FROM PLOT TO WATERSHED MANAGEMENT: EXPERIENCE IN FARMER PARTICIPATORY VERTISOLS TECHNOLOGY GENERATION AND ADOPTION IN HIGHLAND ETHIOPIA[1]

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Vertisols are important underutilized resources in the East African highlands because of their inherent waterlogging problem. In this paper, group experience in the design, development and diffusion of a technology package through farmer participation for improving management and productivity of Vertisols is described. The results indicate that farmer knowledge, capacity and incentives are important considerations at every step in technology generation and diffusion. Results also indicate that technology adoption is not a one-off decision rather farmers move from acquisition of knowledge to adoption to continuous or discontinuous use. The set of factors influencing each decision may be also different. The experience also indicates that for effective use of technologies that are complex and may create externality, household level decisions are not adequate, rather involvement of the community in watershed or landscape management may be required. Participation of individual households in such collective action for common resource management is most likely to be influenced by the potential benefit to the participants. The experience of the project also indicates that introduction of component technologies and other interventions in a haphazard manner may not lead to sustained improvement in productivity and human welfare and maintenance of the ecosystem. An integrated and holistic approach incorporating biophysical, economic and social dimensions of any ecosystem is more appropriate for achieving those goals.

Background

Highlands (1500 masl) cover about 10% of tropical Africa, mostly located in the East Africa region, but they support close to half the human and about 30% of the total livestock populations. Major problems encountered in the highlands of this region are poverty and malnutrition, low crop and livestock productivity, widespread land degradation, and under-utilization of some resources due to specific constraints

The highlands of Ethiopia make up over 60% of the East African highlands and account for more than 80% of the agricultural lands. In addition, they serve as the major catchment for many tributaries that feed the river Nile. The majority of agricultural production is in the hands of the peasant sector, and farm technology has undergone little change for hundreds of years. As in other countries in the region, the smallholder farmers in the Ethiopian highlands are poor, individual land holdings are no more than 0.5 to 2.5 ha, family sizes are large, land productivity is low; thus food requirements are not met. Deforestation is common, steep-slope cultivation and over grazing have become rampant in response to the increasing

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pressure on land, and fallowing as a means of fertility replenishment has almost disappeared or is ineffective because of the use of dung and crop residues for fuel (which represent an annual loss in crop production of 700,000 tons of grain). A major problem for agricultural growth in the country is land degradation, including soil erosion and loss of soil fertility, water resource degradation and loss of biodiversity. At present rates, it is estimated that land degradation could destroy farmlands of some 10 million highland farmers by the year 2010 (Sutcliffe, 1993). Land degradation also contributes to the deterioration of grazing land. This in turn has contributed to feed shortage due to breakdown of traditional systems of livestock grazing, and to the low performance of livestock.

While population pressure has induced cultivation and livestock grazing to steep slopes and fragile lands causing serious devegetation and soil erosion, a large amount of Vertisols (heavy black clay soils) remain underutilized. Vertisols cover some 43 million hactares comprising 19% of total land area in sub-Saharan Africa. Nearly 30% of the Vertisols area is located in Ethiopia alone, particularly in the highland region (Mohamed Saleem, 1995). Vertisols are productive soils but difficult to manage due to their poor internal drainage and resultant flooding and waterlogging during the rainy season. Consequently, Vertisols in Ethiopia are currently largely used for dry season grazing and under 30% is cultivated. The cultivated Vertisols are exposed to soil erosion and give low yields because the fields are ploughed before the main rains and sown towards the end of the rainy season to avoid waterlogging. Therefore in food deficit Ethiopia, removing constraints to crop production in Vertisols areas is of very high importance (Tekalign Mamo *et al*., 1993).

In this paper, experience of a research project for developing and disseminating technologies for better management of Vertisols for improving productivity are summarised.

Vertisol technology development and testing in Ethiopia

In some parts of Ethiopia, particularly around Debre Berhan, farmers practice soil burning to minimise waterlogging problem and improve the fertility of the soil. Small mounds are created with surface soil, dung and left over straw are put inside the mounds to burn the soil, then the burnt mounds are levelled again. In another area around Inewari, farmers construct hand-made broadbed and furrows, principally using women and child labour, to facilitate drainage. Both soil burning and hand-made broadbed making are labour intensive operations, and they are not technically very efficient, so these traditional techniques do not enable full potential use of the Vertisols (Tekalign Mamo *et al*., 1993).

