillera de Mérida

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Potatoes are the single commercial crop in this ecological belt. Other crops, like wheat, oat, and barley are intended for consumption by the peasant's family and his domestic animals.

The potato's cultural phase (Figure 2) starts when a restored field is plowed with an oxen-driven plow. Afterwards, the field remains fallow for four to five months, then it is plowed again, sowed, and fertilized (in the more traditional system fertilizers are not used). After six to eight months, the crop is harvested; meanwhile it has required just one weeding-out. At harvest, the field is plowed again, and it may either enter a new cultural cycle with potatoes or cereals, or it may remain at rest entering thus into the succession-restoration phase. What really happens, will depend on soil conditions that are evaluated by the peasant by taking into account the productivity reached by the crops.

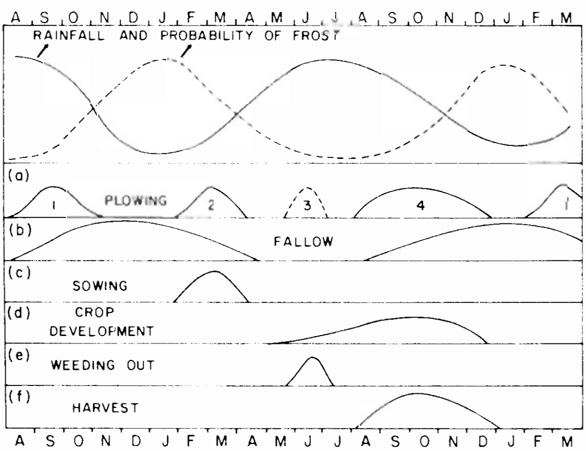

Figure 2: Sequence of events during the cultural phase and its timing with reference to the dry- and rainy seasons and to frost frequency. - a): Plowing times: (1) first plowing in a restored field; (2) second plowing before sowing; (3) third plowing for weeding out; (4) fourth plowing for harvest; (1') first plowing for a new cultural cycle. - b): Fallow times: (1) first fallow before sowing; (2) second fallow after harvest. - c): Sowing takes place at the end of the dry season. - d): Harvest time in the "Páramo de Gavidia" extends for five months.

The study of this traditional peasant system of land-use is of particular ecological interest, since it permits the maintenance of a high natural diversity, reduces the use of chemical fertilizers (sometimes almost completely), and allows a regulation of the utilization pressure on the natural environment. As another consequence of this system, the landscape resembles a mosaic, where successional stages alternate with the actual crops, and natural ecosystems intermingle with agroecosystems.

Two main aspects have to be considered in order to evaluate the ecological rationale of this management system. First, it operates under low population pressure, where land availability is not a limiting factor. Second, as most soils in these Páramos are quite deficient in nutrients, their agricultural management must be directed towards an efficient use of their limited nutrient pool.

2. Objectives

Our main objective was to evaluate the ecological rationale of some agricultural practices involved in the succession-regeneration system. We consider a given practice as "rational" from an ecological viewpoint, when it allows the efficient utilization of the limiting resources. As one of the major constraints to agricultural production is the low availability of soil nutrients, our analysis centered on the effects of land management on the nutrient budgets.

We will try to answer the following questions:

1. What are the processes in the recuperation of soil fertility resulting from the period of succession-regeneration? If the restoration of soil fertility is derived from the re-accumulation of an adequate stock of nutrients, where in the ecosystem do the nutrients, which are potentially available to cultivated plants, accumulate?

2. What is the ecological importance of plowing the land several months before sowing? In which way does the fallow period affect the nutrient budgets?

3. Why do the fields have to be abandoned after one to three consecutive harvests?

3. Study area

The study area (Páramo de Gavidia) is localized in the Sierra Nevada de Mérida, and is a part of the Sierra Nevada National Park. The geographical situation is from 8°35' to 8°45'N and from 70°52' to 70°57'W.

About 70 families, with a total of 500 inhabitants, constitute the local peasant community that normally applies the field rotation system formerly discussed.

4. Methodology

Research was conducted on a field of 1,650 m², belonging to one of the peasants of the community, who worked it according to the current practice of the area. The field is located at 3,300 m a.s.l., on a colluvial fan with a 21 % slope. The soil is a ustic Humitropept developed on postglacial colluvium derived from metamorphic rocks.

This plot has already been under the process of succession-restoration for twelve years, and maintained a Páramo vegetation dominated by the association of the caulescent rosette *Espeletia schultzii* and the evergreen shrub *Hypericum laricoides*.

