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Peter Messerli

Use of Sensitivity Analysis to Evaluate Key Factors for Improving Slash-and-Burn Cultivation Systems on the Eastern Escarpment of Madagascar

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Slash-and-burn for pluvial rice cultivation (Tavy) is a predominant component in the land use system on the Eastern Escarpment of Madagascar. It causes ecological degradation and subsequent aggravation of rural poverty. After

conducting multidisciplinary research resulting in an in-depth diagnosis of the area's agroecological system, the BEMA (Bilans écologiques à Madagascar) project now aims to propose improvements and alternatives to the land use system. The objective of contributing relevant knowledge to stakeholder discussions and enhancing the choice of development priorities has called for a method allowing aggregation of existing knowledge, in order to constitute an integrated overall picture of the local level. The present article illustrates the application of a sensitivity analysis. This method allows exploitation of existing knowledge with a view to setting priorities among key factors with regard to a postulated development objective and discussion of possible strategies for development activities. For this study, intensification and stabilization, which are common concerns among the region's stakeholders, were chosen as development objectives to be analyzed by example. Analysis of the local land use system has revealed that actions aiming to retard degradation caused by the slash-and-burn technique, as well as to promote self-sufficiency of Tavy, have hindered intensification and stabilization. This paper concludes that the key factors in promoting more sustainable development are the intensification and the spatial concentration of permanent crops (irrigated rice and home gardens), cash cropping, and animal husbandry on the valley floors. Interventions at the socio-organizational level (collective conventions, improved access to land, etc.) and efforts to improve the dynamics of the local market are the most important factors in inducing and perpetuating such changes.

Keywords: slash-and-burn systems; agricultural improvement; natural resource management; Madagascar; sensitivity analysis; evaluation of key factors.

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Introduction

Slash-and-burn for pluvial rice cultivation (*Tavy*) is predominant in the land use system of the Beforona region. Increasing population density has rendered this cultural practice unsustainable. Burning leads to ecological and, subsequently, socioeconomic degradation, both of which farmers recognize but are as yet unable to slow down. The extent and speed of deforestation are endangering a unique rainforest in which 80% of the species are endemic (White 1983). Soil degradation is leading to diminishing yields and aggravates rural poverty. Furthermore, on a planetary scale, the combined effects of burning and the disappearance of forests have been recognized as key factors leading to global warming (Andreae 1991).

On the Eastern Escarpment of Madagascar (see Figure 1 for a map of the study area), the Swiss–Malagasy research projects Terre-Tany and BEMA have adopted a joint systemic and multidisciplinary approach to identifying ways of improving the land use system. An understanding of past dynamics and key factors determining sustainable development was gained by combining an analysis of the spatial extent of degradation with complementary research themes and methods (Terre-Tany/BEMA 1997a, 1997b, 1998, 1999). At present, one important goal of the project is to contribute to stakeholder negotiations about future development options (Hurni et al 1998; Wiesmann 1998). Detailed knowledge about many components of the agroecological system and their interrelations needs to be crystallized and then offered in such a form that decision makers and stakeholders have an overall picture of the puzzle and can identify relevant factors and promising strategies. The main goal is therefore not to generate new knowledge but rather to render existing knowledge more operational.

An analysis of the visions, needs, and options of the different stakeholders (Messerli, unpublished data) reveals a general consensus that, within the context of improving slash-and-burn cultivation systems on the Eastern Escarpment of Madagascar, intensification and stabilization of the land use system are two development objectives that are considered prerequisites for more sustainable development. This article therefore evaluates opportunities and limitations of intensifying and stabilizing the land use system; at the same time, it illustrates how sensitivity analysis can be applied.

The methodology and its application to the region of Beforona

Toward the end of the 1970s, within the context of the UNESCO Man and the Biosphere program, Vester and Hesler (1987) elaborated a sensitivity model to analyze

FIGURE 1 The study area and pluvial rice cultivation (Tavy) in Beforona, East Coast of Madagascar. (Map by Andreas Brodbeck; photo by author)



dynamic systems. This methodological tool was first conceived for regional planning. Later on, it was adapted several times and applied to different projects and different domains (Principe 1994). However, its basic principles have not changed. The starting point is always the question “What key factors determine the success or failure of a chosen objective?” The basic steps of sensitivity analysis then consist of:

- a reduction of the system to be described to a set of relevant key factors,
- an assessment of interrelations between selected key factors by means of matrices in order to understand the influence exerted and received by each key factor, and
- interpretation and discussion of each key factor to identify its potential to influence the entire system.