Animal traction is extensively used for tillage in Ethiopia but the traditional plough, called *Maresha*, pulled by a pair of oxen cannot invert or shape the soil so that land tilled with *Maresha* remain covered with water during heavy rains. In order to facilitate drainage, the Ethiopian Joint Vertisol Project (JVP)[2] developed, through a series of experiments on design, a broadbed maker (BBM) by joining two *Mareshas* with a crossbar about 1.5 meter long, then attaching a metal wing on the outside of each *Maresha* and link the two wings with

[2]A consortium comprising Ethiopian Agricultural Research Organization (formerly Institute of Agricultural Research), Alemaya University of Agriculture, Ministry of Agriculture, International Livestock Research Institute (ex-International Livestock Center for Africa) and International Crops Research Institute for the Semi-Arid Tropics as partners.

a looping metal chain from behind. When operated by a pair of oxen, the two *Mareshas* of the BBM create two furrows on two sides of a 1.2 meter bed, the chain levels the soil on the bed and covers seeds when sown or planted on the bed. At the time of heavy rain, the furrows allow excess water from the bed to be expelled to a sub-field or main drain at the end of the plot. This drainage technique allows early sowing and longer growing period thus resulting in higher yield and less erosion. The JVP has developed a suitable agronomic package (crop varieties, planting dates, fertilizer regime and crop protection measures) to complement the BBM (Mohamed Saleem, 1995). Together it is called 'BBM package' but henceforth BBM and BBM package will be sometimes used interchangeably for brevity.

After on-station trials, the BBM package was tested on-farm during 1986-89 at five Vertisol sites in the Ethiopian highlands (Inewari, Hidi, Ginchi, Dogollo and Dejen) at altitudes ranging from 1850 to 2600 meters above sea level and receiving from 850-1200 mm annual rainfall. Tests were performed in collaboration with a small number of farmers selected in consultation with the local Peasant Associations, which had a dominating role in rural Ethiopia at that time. These initial tests provided opportunities to verify the technical and economic performance of the BBM package and related problems. The results showed that with BBM package, wheat yields averaged 1.5 –3.0 t ha^{-1} in different locations compared to average yields of 0.6-0.8 t ha^{-1} of traditional wheat or teff, which the BBM package replaced. The test also led to modification of some components of the package.

During 1990-95, on-farm research was continued in three (Inewari, Hidi, and Ginchi) of the five sites with a particular focus on the adoption behaviour of farmers. Through the local extension office of the Ministry of Agriculture (MOA) training was given to prospective participants in the BBM package including handling, dismantling and reassembling of the BBM. Additionally in 1993, experienced and well performing farmers in Inewari were contacted to recruit new farmers and train them with the objective of encouraging farmer-to-farmer diffusion. Participants were provided with improved seeds and fertilizers on credit to be repaid after harvest of the crop, and the services of BBM were provided free of charge. One set of BBM served 6-8 farmers. The credit was provided out of a revolving fund granted by Oxfam America. A committee composed of representatives from JVP, the MOA and the Peasant Associations managed the fund. In 1995, the management of the revolving fund was handed over to the Peasant Associations with local MOA staff having a supervisory role.

In 1995/96, an assessment of the economic impact of the BBM package in the three research sites showed that in all three sites improved wheat replaced traditional wheat as expected but in Ginchi improved wheat also replaced teff and pulses to some extent. Cash income increased in Inewari from Birr 269 to Birr 865, in Hidi from 546 to 679, and in Ginchi from 684 to 1221. Larger holdings had higher potential for increased cash income than smaller holdings because they could devote larger area to BBM package without reducing area under other subsistence crops. Because of low cash income of the farmers, the benefit from the BBM package, which require purchased inputs like seeds and fertilizers, could be substantially increased by relaxing cash constraint through credit (Weber, 1996).