Nine samplings were taken during the 439 day's period from the first plowing to four months after harvesting. During each sampling, all above- and below-ground plant material in the uppermost 20 cm of soil was collected from 20 random quadrats of 0.2 m². In the material collected, decomposing plant parts remaining from the natural vegetation were separated from the actual crop biomass. All the material collected was washed, dried, and weighed, setting apart a subsample for chemical analysis. On each sampling date, five soil samples were taken for chemical analysis.

A more detailed account of field procedures and analytical methods is presented in SARMIENTO et al. (in pr.).

5. Results and discussions

As all the plant biomass on the restored field becomes incorporated into the plowed soil as a sort of green manure, it is important to know the significance of this nutrient input as compared with the requirements of the crop plant. Comparing the nutrient content of this green manure with the total amounts taken up by the culture (Figure 3), it may be seen that, in principle, the green manure could provide more than half the nitrogen and potassium required by the crop, as well as furnishing phosphor, calcium, and magnesium in quantities above the crop's requirements. In the particular case of calcium, for instance, the green manure contains more than seven times the amount incorporated by the crop.

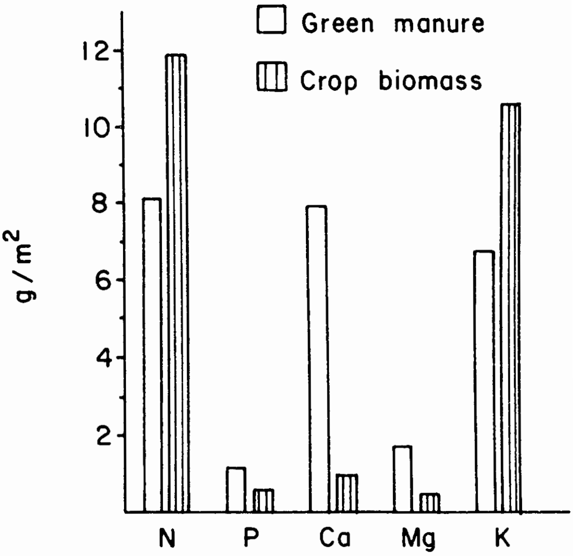

Figure 3: Nutrient content of the green manure and total amount of nutrients taken up by the crop

The dynamics of decomposition of the green manure may be taken as indicative of the nutrients available to the crop during its development. Figure 4 shows both processes: decomposition of the green manure and production of the crop and its weeds during the first 70 weeks of crop development. It could be seen that about 80 % of the plant material buried decomposes before harvesting, suggesting that the nutrients liberated by the decomposing plant materials could be used by the potato plants.

A further point to notice in Figure 4 is the apparent occurrence of a lag period between decomposition and production, since at sowing time more than 50 % of the decomposing plant material had already disappeared.

This asynchronism leads one to inquire about the ecological significance of already plowing the restored field four to five months before sowing. Would this procedure lead to significant losses from the original nutrient pool stored in the decomposing plant material?

Perhaps the soil-pH, as a good indicator of soil nutrients availability, could provide a first answer to this question (Figure 5). Immediately after plowing, the pH decreases significantly, afterwards it increases reaching a stable level, somewhat higher than the initial-one, about 25 weeks after plowing. Both the initial decrease and the later increase occur during the fallow period, while the development of the crop plants takes place during the period with highest pH-values. This pattern of soil pH-variability suggests a lower availability of nutrients during the fallow period, thus explaining the practice of postponing sowing for a few months.

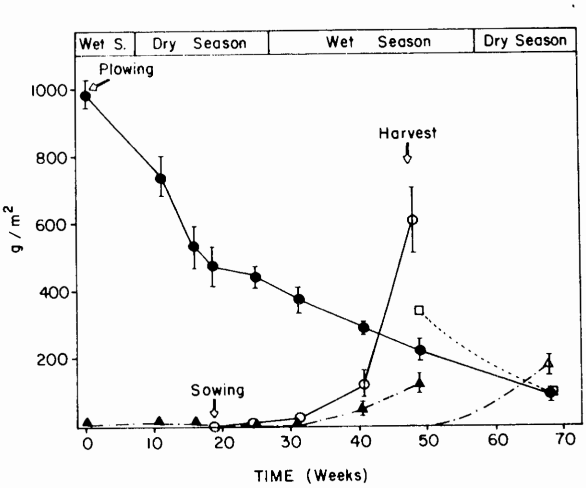

Figure 4: Decomposition of the green manure remaining on the ground after the first plowing (●-●-●). Crop production (o-o-o). Weed production before harvest (▲-▲-▲). Weed production after harvest (△-△-△). Decomposition of crop residues (second green manure) (□-□-□)