These three steps were also covered by the method used and designed by Bürki (1997; unpublished data) for the Terre-Tany/BEMA project. The present article focuses

on the description of this method. Contents, however, are only presented in an exemplary manner; Terre-Tany/BEMA (1999) and Messerli and Pfund (1999) provide further reading.

Of course, from the point of view of the theory of knowledge generation, Vester and Hesler’s model is subject to methodological and conceptual criticism; the systems analysis approach in particular can be questioned. But such a critique was not the object of the present study, the main goal of which was to test the practical usefulness of the tool.

First step: Reduction of the land use system to a set of representative key factors

The first step allows identification of key factors for intensification and stabilization within the local land use system. A first rough examination of most important opportunities and constraints reveals that key factors can be grouped into different categories. Each category represents a subsystem of interactions at that level (Figure 2). The first subsystem contains key factors of

national and international significance, the second subsystem includes factors with regional impacts, and the third subsystem includes key factors at the local level (Figure 3). As shown in Figure 2, each subsystem is represented as one factor within the next higher subsystem. Accordingly, each subsystem will be evaluated separately by a sensitivity analysis, which will then allow integration of partial solutions into a more general context. For reasons of space, the present article, however, focuses only on the analysis of the local subsystem.

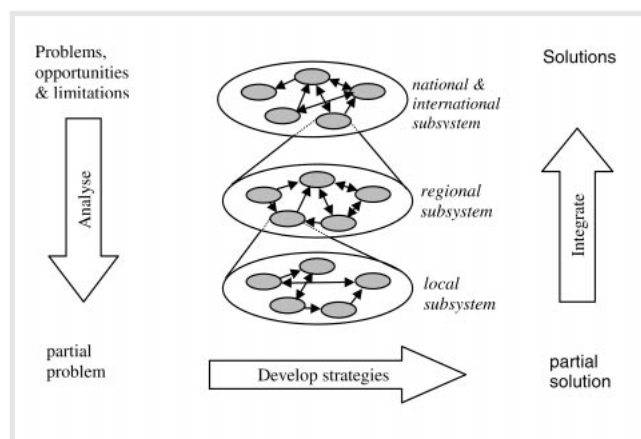
The choice of key factors is based on the principle that a system that includes human actors should cover the following domains: economy, population, land use, conditions of well being, nature, infrastructure, and the public interest (Principe 1994). Each subsystem should not consist of less than 12 key factors. In the present study, key factors for these domains were identified by researchers in the respective disciplines and submitted to restitution and modification by participatory panel group discussions. Figure 3 depicts the 12 key factors that were determined with regard to intensification and stabilization within the local land use system, ie, at the local level.

Second step: Assessment of all interrelations

The next step of the sensitivity analysis consists of assessing all interrelations between the different key factors. In doing so, attention must focus on three important aspects, ie,

- making sure that no interrelation is ignored;
- distinguishing positive interrelations from negative interrelations; with regard to the study's develop-

FIGURE 2 Three equally important subsystems of key factors and their interrelations.



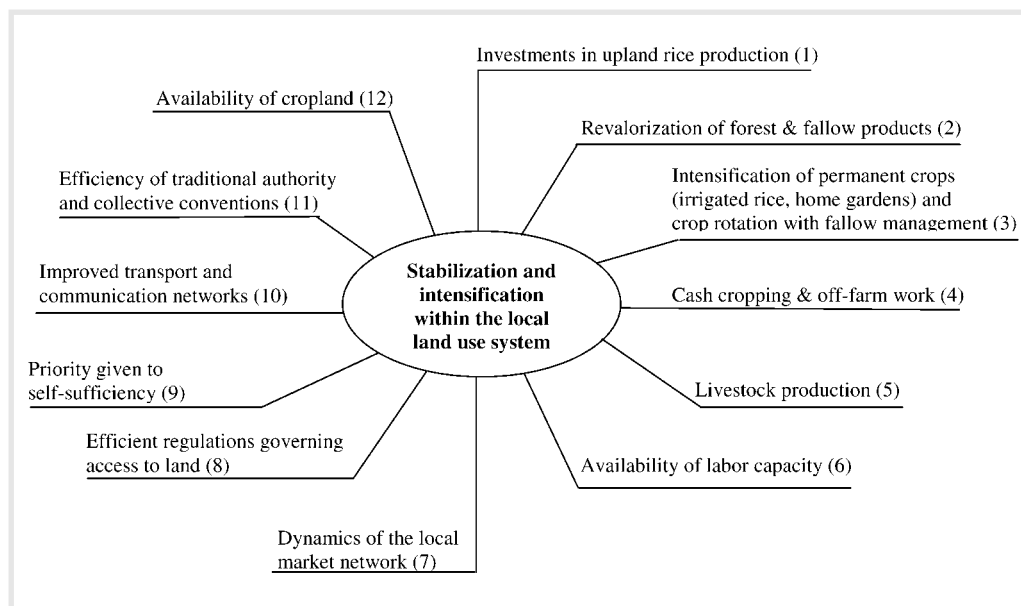
ment objectives, they are henceforth called stimulations and inhibitions;

- taking into account the intensity of the interrelations.

