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ECOLOGICAL BASES, SUSTAINABILITY, AND CURRENT TRENDS IN TRADITIONAL AGRICULTURE IN THE VENEZUELAN HIGH ANDES

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ABSTRACT The traditional land-use system in the agricultural belt of the Venezuelan High Andes (3,000-4,000 m) includes extended fallows (from 7 to more than 20 years) alternating with short cultivation periods (1-4 years). This management produces a mosaic landscape where potato or cereal fields coexist with recuperating fallows of various ages and with land remaining uncultivated because of limitations of slope or stoniness. This land-use strategy maintains a high natural diversity in a way that allows an acceptable productivity without the use of mineral fertilizers. The ecological base underlying the functioning of the agricultural system is analyzed, mainly in relation to the recuperation of nutrients during the fallow periods. The ecological sustainability is discussed in light of the negligible erosion rates and the maintenance of high levels of soil organic matter. The massive introduction of chemical fertilizers in recent years induced important changes that are exemplified by the case study of the land-use strategy of a farmer.

RÉSUMÉ *Fondements écologiques, sustentabilité et tendances de changement de l'agriculture traditionnelle dans les hautes Andes du Vénézuéla.* Dans l'étage agricole des hautes Andes du Vénézuéla (de 3.000 à 4.000 m) le système de culture traditionnel comprend des longues jachères (de 7 à plus de 20 ans) suivis de courts intervalles de culture (de1 à 4 ans). Sous ce système agricole le paysage apparaît comme un mosaïque, ou coexistent des parcelles de pomme de terre ou de céréales avec des jachères de différents âges et des terrains non cultives à cause de limitations de pente ou d'une haute proportion de cailloux. Cette strategie permet de maintenir une haute diversite naturelle dans la région. A la base du système se trouve la conservation de la fertilité des sols, ce que permet d'obtenir une production agricole sans l'utilisation d'engrais minéraux. Les fondements écologiques du fonctionnement du système sont analysés, principalement en relation avec la récuperation des reservoirs d'éléments nutritifs pendant la jachère. La sustentabilité écologique est discutée sur la base des faibles taux d'érosion et de la conservation de la matière organique du sol. La récente introduction massive d'engrais mineraux entraîne une série de changements qui seront exemplifiés par l'analyse de la stratégie d'utilisation des parcelles d'un paysan local.

ZUSAMMENFASSUNG *Ökologische Grundlagen, Erhaltung und gegenwärtige Trends in der traditionellen Landwirtschaft der Hochanden von Venezuela.* Das traditionelle Landnutzungssystem im Agrargürtel der Hochanden von Venezuela (3.000 m-4.000 m ü. M.) schließt längere Brachzeiten (7 bis über 20 Jahre) ein, die sich mit kurzen Kultivierungsperioden (1 bis 4 Jahre) abwechseln. Diese Art des Landmanagements erzeugt ein mosaikartiges Landschaftsbild, in dem Kartoffel- und Getreidefelder neben Brachland verschiedenen Alters und neben Landflächen koexistieren, die wegen ihrer ungünstigen Hangbeschaffenheit oder ihres steinigen Bodens unbebaut bleiben. Diese Landnutzungsmethode führt zu natürlicher Vielfalt, die ausreichende Produktivität ohne Kunstdünger erlaubt. Wir untersuchten die ökologische Grundlage dieses Agrarsystems hauptsächlich in bezug auf Nährstoffregeneration der brachliegenden Flächen. Der ökologische Bestand ist gegeben, wenn geringe Erosionsraten und ein hoher Anteil an organischem Bodenmaterial vorliegen. Die massive Einführung von Kunstdünger in den vergangenen Jahren hatte wichtige Veränderungen zur Folge. Eine Fallstudie veranschaulicht am Beispiel eines Bauern die veränderten Bedingungen bei der Landnutzung.

RESUMEN *Bases ecológicas, sustentabilidad y tendencias de cambio de la agricultura tradicional en los altos Andes de Venezuela.* En el piso agricola de los páramos venezolanos (3,000-4,000 msnm) el manejo campesino tradicional incluye descansos muy largos de las parcelas (10 a mas de 20 anos) alternando con períodos cortos de cultivo (1 a 4 años). Bajo este sistema el paisaje se estructura en forma de un mosaico, donde coexisten parcelas cultivadas con papa o cereales con otras que tienen diferentes tiempos de descanso y con áreas no cultivadas por limitaciones de pendiente o pedregosidad. Esta estrategia de manejo tiende a mantener una alta diversidad ecológica en la zona. En su base está la conservacion de la fertilidad de los suelos, lo que posibilita la obtención de una producción agrícola sin fertilizantes minerales. Se analizan las bases ecológicas del funcionamiento del sistema, principalmente en relación al restablecimiento de los reservorios de nutrientes durante el descanso. La sustentabilidad ecológica se discute en base a las bajas tasas de erosión y al mantenimiento de la materia orgánica del suelo. La reciente introducción masiva de fertilizantes minerales genera una serie de cambios, los cuales se ejemplifican a través del analisis de la estrategia de uso de las parcelas de un campesino.