The next question raised is: if most of the green manure decomposes during this pre-sowing phase, why does the fallow period appear as a low nutrient-availability period? Figure 6 suggests a possible answer by considering the variation in the green manure's C/N-ratio during its decomposition. It is well known that, during the initial phases of decomposition, the mineralized nutrients are rapidly immobilized in the biomass of the decomposer organisms (SWIFT et al. 1979; BERG/STAAF 1981). This immobilization occurs, when the C/N-ratio of the detritus is high, in which case the nutrients are sequestered in the biomass, while the carbon is expended as a source of energy. It is only when the C/N-ratio of the decomposing material attains a level similar to that found in the decomposer microorganisms that nitrogen mineralization does start. This threshold C/N-ratio triggering a net nitrogen mineralization varies according to the characteristics of the decomposing system. Its average value ranges between 25 and 30. Applying these principles to the analyses of Figure 6, we may conclude that the fallow period represents a period of immobilization both of nitrogen and other mineral nutrients. If the immobilization/mineralization threshold ranges between 25 and 30, it is only during the last weeks of crop development, when most of the green manure nutrients become available to the crop. It is only 40 weeks after plowing when the C/N-ratio of the decomposing material reaches a C/N-ratio lower than 30, and it is precisely from this moment up to harvesting, eight weeks later, that the crop takes up 74 % of its nitrogen, 63 % of its phosphor, 92 % of its calcium, 47 % of its magnesium, and 72 % of its potassium.

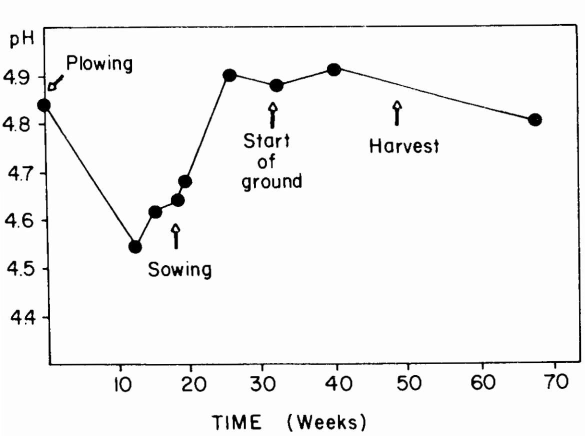

Figure 5: The soil pH during the cultural phase

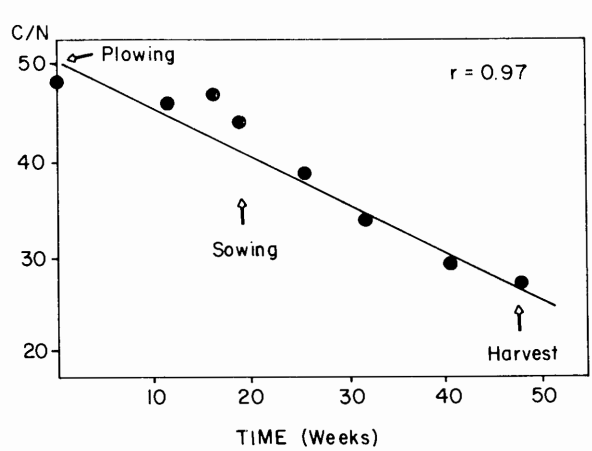

Figure 6: The C/N-ratio of the decomposing plant material (first green manure) during the cultural phase

We will now try to explain the factors involved in the loss of soil fertility that leads to the abandonment of a field, which then enters into its restoration-regeneration period. When the second crop cycle starts, the original plant material derived from the recovered vegetation and buried after the first plowing (serving as a green manure) has already been entirely decomposed. However, a new green manure, the crop residues and the weeds, is added to the soil during the harvest. But this second green manure shows some characteristics differing from those of the first-one (Table 1):

a) Its biomass is 66 % lower than that of the first green manure.

b) Its nutrient concentration is quite different.

c) The total amount of nutrients also differs, the second green manure has more nitrogen and potassium, but much less phosphor, calcium, and magnesium.

d) The decomposition rates are different: the first green manure had a decomposition rate of 4.59 mg/g.day during the first 135 days, while the new plant material added to the soil after harvesting had a decomposition rate of 5.36 mg/g.day (Figure 4).

e) The C/N-ratios are strikingly different (48.4 and 12.8 for the first and the second manure respectively), promoting a more rapid mineralization of the plant residues freshly incorporated to the soil during the second cultural cycle.