The use of matrices allows compliance with these three stipulations. A matrix facilitates systematic assessment of every single interrelation and of its intensity. In order to take into account the positive and negative interrelations, two matrices were used—one for all the stimulating interrelations and one for the inhibiting interrelations. The interrelations were assessed qualitatively and assigned values to represent their intensity according to a scale with four degrees of intensity: no direct influence = 0.1, weak influence = 0.5, medium influence = 1.0, and strong influence = 2.

Qualitative assessment of each interrelation is the core process of sensitivity analysis because it is at this

FIGURE 3 Key factors in the local subsystem relevant to intensification and stabilization (numbers correlate with the numbers in Figure 4).



	Stimulation by... ↓ of... →	1	2	3	4	5	6	7	8	9	10	11	12	Active Sum (AS)	Degree of interrelation (AS/PS)
1	Investments in upland rice production	1	0.5	0.1	0.1	0.1	0.1	0.1	0.5	1	0.1	0.5	0.1	3.2	23.7
2	Revalorization of forest and fallow products	1	1	0.1	0.5	0.1	0.1	1	0.5	0.1	0.5	1	0.5	5.4	29.2
3	Intensification of permanent crops and crop rotations with fallow management	0.1	0.5	1	2	1	1	2	1	0.1	1	0.5	2	11.2	109.8
4	Cash cropping & off-farm work	0.5	0.5	1	1	1	1	2	0.1	0.1	1	0.1	2	9.3	105.1
5	Livestock production	0.1	0.1	1	1	1	2	1	0.1	0.1	0.5	1	0.1	7	52.5
6	Availability of labor capacity	1	0.1	2	2	1	1	0.5	0.5	0.1	0.5	0.5	0.5	8.7	67.9
7	Dynamics of the local market network	0.1	1	2	2	1	0.5	1	0.1	0.1	2	0.1	0.5	9.4	84.6
8	Efficient regulations governing access to land	2	1	1	0.5	0.1	1	0.1	1	0.1	2	0.5	0.5	8.4	53.8
9	Priority given to self-sufficiency	1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	0.1	0.1	0.1	2	7.8
10	Improved transport and communication networks	0.5	0.5	1	2	2	0.5	2	1	0.1	1	1	0.1	10.7	68.5
11	Efficiency of traditional authority and collective conventions	1	1	1	1	1	1	0.1	2	0.1	0.5	1	0.5	9.2	71.8
12	Availability of cropland	0.1	0.1	0.5	0.1	0.1	0.5	0.1	0.5	2	0.1	1	1	5.1	35.2
	Passive Sum (PS)	7.4	5.4	9.8	11.3	7.5	7.8	9	8.4	3.9	6.4	7.3	6.9		
	Degree of Activity (AS/PS)	0.4	1.0	1.1	0.8	0.9	1.1	1.0	1.3	0.5	1.7	1.2	0.7		

	Inhibition by... ↓ of... →	1	2	3	4	5	6	7	8	9	10	11	12	Active Sum (AS)	Degree of interrelation (AS/PS)
1	Investments in upland rice production	1	0.1	2	1	1	2	1	0.5	0.1	1	1	2	11.7	48.0
2	Revalorization of forest and fallow products	0.1	1	0.5	0.1	0.1	0.5	0.1	0.1	0.1	0.1	0.1	0.1	1.9	4.4
3	Intensification of permanent crops and crop rotations with fallow management	0.5	0.1	1	0.1	0.1	0.1	0.1	0.5	1	0.1	0.1	0.1	2.8	20.2
4	Cash cropping & off-farm work	0.5	0.5	0.1	1	0.1	0.1	0.1	0.5	1	0.1	0.5	0.1	3.6	23.8
5	Livestock production	0.1	0.1	0.1	0.1	1	0.1	0.1	0.5	1	0.1	0.1	0.1	2.4	6.7
6	Availability of labor capacity	0.1	0.1	0.1	0.1	0.1	1	0.1	0.1	0.5	0.1	0.1	0.1	1.5	9.3
7	Dynamics of the local market network	1	0.1	0.1	0.1	0.1	0.1	1	0.5	1	0.1	0.5	0.1	3.7	15.5
8	Efficient regulations governing access to land	0.1	0.1	0.1	0.5	0.1	0.1	0.1	1	0.5	0.1	0.1	0.1	1.9	7.4
9	Priority given to self-sufficiency	0.1	0.5	2	2	0.5	2	1	0.5	1	0.1	0.5	1	10.2	74.5
10	Improved transport and communication networks	0.5	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1	1	0.1	0.1	2.4	4.8
11	Efficiency of traditional authority and collective conventions	0.1	0.1	0.1	0.5	0.5	0.1	0.5	0.1	1	0.1	1	0.1	3.2	10.2
12	Availability of cropland	1	0.5	2	2	0.1	1	1	0.5	0.1	0.1	0.1	1	8.4	32.8
	Passive Sum (PS)	4.1	2.3	7.2	6.6	2.8	6.2	4.2	3.9	7.3	2	3.2	3.9		
	Degree of Activity (AS/PS)	2.9	0.8	0.4	0.5	0.9	0.2	0.9	0.5	1.4	1.2	1.0	2.2		