Also in 1995, a survey was conducted in two of the three research villages to test if farmers were willing to buy and own the old BBM sets, consisting of two wings and a chain (farmers already had *Mareshas*), rather than getting free BBM service from the project, and the price they were willing to pay. In the third village, farmers were already using the research project supplied BBM sets on a share basis, 5-6 farmers sharing each set. Willingness to buy and own would indicate farmers' confidence in the technology and interest in its continued use. The survey revealed that over 150 farmers were willing to buy the 90 BBM sets available, so the sets were sold through a lottery among interested buyers present on a pre-arranged day in each location. New BBM owners used it themselves, lent to relatives and neighbours and in some cases rented out at a fee. This was also an indication that farmers with traction animal could earn extra income by renting out BBM services to those without traction animal or with inadequate traction animal.

The adoption pathways for BBM package in research sites and related factors[3]

During on-farm research, information on the BBM package was made accessible to all the farmers in the research villages yet it was observed that some farmers participated in the research process for different duration either continuously or discontinuously, some did not yet participate, some even did not know how the BBM package functioned. So during 1995-96, 585 households were surveyed from the three research villages to understand adoption behaviour and related factors. Empirical studies on agricultural technology adoption generally divide a sample into adopters and non-adopters and analyse the reasons for adoption or non-adoption at a point in time. However, simple distinction between adopters and non-adopters was found inadequate in the present study as about half of the non-adopters did not yet acquire sufficient knowledge about the BBM package while the other half had acquired knowledge but did not yet decide to adopt[4]. Among adopters, about two thirds used the package discontinuously and one third continuously (Figure 1, Panel A). Acquisition of knowledge and information precedes any decision to adopt so the sample was first divided into those who knew about BBM and those who did not (Panel B, Figure 1). Result shows that 9% of the sample did not yet know about the BBM package, 91% knew about the package of which 89% adopted; among adopters the use pattern (continuous vs discontinuous) was the same as that in Panel A. Therefore Panel A cannot be considered to correctly depict the sequence of learning and adoption. Panel B shows a more appropriate sequence: farmers move from learning to adoption to continuous or discontinuous use.

Several logistic regression equations were estimated to identify factors influencing farmers' probability of acquisition of knowledge, probability of adoption and probability of continuous use of the BBM package on the basis of classification Panel B in Figure 1. A summary of the best-fit model estimates is shown in Table 1. The model correctly predicted 91% cases in terms of BBM knowledge, 92% cases in terms of BBM adoption and 78% cases in terms BBM use pattern.

In general, there were significant differences among the tree sites in terms of acquisition of knowledge, adoption and use patterns. Compared to Inewari, a farmer located in Hidi or Ginchi was less likely to have acquired BBM knowledge. Among those who had BBM knowledge, a farmer located in Hidi was many times more likely to have adopted BBM while a farmer in Ginchi was significantly less likely to have adopted BBM. Among adopters, a

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[3] This section has been derived primarily from Jabbar *et al*. (1998).

[4] A producer is considered to *know* about a new technology if his/her acquired information reaches a threshold level. In the present case, the threshold level of information was not directly observable, so a farmer was considered to have knowledge about BBM package if he/she heard about the BBM package and its functions and/or saw it functioning. At this stage acquisition of information was the key, acquisition of operational skill for the BBM was not yet an issue.

farmer located in Hidi or Ginchi was significantly less likely to have used the package continuously. The discontinuous use was more pronounced in Ginchi.

Figure 1: Distribution of sample households according to knowledge, adoption and use pattern of BBM package in three research sites

Panel A: Total Sample (585)

Non-adopters (111)
- Don't have BBM knowledge (54)
- Have BBM knowledge (57)

Adopters (474)
- Discontinuous use (313)
- Continuous use (161)

Panel B: Total Sample (585)

Don't have BBM knowledge (54)

Have BBM knowledge (531)
- Non-adopters (57)
- Adopters (474)

These differences might be because farmers in Inewari use handmade broadbeds, so they probably were generally more eager to learn about a better substitute and use it. Also the farmer-to-farmer training programme organised in Inewari in 1993 gave farmers there a better opportunity to learn compared to the other two locations. Inewari and Hidi farmers also had more regular access to credit compared to those in Ginchi. Some of the other factors, or their interactions, which might have influenced differences among the three sites are size of land , extent of Vertisols and waterlogging problem, animals owned and education (Table 2).