INTRODUCTION

In the crop belt of the Venezuelan paramos (3,000–4,000 m), potatoes and cereals (mainly wheat and oat) are grown in a traditional land-use system. Short periods of crop production (1–4 years) alternate with fallows extending from 7 to more than 20 years (Sarmiento *et al.*, 1990). During these fallows an ecological succession occurs. The abandoned fields are first colonized by pioneer species, mainly *Rumex acetosella,* then by late successional ones, such as *Lupinus meridanus* and *Senecio formosus,* and finally by a shrubby formation, which represents the paramo climax vegetation, dominated by the caulescent rosettes of *Espeletia* and by several species of shrubs (Montilla *et al.*, 1992).

In several aspects this system is similar to the slash-and-burn agriculture or shifting cultivation, the more traditional form of agriculture in the tropics. One important difference is that in the Venezuelan paramo burn is not frequent. The sustainability of the agricultural system can be negatively modified if the residues of natural vegetation are burned, restricting inputs of organic materials to the soil and the protection against the erosive impact of the rain drops. In the forest, the burn is necessary because the woody residues do not easily decompose to be incorporated into the soil, but this is not a problem with the shrubby paramo vegetation.

From an ecological viewpoint, the traditional system used in the Venezuelan paramos has a particular interest since it controls the pressure exerted on the environment, minimizes the utilization of external inputs (seeds, pesticides, fertilizers) and at the same time maintains a high natural diversity. It seems to be a successful model of sustainable agriculture in the fragile environments of high tropical mountains. However, this traditional agriculture cannot adequately provide a surplus for the market because it requires a rather large number of fields per farmer, with a majority remaining unproductive for a long time in order to restore soil fertility.

This traditional system is now under rapid transformation, with the incorporation of elements from the high-input cash agriculture which is expanding from the nearby high valleys. It is important, therefore, to analyze the ecological bases of the succession-regeneration system, as well as the actual trends of change and their possible consequences to the socioeconomic stability of the local peasantry.

THE STUDY AREA

The fieldwork was undertaken in Gavidia (Figure 1), a rural community of about 350 people. Gavidia is located above the continuous timberline, in the paramo ecological belt, where low temperatures strictly limit crop production (Monasterio, 1980). The area of about 5,000 ha lies within the Sierra Nevada National Park, in the Cordillera de Merida (8°35'–8°45' North, 70°52'–70°57' West). Within this small watershed, fields occupy narrow river terraces, small alluvial fans, as well as the rather steep mountain slopes.

The mean annual temperatures range from 10 to 6°C and the rainfall attains 1,200 mm, leaving a dry season between November and March when frost frequency becomes higher (Monasterio and Reyes, 1980). The acid, stony, sandy soils have a high organic matter content but low nutrient availability (Sarmiento *et al.*, 1990).

A traditional crop system characterizes Gavidia, although an increasing trend towards the use of fertilizers is evident. Thus, it has been possible to analyze both the original system and the actual trends of change.

THE TRADITIONAL SYSTEM OF LAND USE

In Figure 2 the two complementary phases that comprise each agricultural cycle are shown: the cropping period and the succession-restoration period. In the first phase plowing begins on a plot that was either under original paramo vegetation or already subject to a succession-restoration phase. Potato is always the first crop, and after two or three consecutive harvests (one per year), the crop phase is often closed by sowing a cereal. The crops develop during the rainy season, under dry farming conditions and in an almost frost-free period.

In the more traditional system long-cycled local varieties of potato (6–8 months) are grown without mineral fertilizers. At the start of the cropping cycle, the vegetation biomass accumulated during the plant succession is incorporated into the soil, thus functioning as a green manure.

When the farmer considers that a field has lost its fertility, it is abandoned and the succession-regeneration period begins. During this phase a series of changes takes place leading to the recuperation of fertility. Undoubtedly, this succession not only induces changes in the soil's nutrient status but also constitutes a reliable method of pest control.

As a consequence of the agricultural cycle, the landscape is highly diversified. A mosaic is formed by fields cultivated with potatoes and cereals, fields under succession with various types of plant cover, and the natural paramo, uncultivated due to limitations of slope or rock outcrops. In Figure 3 the land surface covered by each of these units is shown for one of the small valleys of the Gavidia watershed. Crops occupy 10% of the surface area, divided into 75% potatoes and 25% cereals. The early successional fields (0–8 years) represent 25% of the area.