FIGURE 4 Matrix of stimulations and matrix of inhibitions.

point that the existing knowledge is applied and aggregated; it was therefore carried out carefully by the panel group. It is very important that a team consisting of experts from several different fields carry out the assessment. In the present case, it was also important for representatives of different disciplines to come to an agreement. Figure 4 shows the two matrices for all stimulations and for all inhibitions that resulted from this process.

Since the study's concern was to find out what role each factor plays within the system, four more figures for each matrix in Figure 4 needed to be calculated. These figures are as follows:

- The sum of each line is the active sum of each key factor. It represents the total influence the factor exerts on the system (stimulation or inhibition).
- The sum of each column is the passive sum of each key factor. It represents the total influence of the system on the factor (stimulation or inhibition).

- The product of the active sum multiplied by the passive sum represents the degree of interrelation. The higher the value, the more the factor is interrelated within the system.
- The quotient that is the result of dividing the active sum by the passive sum represents the degree of activity of each factor. A small quotient ($Q < 1$) obviously means that the influence the factor undergoes is greater than the influence the factor exerts on other components. The opposite applies for high quotients.

The degree of interrelation and the degree of activity represent the basis for the following interpretation of the role each key factor plays within the system (Figure 5). To illustrate the value of the two degrees for all factors at the same time, we can depict them as a pair of coordinates in a coordinate system. The x-value is attributed to the degree of activity and the y-value to the degree of interrelation. As we have two matrices, one for