Table 1: Biomass and nutrient inputs from the initial green manure (successional vegetation) and second green manure (crop residues)

	Initial Dry Weight	C g/m^2 (%)	N g/m^2 (%)	C/N g/m^2 (%)	P g/m^2 (%)	Ca g/m^2 (%)	Mg g/m^2 (%)	K g/m^2 (%)
Initial Green Manure (successional vegetation)	988.6	392.9 (39.74)	8.12 (0.82)	48.39	1.12 (0.11)	7.93 (0.80)	1.77 (0.18)	6.83 (0.69)
Second Green Manure (crop residues)	388.0	125.0 (36.98)	9.78 (2.89)	12.78	0.48 (0.14)	0.98 (0.29)	0.73 (0.22)	7.77 (2.30)

Table 2: Soil-nutrient concentrations in fields with various successional ages ($x \pm s \sqrt{n}$)

Years of Rest	C (%)	N (%)	P ppm	Ca meq./100g	Mg meq./100g	K meq./100g
1	10.16 ± 0.01	0.683 ± 0.01	26 ± 5.97	1.65 ± 0.13	0.39 ± 0.05	0.32 ± 0.03
3	10.12 ± 0.02	0.601 ± 0.01	18 ± 6.47	1.10 ± 0.16	0.30 ± 0.02	0.29 ± 0.04
6	10.08 ± 0.10	0.621 ± 0.03	19.4 ± 4.52	2.52 ± 0.33	0.38 ± 0.03	0.47 ± 0.02
12	9.80 ± 0.10	0.653 ± 0.03	21.4 ± 2.40	1.83 ± 0.33	0.24 ± 0.33	0.28 ± 0.02

To gain a more global overview of the whole management system, we have to consider what is happening during the succession-regeneration phase. Available data on soil nutrients (MONTILLA/MONASTERIO, unpubl.) only show slight changes in soil nutrient content along plant succession (Table 2). There is not a defined trend towards nutrient accumulation as vegetation succession proceeds, on the contrary, all nutrients, except calcium, show lower concentrations after 12 years than in the first year. The key then does not seem to be in the accumulation of nutrients in the soil.

In Páramo vegetation, adapted to poor soils, several mechanisms leading to an optimization in the use of nutrients have probably evolved. Among these mechanisms, we may name the widespread occurrence of several growth-forms, such as the giant rosettes and the cushion plants, which accumulate a nutrient pool during their life cycles that is afterwards recycled through more or less closed internal pathways (GARAY et al. 1983; SARMIENTO 1987 ; MONASTERIO/SARMIENTO, in pr.). In this sense, the rosettes of the genus *Espeletia* seem to be very efficient in the scavenging and accumulation of nutrients. These nutrients remain sequestered in the standing dead material attached to the stem for rather long periods. We think that the key in the restoration of soil fertility lies in the nutrient pool accumulated in successional vegetation. *Espeletia schultzii* could be one of the important species in this process of nutrient accumulation. Indeed, the peasants consider that a given abandoned field is ready to enter into a new cultural cycle, when the population of this species reaches a good cover.

6. Final remarks

The agricultural system under consideration may be qualified as highly rational, if we point out that, with low population pressure, it allows a good crop production without any use of chemical fertilizers. This is attained through the manipulation of certain ecological processes, such as the accumulation of a nutrient pool in successional vegetation and its subsequent mineralization during the cultural phase. An empirical knowledge allows the synchronization of nutrient liberation by the decomposing plant residues in the soil with their uptake by the crop plant. This knowledge is responsible for the existence of a fallow period of several months between the first plowing of the field and the sowing of the crop. Another point we want to stress for qualifying this system as rational is that, if its carrying capacity is respected, it guarantees the maintenance of soil fertility and ecological diversity.

When demographic pressure and/or demands of the market lead to an intensification of land-use, one of the first consequences is the reduction, or even the total disappearance, of the rest phase, together with the substitution of the green manure by chemical fertilizers.

In this way, it becomes feasible to increase the surface of land cultivated by unit time. But besides its ecological consequences, such as soil losses and increased erosion, it induces economic and social changes towards the proletarization of the peasantry, the development of clientele rapport, and a great dependency towards the drifts of the market. The transformation of the peasant system, if not submitted to a social or ecological rationality, may lead to the destabilization of the peasant communities and to an irreversible decay of the fragile slopes, where these agricultural activities take place.

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