FIGURE 1. A panoramic view of the study area (Paramo de Gavidia, 3,300 m)

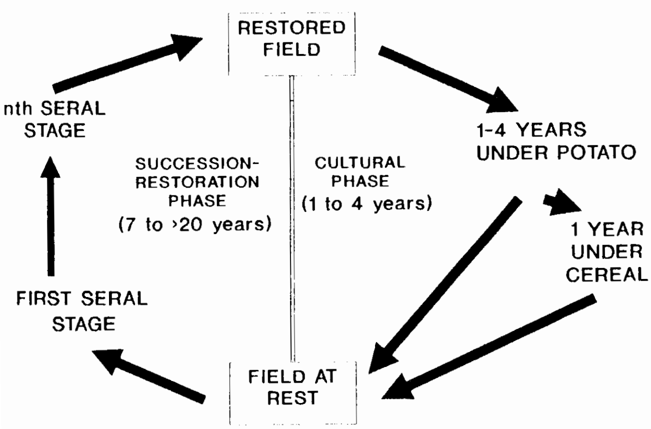

FIGURE 2. Schematic representation of the traditional agricultural cycle in the Venezuelan paramos (from Sarmiento *et al.*, 1990).

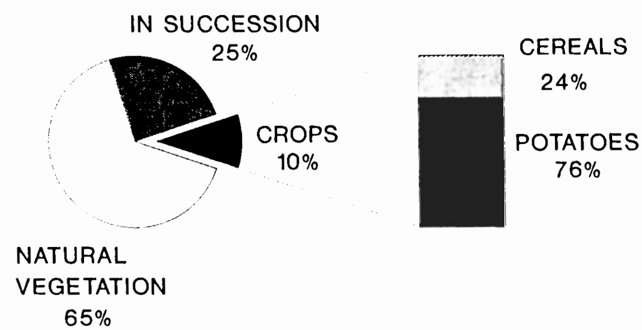

FIGURE 3. Percentage of land under cultivation, in succession-regeneration stages, and under natural paramo vegetation in a small valley in Gavidia.

The last group includes the late successional stages and the original paramo (Figure 4) that are physiognomically difficult to distinguish. These data show that under this management system large areas of natural vegetation persist, in spite of the land-use pressure.

THE ECOLOGICAL BASIS OF LAND USE

In 1986, a program directed towards the appraisal of the ecological basis of this traditional highland farming system was initiated; the objective was to assess the consequences of fallows on the maintenance of fertility and soil conservation. Until quite recently very little was known about the functioning of these agrosystems in terms of the agents, factors, and processes involved in crop production and in the accumulation and recycling of nutrients. In the long term, our aim is to gain further knowledge about the basic processes controlling soil fertility in tropical high mountains, so that we can evaluate the local ecotechnologies. In this paper some results are discussed.

One of the keys to the functioning of the system is the restoration of fertility during the fallow period. The recuperation results from the accumulation of mineral

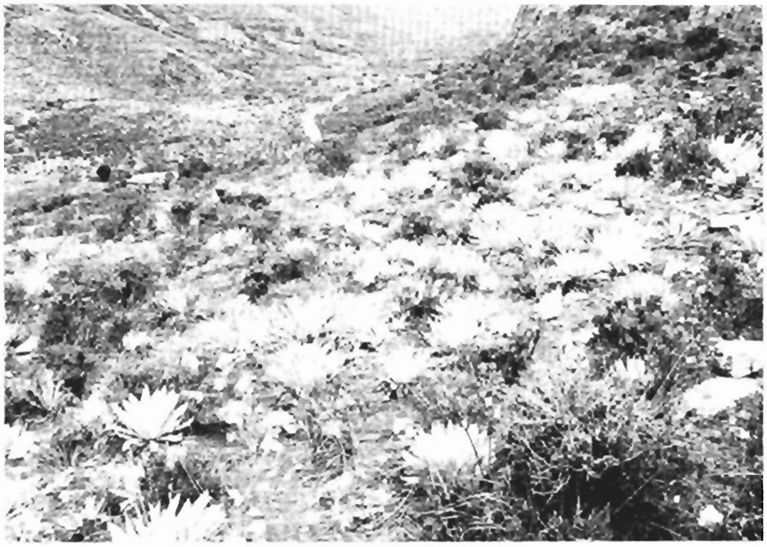

FIGURE 4. A view of paramo vegetation with the characteristic rosettes of *Espeletia schultzii* WEDD.