Intensification and stabilization within the local land use system

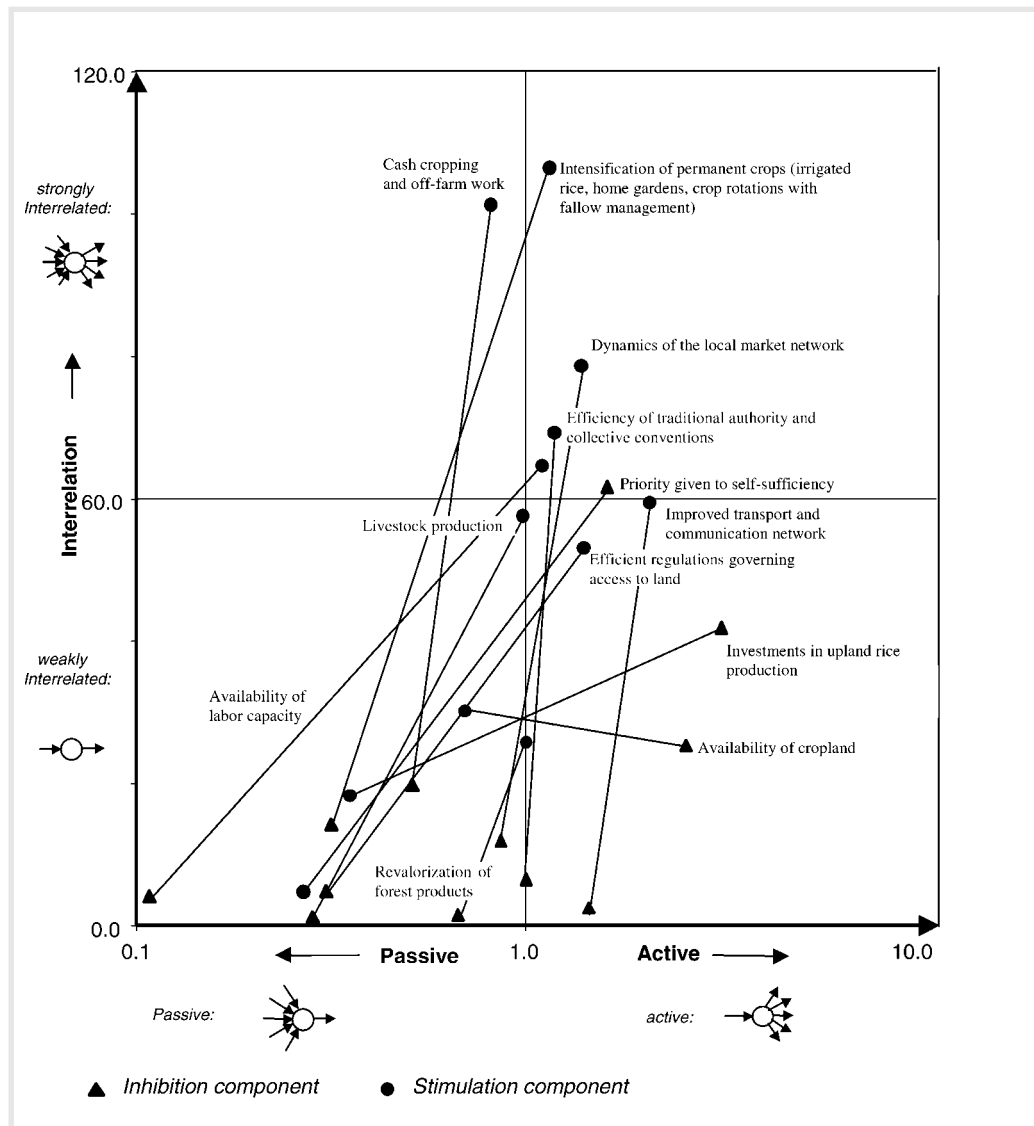


FIGURE 5 Stimulation and inhibition components of the key factors of the local subsystem.

stimulations and one for inhibitions, each factor is given two pairs of coordinates, one for its stimulation component and one for its inhibition component. Each factor is therefore represented in the coordinate system by two points, one showing the systemic role of its stimulation component (depicted by a dot) and one representing the systemic role of its inhibition component (depicted by a triangle). A line links the dot and the triangle.

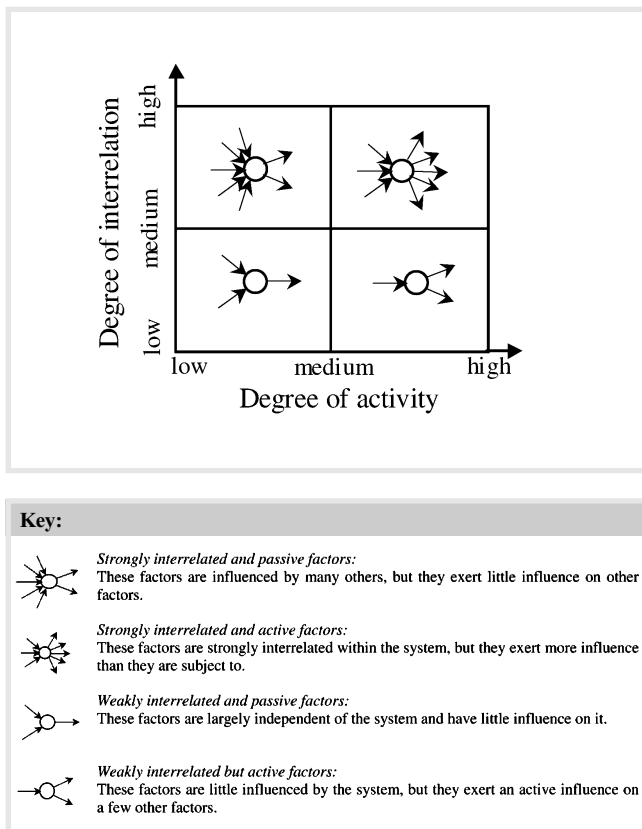
Third step: Interpreting the factors according to their potential to influence the entire system

As mentioned above, the degree of activity and the degree of interrelation are the most important values

when interpreting the different roles the factors play within the system. The coordinate system serves to illustrate the position of the stimulation and inhibition components of each of the factors and can be subdivided into four fields to facilitate interpretation. The pictograms in Figure 6 help illustrate the characteristics of components found within the four fields.

Having understood the characteristics of these four fields, we can now proceed to interpret the role each key factor plays within the system. This requires taking into account the position of the pictograms representing stimulation and inhibition components in the system of coordinates. The following description of some

FIGURE 6 Interpretation of factors within the system of coordinates.



standardized roles (Figure 7) is very general; it is meant to facilitate interpretation.