Table 1: Significant factors influencing acquisition of BBM knowledge, BBM adoption and BBM use pattern

Factors	**BBM knowledge** (yes =1, no = 0)	**BBM adoption** (yes =1, no = 0)	**BBM use pattern** Continuous=1, discontinuous =0)
Location	yes	yes	yes
Education	-	-	+
BBM training		+	
Age of hh head			
Cropland area	+	+	
Vertisol area	+		+
Waterlogged area		+	+
Family size	-	+	
Distance from market		-	
Work animals	+	-	
Perceive BBM has problem			+
Expected extra yield			
Access to credit		+	+

+ indicate positive influence on the dependent variable, - indicate negative influence, blank means non-significant

Table 2: Some characterisctics of the three research sites

Attribute	**Inewari**	**Hidi**	**Ginchi**
Cropland per farm, ha	1.45	1.75	2.95
Vertisol area, %	49	51	91
Area with major waterlogging problem, %	19	17	42
% household heads with primary or higher level education	59	61	38
Work animals per farm	1.66	2.21	2.17

Source: Field survey

Education, area of cropland, area of cropland under Vertisosl, number of work animals, family size and distance from market had significant influence on whether a farmer had acquired BBM knowledge or not. Household heads with better education (primary level or over) were less likely to know about the BBM package than those with no formal education. Households with larger cropland area and area under Vertisols and larger number of work animals were more likely to have acquired knowledge about the BBM package. Among these, area under Vertisols had the most dramatic effect on the odds of a farmer acquiring knowledge about the BBM package : with one unit increase in the area under Vertisols, the odds of a farmer knowing about the BBM package increased 4.5 times. Since the BBM is specifically meant to address the problem of Vertisols, high degree of influence of this variable on farmers' willingness to learn about BBM would be normally expected. The positive effect of number of work animals on acquisition of BBM knowledge might be explained by the fact that a pair of animals was required to pull the BBM, so farmers with two or more animals were perhaps more interested to know about the BBM than those having none or only one animal.

Larger family size decreased the odds of learning about BBM to some extent perhaps because larger family labour supply decreased the need for alternative technology. Greater distance from market also decreased the odds of learning about BBM perhaps because the transaction costs of acquiring knowledge increased with distance and also information to distant parts of the research areas might have trickled down slowly.

Among those having knowledge about the BBM package location, education, BBM training, cropland area, area with major waterlogging problem, distance to market and work animal ownership had significant influence on whether the BBM package has been adopted or not. The odds of adoption decreased as the level of education increased while skill training in BBM increased the odds of adoption several times. Some adopters actually did not initially acquire the skill to operate the BBM, they hired somebody else to operate it. A typical example would be a farmer without BBM operational skill and another farmer with skill joining together with their *mareshas* to make the BBM.

Farmers with larger cropland area and larger area with major waterlogging problem were more likely to have adopted BBM. Although area under Vertisols significantly increased the odds of a farmer acquiring knowledge about BBM, it had no influence on adoption. Instead area with major waterlogging problem significantly increased the odds of adoption. In the sample sites, 60% of the cropland was under Vertisols, nearly 50% of cropland had some waterlogging problem but only 23% of cropland suffered from heavy waterlogging problem that would benefit from BBM type technology package.

Greater distance to market decreased the odds of adoption perhaps because distance adds to costs of a new technology and reduces potential net benefits. Ownership of larger number of work animals also decreased the odds of adoption, a characteristic rather difficult to explain except that work animal ownership and cropland are highly correlated and cropland has a strong positive influence on adoption.

Among those who adopted BBM package, area under Vertisols, area with major waterlogging problem, perception about problem with BBM technology package and access to credit had significant influence on whether the BBM package was used continuously or discontinuously. Higher level of education increased the odds of continuous use but BBM training had no influence on use pattern. Both area under Vertisols and area with major waterlogging problem increased the odds of using the BBM package continuously, which would be expected. The odds of continuous use was higher for farmers who perceived that the BBM package had some problems or disadvantages compared to those who did not perceive such problem. This was an apparently unexpected result but could be explained by the fact that those who used continuously and for a longer period also were more likely to have experienced or detected problems of the BBM package. The most important problem reported by farmers was about the heaviness of the BBM unit. The other problem mentioned by a few was the unsuitability of the BBM for too wet soil and weed problems. Longer duration of access to credit for BBM package significantly increased the odds of continuous use among adopters.