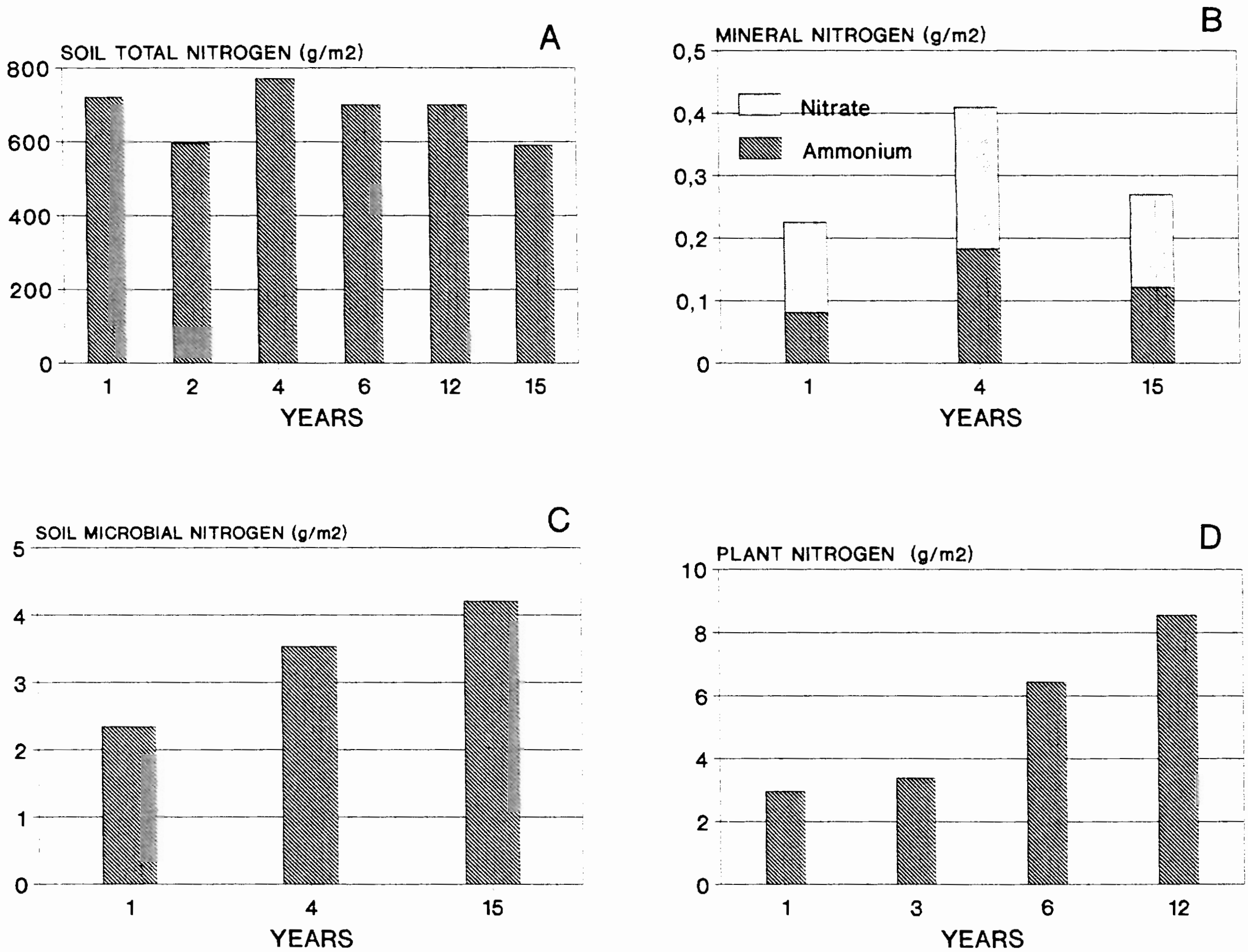

FIGURE 5. Nitrogen content in various components in fields with different fallow periods. All data correspond to the dry season. n= 5 for soil total nitrogen; n = 4 for mineral nitrogen; n = 4 for soil microbial biomass, and n = 20 for plant nitrogen.

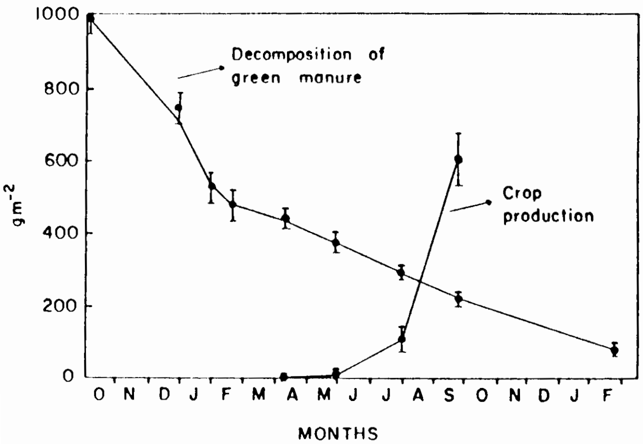

FIGURE 6. A comparison between the dynamics of green manure decomposition and potato development. Potato production is in dry biomass of the whole plant. n = 20.

elements in various components such as vegetation, microbial biomass, and soil organic matter. To illustrate this aspect the case of nitrogen will be considered (Figure 5). The data correspond to fields with an average slope of 20°, situated in similar topographic conditions and aspect but with different recuperation times. It can be seen that there is no clear trend towards total nitrogen accumulation in the soil (Figure 5A). In these soils, where low temperatures limit decomposition, important stocks of nitrogen do exist, an average of 650 gN m^{-2} in the uppermost 20 cm. However, most of this nitrogen is not available to plants because it is in the form of recalcitrant humus compounds. Mineral nitrogen, the only form directly available to plants, occurs in small amounts: 0.2 to 0.4 g m^{-2} (Figure 5B; see Aranguren,1988). There is no trend toward accumulation along the succession. One explanation is that the mineral nitrogen is a component with rapid turn-over, particularly in dystrophic soils, where microorganisms and plants compete for it.