Results of the concrete analysis

The third and last step of sensitivity analysis groups the factors according to the manner in which they influence the system. It reveals their potential to stimulate or inhibit intensification and stabilization within the local land use system. The examples of interpretations proposed above are explained in greater detail below with reference to the example of slash-and-burn cultivation on the Eastern Escarpment of Madagascar.

However, a crucial point about the use of sensitivity analysis must first be made. While applying the method, no new information was added to existing knowledge. We simply capitalized on it by assessing all interrelations one by one. In the concrete case presented here, the following explanations therefore only represent an aggregation and crystallization of knowledge acquired by the groups involved in the work. Nevertheless, though no new knowledge was gained, it is obvious that understanding of the complex issues greatly improved.

The two initial premises were the following: Intensification and stabilization of the land use system is a prerequisite for more sustainable development in the region, and furthermore, a consensus about this concern exists among the different stakeholders and decision makers at the local level. (See Figure 8 for an example of intensified cultivation.) If answers to the question of how intensification and stabilization could be enhanced within the local land use system are to be found, recognition of what must be avoided should first be gained by looking at different blocking factors.

Blocking factor 1

Increasing priority given to self-sufficiency: The higher the priority given to the objective of self-sufficiency, and thus to food security for a growing population, the more intensification and stabilization of the system is inhibited. Today each household tries to produce all the rice it needs. If self-sufficiency in rice is a goal at the level of each household, the blocking effect on other activities is understandable. From an economic point of view, pluvial rice production (*Tavy*) is no longer an optimal form of productivity with regard to labor. With 4 kg of paddy or \$0.6 per day, the return for labor is lower than with all other production activities (Messerli 1998; Terre-Tany/BEMA 1999). The fact that each household continues to produce *Tavy* shows the current lack of alternatives. With regard to potential interventions, it can be concluded that (1) actions with the sole objective of increasing the self-sufficiency of household *Tavy* rice not only treat a symptom but very effectively inhibit improvement of the entire system. (2) Considering the high consumer preference for rice, self-sufficiency should be conceived at a regional level, the objective being to establish an exchange on the local market between farmers producing high rice yields (through irrigated rice and intensive rice cropping on the valley floors) and farmers who could specialize in cash crops (eg, coffee, bananas) or animal husbandry. At the same time, it is also indispensable to reduce market constraints and improve the attractiveness of cash cropping.

Blocking factor 2

Increasing investments in upland rice production: This is a block directly linked to the one discussed above. If economic investments in *Tavy* production are increased, an important resource is removed from other activities. The lack of labor and capital represents a fundamental constraint. The indirect cost of such an investment by far exceeds its profits. This has important implications for interventions aiming at making *Tavy* ecologically more sustainable. All attempts to reduce degradation or improve fallow should only require a minimum investment in terms of working time and capital.