Factors influencing adoption outside research villages

Since 1992, the government has gradually introduced market liberalisation policies and a drive for achieving food self-sufficiency. Consequently a congenial environment has emerged for diffusion and adoption of improved technologies. Responding to this opportunity, the MOA and several NGOs including Sasakawa Global 2000 have started diffusion of the BBM package alongside other improved technologies. A private manufacturer of BBM, who was formerly an ILRI technician involved in the design and testing of BBM, is also active in the diffusion effort through selling BBM sets as well as imparting training to local blacksmiths in the fabrication of the equipment. This manufacturer alone claimed to have sold over 12000 sets of BBM by 1997 and participated with other agencies in training 26000 farmers in using BBM[5] (Chapotchka, 1997). Including supplies from government workshops, about 15000 BBM sets have been reportedly distributed by different agencies to different parts of the highlands of Ethiopia and Eritrea until 1998. Moreover, there are reports that BBM has been adapted in several lowland areas in the country for ridging to conserve water rather than for expelling excess water. However the number of BBMs actually in use and number of farmers using them in each year are yet to be ascertained.

In order to understand factors influencing adoption of BBM in the wider economy, a survey was conducted among adopters and non-adopters in two areas in 1996/97. Using Probit and Tobit regressions on the survey data, it was found that access to credit, history of fertilizer use and high school education significantly increased probability and intensity of adoption, and number of draught oxen ownership, distance from market and area of teff production significantly decreased the probability and intensity of adoption. The intensity of adoption was measured by the area devoted to BBM package (Gezahegn Ayele and Heidhues, 1998). These results are fairly consistent with the findings presented above from research sites except that in this study, only adoption and non-adoption was the focus of analysis, knowledge acquisition was not .

Externality and the need to move from plot to watershed

During on-farm testing, it was observed that although the BBM solves the problem of waterlogging of the plot on which it is used, sometimes it also creates enhanced waterlogging on the plot downstream. This is described as the problem of negative externality of a technology. This problem is more serious at lower slopes where the problem of waterlogging is generally higher than at higher slopes where water expelled from a plot is likely to move quickly further down the slope. Such problem may create conflict among farmers and may work as a disincentive for adoption. If BBM is used on a number of contiguous or scattered plots in a landscape or large field, finding or creating appropriate common outlet(s) for expelled excess water from individual plots can solve this problem of externality. This may require creation of field drains as well as longer common drains into which field drains will carry excess water. Implementation of such a strategy requires land and water use planning at micro-watershed level through participation of the community in design, development and maintenance of common goods e.g. drains. If the BBM plots are fairly close or contiguous, creation of common outlets may be easier than if they are scattered.

[5] A separate report quoted the same supplier as selling at least 25000 sets of BBM (Schioler, 1998). Perhaps this higher figure refers to the number of farmers using BBM, which is consistent with the number of farmers trained, rather than the number of sets sold. Normally a set is shared by a number of farmers.

Experience on watershed management

In 1994, the JVP started work on a pilot watershed in Ginchi Wereda in the highlands. The objectives of this project are, among others, to assess if negative externality in BBM use can be overcome by creation of common drains through community participation, to assess how the community can organise itself to undertake such tasks voluntarily, and to assess which factors may motivate farmers to participate and contribute in the creation of such local common good. The project provided opportunity to test standard theories of collective action in local resource management.

The pilot watershed comprises about 350 ha which itself is part of a Peasant Association (PA) of about 250 households with about 800 ha of land area. Within the 350 ha watershed, a sub-watershed of about 50 ha of mostly Vertisols held by a total of 57 households was delimited by the JVP for the purpose of construction of a main common drain with the participation of landowners concerned (the beneficiary group). The possibility of extending the drain to the whole watershed area in subsequent years was explicitly envisaged if the experience was to prove a success.