Given that neither total nitrogen nor mineral nitrogen accumulate, the question is: how does the plot recuperate? In order to answer this question, two other components, plant and microbial biomass, have to be considered.

The soil micro-organisms do not represent a major proportion of the nutrient pools within an ecosystem, but they may be considered as the main transforming agent in the movement of nutrients through the soil and as an important source of nutrients to plants during their turnover cycles (Anderson and Domsch, 1980; Paul and Voroney, 1980; Jenkinson and Ladd, 1981; Azam *et al.*, 1986; Duxbury *et al.*, 1989; Brookes *et al.*, 1990; Gregorich *et al.*, 1991). Little information is available on microbial biomass of tropical soil and less on the successional dynamics. In Gavidia, the nitrogen stored in the microbial biomass was estimated by the fumigation-extraction method (Brookes *et al.*, 1985) for plots with one, four, and fifteen years of fallow (Figure 5C). An increase occurs from 2.3 gN m^{-1} in the first year to 4.2 gN m^{-1} after 15 years. These data correspond to a sampling during the dry season. During the rainy season the microbial nitrogen was 9 g m^{-2} in the plot with 15 years of fallow, a figure comparable to the total nitrogen requirements of the crop (11.87 g m^{-2}). The accumulation of nitrogen in the microbial biomass is probably an important mechanism of fertility restoration in Gavidia. The microbial nitrogen, which is normally protected within undisturbed soil is mineralized and made available to crops by cultivation (Elliot, 1986). According to Anderson and Domsch (1980) the microbial biomass can supply different crops with much of the nitrogen they require.

The decrease in microbial biomass caused by clearing and cropping is reported for several ecosystems (Lynch and Panting, 1980; Granatstein *et al.*, 1987; Cochram *et al.*, 1989). Adams and Laughlin (1981) measured a decrease of 64% of microbial nitrogen after 3 years of cultivation in a temperate grassland, and Srivastava and Singh (1989) report a value two-to-three times lower in a cropland derived from a tropical forest in India.

Along the succession nitrogen also accumulates in the above and below ground plant biomass (Figure 5D). After 12 years, the nitrogen stocked in the phytomass reached 8.5 gN m^{-2}. This biomass is incorporated into the soil as green manure at the start of a crop cycle. Figure 6 shows the dynamics of decomposition of this green manure and its relationship to crop growth. More than 80% of the green manure is decomposed before harvest, being a potential source of nutrient to the crop.

Montilla *et al.* (1992) studied the same plots in the Paramo de Gavidia and report an increase of mycotrophy and of the amount of external mycelium of vesiculo-arbuscular micorrhizae along the succession. The increased incidence of micorrhizae is a possible mechanism of nutrient accumulation in plant biomass.

THE ECOLOGICAL SUSTAINABILITY OF THE SYSTEM

The sustainability of the system will be analyzed by indicating its impact on the erosion processes and on soil organic matter.

Table 1 shows the rates of erosion in crop fields and fallows. The erosion rate was quite low, not reaching 0.6 t ha^{-1} yr^{-1}. In fields under crops the rate was only 0.08 t ha^{-1} yr^{-1} higher than in the fields under restoration for 15 years, indicating that the current agricultural practices do not significantly increase the erosive processes. These negligible erosion rates are a consequence of low runoff, representing only 0.83% of total rainfall in the crop fields and 0.80% in the fallow fields (Table 1). The low runoff amounts can be explained by the high organic matter content of the topsoil, and thus a good soil structure that favors infiltration over runoff. It is also possible that the rainfall pattern—many events of low intensity—favors infiltration.

For a system of slash-and-burn agriculture (*jhum*), located at 1,500 m in northeastern India, Mishra and Ramakrishnan (1983) report a total loss of sediments of 50 t ha^{-1} yr^{-1}, a figure one hundred times greater than that in Gavidia. In the Indian system potato is also cultivated on steep slopes. The contrast between both systems can be explained, among others factors, by the significant difference in runoff: in the *jhum* system runoff represents 30% of the rainfall compared to 0.8% in Gavidia. The greater runoff in the *jhum* system is probably a consequence of the lower soil organic matter content (2% compared to 10% in Gavidia), the practice of burn, and the greater intensity of rainfall in India during the monsoon period.