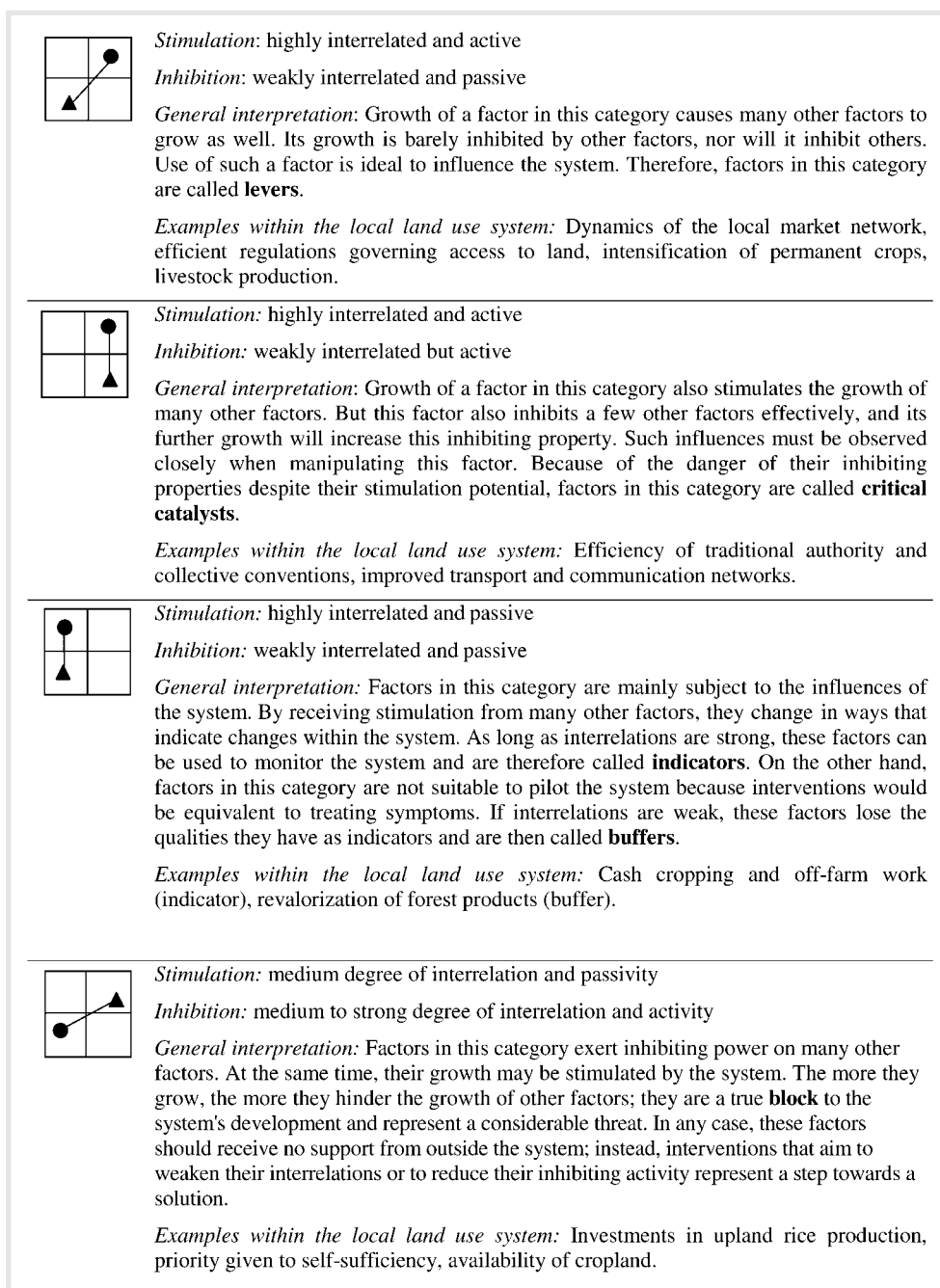


FIGURE 7 Description of standardized roles of factors, with examples from the study area.

Blocking factor 3

Availability of cropland: Although this factor cannot be influenced directly by external interventions, the fact that it acts as a block is significant. It reflects the assumption that, in the long run, intensification and stabilization will be inevitable. A decrease in available cropland leads to a general increase of problems related to the livelihood of local people, which in

turn stimulates the adoption of innovations. More degraded areas with a longer history of land use actually show a higher level of diversification. With regard to possible interventions, a second point must be made: If development succeeds in raising productivity per available unit of cropland and entails a relative increase of cropland, this may again inhibit ongoing development.

Blocking factor 4

Revalorization of forest and fallow products: This factor does not in itself block intensification and stabilization of the system. Nevertheless, an attempt to enhance intensification and stabilization by supporting this factor would be equivalent to treating a symptom. Investing scarce resources for such an intervention would thus not be very sensible.

The first lesson we have learned concerns the key factors that hinder intensification and stabilization of land use. Now more promising strategies with regard to the chosen development objectives can be examined and classified according to three different areas of intervention: the area of production, the economic field, and the field of socio-organizational improvements.

- In the area of production, it is clear that intensification of permanent crops (irrigated rice and home gardens) as well as crop rotations with intensive fallow management represent the greatest opportunities. Despite their strong interrelations with many other factors, the degree of activity of these two factors depends to a great extent on stimulation that comes from other factors. This is also true for cash cropping as well as for livestock production, which are, however, less interrelated. To conclude, these production components can represent important motors for transforming the system, as long as other factors perpetuate them. Availability of labor also plays an important role, even if it cannot be directly manipulated. It can also be strongly stimulated by the above-mentioned production activities. Indeed, if labor-intensive and spatially dispersed upland rice production were gradually abandoned in favor of permanent and spatially concentrated crops, the lever effect of available labor would reinforce intensification of permanent crops. This underlines the importance of synergies that can be capitalized on by focusing interventions on the appropriate factors.
- In the economic field, one important factor stands out—the dynamism of the local market. It can be considered as one of the levers that can play an important role in stimulating the production components mentioned above. Apart from offering better sales opportunities for cash crops, home garden products, etc., a strengthened market network is essential to enhance the exchange of rice and improve the supply of inputs.
- In the socio-organizational field, two promising factors are closely linked to one another: the efficiency of traditional authority and collective conventions, and efficient regulations governing access to land. Their quality as levers underlines the fact that organizational capacity among local actors is more than a precondition to achieve the chosen development

objectives. If collective conventions and land access regulations are successfully supported, they actively contribute to inducing sustainable changes. Improvement of communication networks has an active and quite strongly interrelated stimulation component that influences socio-organizational aspects.