The maintenance of high levels of soil organic matter in the paramo seems to be crucial to the equilibrium of the cultivation system, given that it positively influences water and nutrient retention, infiltration ratios, and the stability of soil structure (Coote and Ramsey, 1983; Oades, 1984; Havlin *et al.*, 1990). Figure 7 shows the soil carbon content in five plots at different stages of the agricultural cycle. The highest content corresponds to a plot that has been under cultivation for one year. During the restoration cycle, carbon levels show a slight trend towards decrease. This oscillation may be ascribed quantitatively to the incorporation of the green manure into the soil; this would explain the highest level attained in the crop field and its gradual decrease as green manure is decomposed. These results show how the succession-regeneration practice not only maintains high soil organic matter levels, but also increases these levels through the incorporation of green manure.

It has been widely documented that the transition of virgin soil to arable causes a severe reduction in soil carbon during the first years of cultivation (Tiessen *et al.*, 1982; Campbell and Souster, 1982; Coleman *et al.*, 1984; Odell *et al.*, 1984; Johnston, 1986; Buyanovsky *et al.*, 1987). Nevertheless, the incorporation of crop residues and green manure into soils can stabilize or increase the soil carbon (Rasmussen *et al.*, 1980; Unger, 1982). This seems to be the case in Gavidia, where the incorporation of the successional vegetation improved the level of soil carbon.

TABLE 1

Total rainfall, runoff, and erosion during the period from November 1990 to November 1991. Runoff and erosion were measured in 6 m^2 erosion plots with 20° slope

	Rainfall (mm)	Runoff (% of rainfall)	Erosion (ton ha^{-1} $year^{-1}$)
Potato fields (n=10)	1207	1.41±0.17	0.58±0.09
15 year fallow		0.91	0.50
[redacted]			

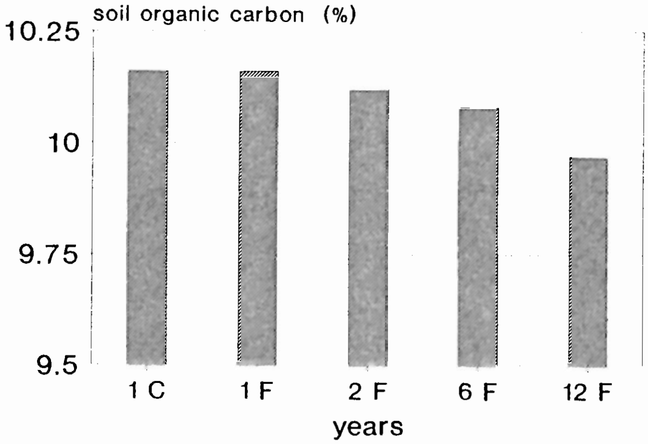

FIGURE 7. Soil organic carbon in fields in different phases of the land-use cycle. C = fields under cultivation, D = fields under fallow. n = 5.

TRENDS OF CHANGE

The opening of a road connecting Gavidia with the major regional centers in 1972 increased the use of chemical fertilizers and induced an abrupt technological change. Figure 8 summarizes the main causes and consequences of this use of mineral fertilizers. The causes include the low price of the fertilizers, which until very recently were subsidized by the government, and the demographic pressure that forces an increase in agricultural production. Among the major consequences are the shortening of the fallow periods, increase in number of consecutive years of cropping, and the increase of the area that is cropped at the expense of the climax ecosystem and successional communities.

The effects of these changes on the sustainability of the system can be predicted. The gradual disappearance of fallows will lead to a decrease in soil organic matter content, thus increasing the erosional risks by inducing runoff rather than infiltration. However, these effects will be apparent only in the long term. A more immediate consequence, one that has already reached dramatic proportions, is the proliferation of outbreaks of pests and disease. The shortening of the fallow periods, the increase of the crop area, and the use of imported potato varieties have induced a sharp increment in pests since 1986. Figure 9 shows the large incidence of pests in 1991 and the beneficial effect of fallow. It is necessary to assess what should be the strategy used by the peasants to confront this problem which could bring about the collapse of the whole system: a return to the traditional practices or a massive utilization of pesticides?

Altogether, these changes are transforming the traditional farming system, originally directed towards self-subsistence, into a market-oriented agriculture. The socio-economic well-being of the peasants has certainly

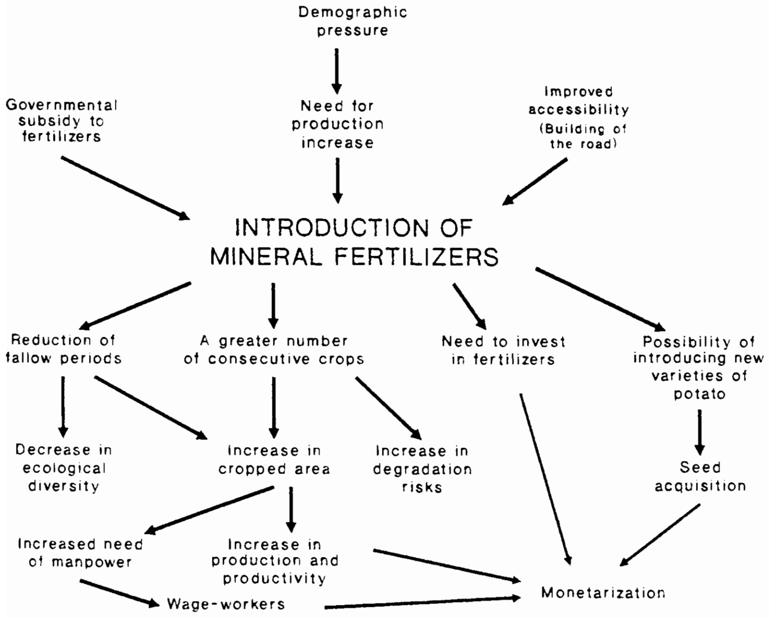

FIGURE 8. A representation of the recent transformations in the productive system.

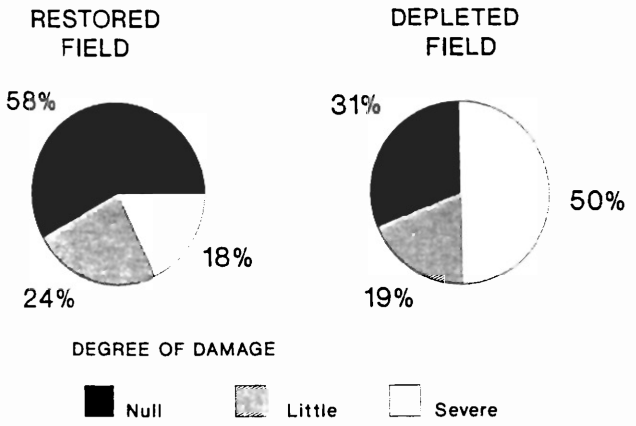

FIGURE 9. Degree of damage caused by the attack of a *lepidoptera* larva to the potato tubers in a restored field (15 years fallow, 1 year under crop) and a depleted field (4 years under crop). Data refer to the percent of tubers with no, slight, or severe damage.

improved, but their autonomy has decreased because of their growing dependency on market fluctuations, fertilizer prices, manpower availability, purchases of seeds, pesticides, and other external factors. An important question is what will happen in the future and what will be the impacts of a much more exploitative agricultural system on these extremely fragile and marginal environments of the High Andes.

A CASE STUDY: THE STRATEGY OF A FARMER

As an example of this analysis of current trends, the land-use strategy of a farmer in the Paramo de Gavidia during the years 1989–91 will be discussed (Figure 10; Tables 2 and 3).

One of the most important trends is the increase in the total surface under crops. The number of field plots in use increased from 13 in 1989, and 19 in 1990, to 34 in 1991 (Figure 10). The area occupied by crops, in the case of this particular farmer, increased from 2.88 ha in 1989 to 6.12 ha in 1991 (Table 3).

The expansion of the cultivated area was accomplished in various ways, the most important being the utilization of fields that had been in the phase of succession-regeneration. The number of fields newly plowed was 2 in 1989, 6 in 1990, and 15 in 1991 (Figure 10). The increase was due also to the reduction in the number of fields entering into the period of fallow (4 in 1989, 3 in 1990). Another mechanism was the extension of the crop area by tenancy, which is the partnership between a landowner, who provides the land, and a tenant who