Improved horizontal and bottom-up communication greatly helps negotiating, promoting, and ensuring important changes in all possible domains and prevents local society from breaking apart.

Conclusions

Possibilities of intensifying and stabilizing slash-and-burn cultivation within the local land use system

The above results show, from a systemic point of view, what should be initiated and what should be avoided in order to identify strategies to intensify and stabilize land use in the study area. However, the quality of these results depends on the understanding and perspective of the team of experts who made the assessment and therefore reflects a necessarily restricted view. Consequently, results and future decisions need to be discussed and negotiated with the concerned stakeholders. Furthermore, and more importantly, the study only presents the subsystem of local land use; influential factors such as governmental policies, economic and conservation interests, etc., were provisionally ignored. For the actual project, an important complementary objective has therefore been to integrate partial solutions into a regional and national context in order to identify a more complete strategy (Figure 2). With this necessity in mind, the following hypotheses limited exclusively to the local land use system can be proposed:

- Combinations of different activities look promising for the local subsystem:
 - In the field of production, the economic and agronomic attractiveness of production on the valley floors must be enhanced. This can be achieved by intensifying cultivation in compact production units consisting of cash cropping (fruit, vegetables, and animal products), irrigated rice, and integrated livestock production.
 - At a socio-organizational level, local capacities should be supported and enhanced in order to increase the effectiveness of traditional collective conventions as well as regulations governing access to land. The same, or even greater, attention should be paid to improving communication networks since they can strongly stimulate and perpetuate changes.
 - The dynamics of the local market can greatly enhance changes within the production domain.



FIGURE 8 Example of a valley floor with intensified cultivation (irrigated rice, surrounded by fruit gardens, cash crops and residual forests). (Photo by author)

Furthermore, they can also successfully increase exchange of rice.

- Certain other activities should be considered as a threat to the intensification and stabilization of the subsystem:
 - Actions that aim to increase the self-sufficiency of rice production at a household level impede improvements of the system as a whole. A discussion is urgently needed concerning the means (purchase or production) of attaining self-sufficiency and the levels (household, community land, region) at which it is appropriate.
 - Conservation activities linked to the slash-and-burn technique and based on investments in terms of labor and capital hinder the sustainable development of the land use system. Conservation of natural resources must be linked to the development of the entire system and thus to the promotion of other, more sustainable components of production.

From a systemic point of view, the future of slash-and-burn agriculture in the region of Beforona will generally not depend on making pluvial rice cultivation (*Tavy*) more sustainable. Pure conservation efforts may even inhibit overall development of the land use system. A greater positive potential resides in intensification on the valley floors through spatially concentrated production units. However, the success of such a strate-

gy will depend greatly on socio-organizational measures and improvement of market opportunities. External interventions that conform to such means of improvement will contribute to preventing the most harmful threat to farmers on the East Coast of Madagascar, ie, the continuous loss of land use options through increasing degradation due to slash-and-burn.

Advantages and constraints of the method

With reference to the experience gained by the BEMA project and presented in this paper, the following advantages and constraints of sensitivity analysis were identified:

- The method essentially represents a way of aggregating existing knowledge gained by a team of experts and rearranging it to produce a more general and clearer picture. This general picture consists of a synoptic consideration of all interrelations. No new basic knowledge is added; rather, new interdisciplinary knowledge is gained—the whole is more than the sum of its parts.
- An integrated picture makes it easier to apply scientific results with regard to development objectives. On the one hand, it helps scientists make more synthetic statements when discussing matters with stakeholders and decision makers. On the other, it supports communication about and understanding of problems that are often complex.
- Assessment of all interrelations one after the other by a team of experts who have the task of reaching

an agreement is a very significant interdisciplinary experience. While keeping a very narrow thematic focus, different ideas can more fruitfully be discussed. This helps to destroy preconceived notions and to reveal disciplinary biases.

- The method can be a useful tool in the context of applied development research. Some important advantages are described above. Nevertheless, it should be considered as a complementary synthetic tool and not as a substitute for an in-depth synthesis

of multidisciplinary research results. Nor should it be misunderstood as a tool that exempts us from promoting societal decision making about future development options.

- Assessment of interrelations depends on a solid base of knowledge, expertise, and sound scientific complementarity. Sensitivity analysis is thus not applicable to all situations, and it requires a considerable amount of collaborative work (in the present case, 264 assessments for a set of 12 key factors).

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