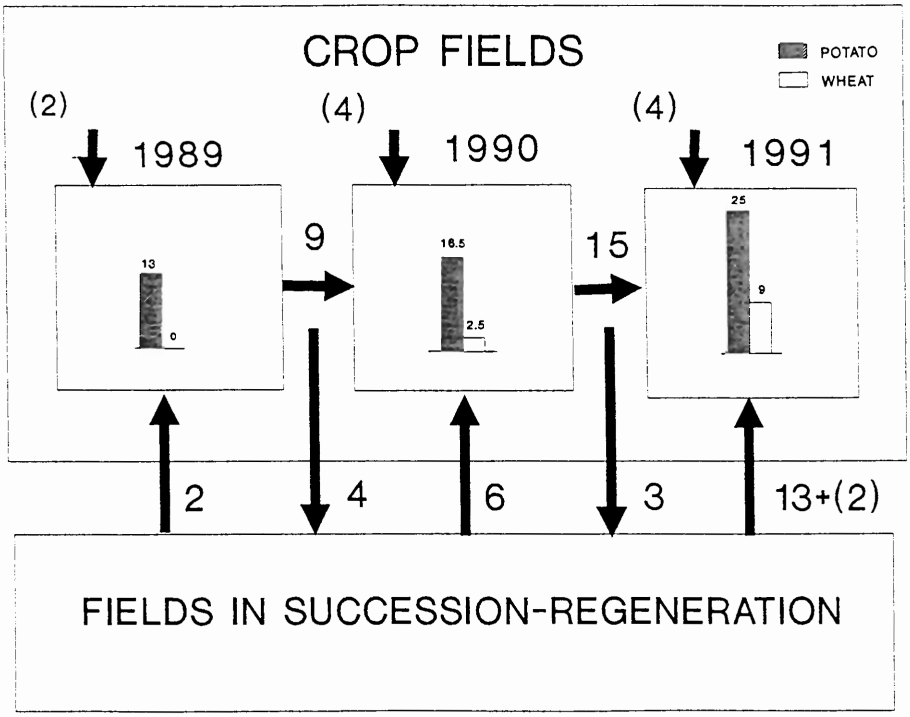

FIGURE 10. Strategy of land use of a farmer in the Paramo de Gavidia. Framed are the number of fields with potatoes or wheat, each year. Arrows indicate the steps from the cycle of succession-regeneration to the cycle of cropping and vice versa. Figures in brackets refer to fields not owned but worked by this farmer.

TABLE 2

Aspects of a farmer's strategy of field use in the Paramo de Gavidia (1989–1991)

	1989	1990	1991
Average number of years under cultivation	?	3.5	3.7
Average number of years under fallow of newly plowed fields	7	9	17
Average size of fields (m²)	2.214	1.895	1.749

TABLE 3

Total cropped area, amounts of fertilizer, and harvest of a farmer in the Paramo de Gavidia

		1989	1990	1991
Total sowed area (ha)	Wheat	0.00	0.49	1.08
	Potato	2.49	3.11	5.03
Amount of fertilizer (NPK, ton)		5.85	6.05	6.00
Fertilizer/area (ton/ha)		2.03	1.95	1.19
Total harvest (Potatoes, ton)		34.7	20.4	57.7
Productivity (ton/ha)		12.1	6.56	11.48

provides the manpower, with a sharing of the harvest. During the time interval considered here, this farmer also worked the land of other farmers who had less available manpower, such as single women, old people, and families whose sons had emigrated or who were unable to invest inputs into the farming practice. The number of plots cultivated under tenancy also increased from 2 in 1989 to 4 in 1990, and 6 in 1991.

Another interesting factor is the number of fields dedicated to wheat. This crop had been gradually disappearing but became important again after a drastic increase in the price of flour. Wheat and oats are grown without fertilizer in fields previously devoted to potatoes.

Between 1989 and 1991 the duration of the cultivation phase increased (Table 2). At the same time, fields entering into the crop cycle had been under recuperation for a longer period, because the farmer was incorporating marginal plots, some of which had never been utilized before and others which had been only sporadically plowed. The mean size of the crop fields has progressively diminished: 2,214 m² in 1989; 1,985 m² in 1990; and 1,789 m² in 1991. This fact also reflects the incorporation of small, marginal fields into the crop cycle.

The amounts of chemical fertilizer used by this farmer remain almost constant in spite of the increase of the cultivated area (Table 3). This is a consequence of the exponential increase in the price of fertilizers, following the withdrawal of governmental subsidy.

The total production and productivity decreased in 1990, probably as a result of an exceptionally rainy year. In 1991 the production was higher but the quality of potatoes was lower due to the strong incidence of pests and disease.

CONCLUSIONS

Three main conclusions result from the above discussion:

1. The traditional system is highly rational from an ecological point of view because it manages the natural processes of nutrient accumulation and cycling to obtain a harvest without the need for external inputs. At the same time, it preserves the natural environment. However, its limited profitability is unable to sustain an increasing population or to be the base for a market-oriented agricultural system.

2. The massive introduction of chemical fertilizers has been the technological alternative used by the farmers to increase land productivity. This change modifies the sustainability of the traditional land-use system. It is not easy to predict what will be the medium and long-term consequences, since many new factors are beginning to influence the functioning of the system. Among these, it is important to distinguish those external to the system, such as market prices, and those that are a direct consequence of the structural modification that is taking place, brought about by shorter fallows and the increase in cropped area. Some of the consequences are greater incidence of pest outbreaks, soil exhaustion, a possible decrease in soil organic matter, and intensification of erosion.

3. To assess what system of agriculture is best suited to these marginal environments is not straightforward. Neither traditional agriculture, ecologically sustainable but unprofitable, nor high-input agriculture, that could exert intolerable pressures on these fragile, tropical high-mountain environments, is acceptable. New alternatives must be based on a greater knowledge of these mountain ecosystems and agrosystems, that take into account the traditional practices and empirical knowledge of the local peasants.

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