The construction of the main drainage channel clearly involved important indivisibilities. Unless a critical amount of labour input was allotted to this task, the channel would not be completed and yield any benefit in the form of increased land productivity. On the other hand, no additional labour contribution beyond that critical amount could give rise to productivity increments. Since landholdings are widely dispersed across the sub-watershed, there was no possible sub-coalition of farmers with lands concentrated in a well delimited part of this area. As a result, it was not conceivable that only a portion of the drainage system would be constructed to the benefit of a fraction of the farmers and at the expense of other farmers with their lands located down the drain. Either the channel was constructed across the entire sub-watershed area with the required technical specifications, or it was not produced at all. To put it in another way, due to scattered ownership, the channel within the sub-watershed area was not susceptible to being divided into several segments that could be the object of separate construction decisions.

The proposed central drainage channel has been built during the months of May and June 1995 by labour-intensive methods. There was a good measure of uncertainty regarding the exact amount of labour input required and the timing of the efforts involved. Farmers may well have believed that their contributions were likely to be sufficient to complete the drain within the prescribed time given their initial expectations concerning the advancement of the work and the advent of the rains. But when the digging was started, it soon became clear that the soil was very hard for manual work. Progress was therefore much slower than expected. In consultation with the farmers and only after it was clear that the problem was real and serious enough to prevent completion of the drain during the season, the project's staff decided to use a tractor to loosen the soil and the farmers then removed the earth and shaped the drain. During the first season after completion of the drain, BBM plots were more effectively drained and gave higher wheat yields and teff plots within the micro watershed also could be better drained so gave better yields.

Determinants of individual household's contributions to drainage construction[6]

In order to identify important factors influencing participation, Tobit regression was used on data collected from 53 of the 57 households in the watershed. The dependent variable was participation, measured by the amount of time spent by each household in earth work as well in attending preparatory meetings in which operational procedures and rules for the drainage project were discussed and decided. The results of the best fit model indicate that the intensity of participation by the sample households in the construction of the drainage system was significantly related to the following factors: First, amount of land owned in the watershed : the greater is the incentive to contribute to an investment that is designed to increase land productivity.

Second, the relative number of parcels owned that form a compact set with one border along the channel . The location of the parcels can be thought to bear upon the benefits derived from the drainage infrastructure in two different ways. On the one hand, the gradient of the parcels may matter since drainage intervention is likely to be less and less needed as lands are located higher up the watershed's foothill. On the other hand, proximity of the parcels to the drain may be expected to bring large benefits if water is more effectively drained away close to the central channel. Moreover, it can be presumed that when a farmer owns a large compact landholding formed by a set of contiguous parcels having a border along the drainage channel, he is able to organise at lower costs a system of secondary drains connected to these channels.

Third, the potential effectiveness of cultivation measured by the capital/labour intensity of owned factors. Households with a higher capital-labour ratio showed a higher tendency to contribute to the public good creation because of the possibility of deriving higher benefits from the improved technology that also requires higher capital input.

Fourth, the leadership quality. The positive effect of leadership on participation indicates that knowledge of the potential gains from collective action may be more easily forthcoming when farmers are members of the executive committee of the local PA. Farmers who are more aware of potential gains from cooperation in general tend to assume responsibilities and leadership roles in PAs. It is noteworthy that members of the executive committee of the local PA have contributed an average of 22 hours, compared with 12 hours for all participating households and with 7.5 hours for all sample households.

In short, what appears most important is that, with the exception of the leadership factor, individual household's labour contributions to the public good are well explained by factors, which clearly determine the potential personal benefits which different households can expect to draw from the creation of the drainage infrastructure. These results are quite close to those arrived at by White and Runge (1995) in a similar watershed management context. They found that cooperation among beneficiaries emerged in many cases, and within a given watershed, practical knowledge of the potential gains from collective action (in this case, the building of a soil conservation infrastructure to prevent externalities in the form of water spillover) and membership in indigenous peasant organizations are the best predictors of landholder choice to cooperate (ibid: 1697-89). In fact, a careful examination reveals that it

[6] This section has been derived primarily from Gaspart *et al. (*1998).

is not only awareness of potential benefits but also the ability to draw those benefits that motivate landholders to cooperate.

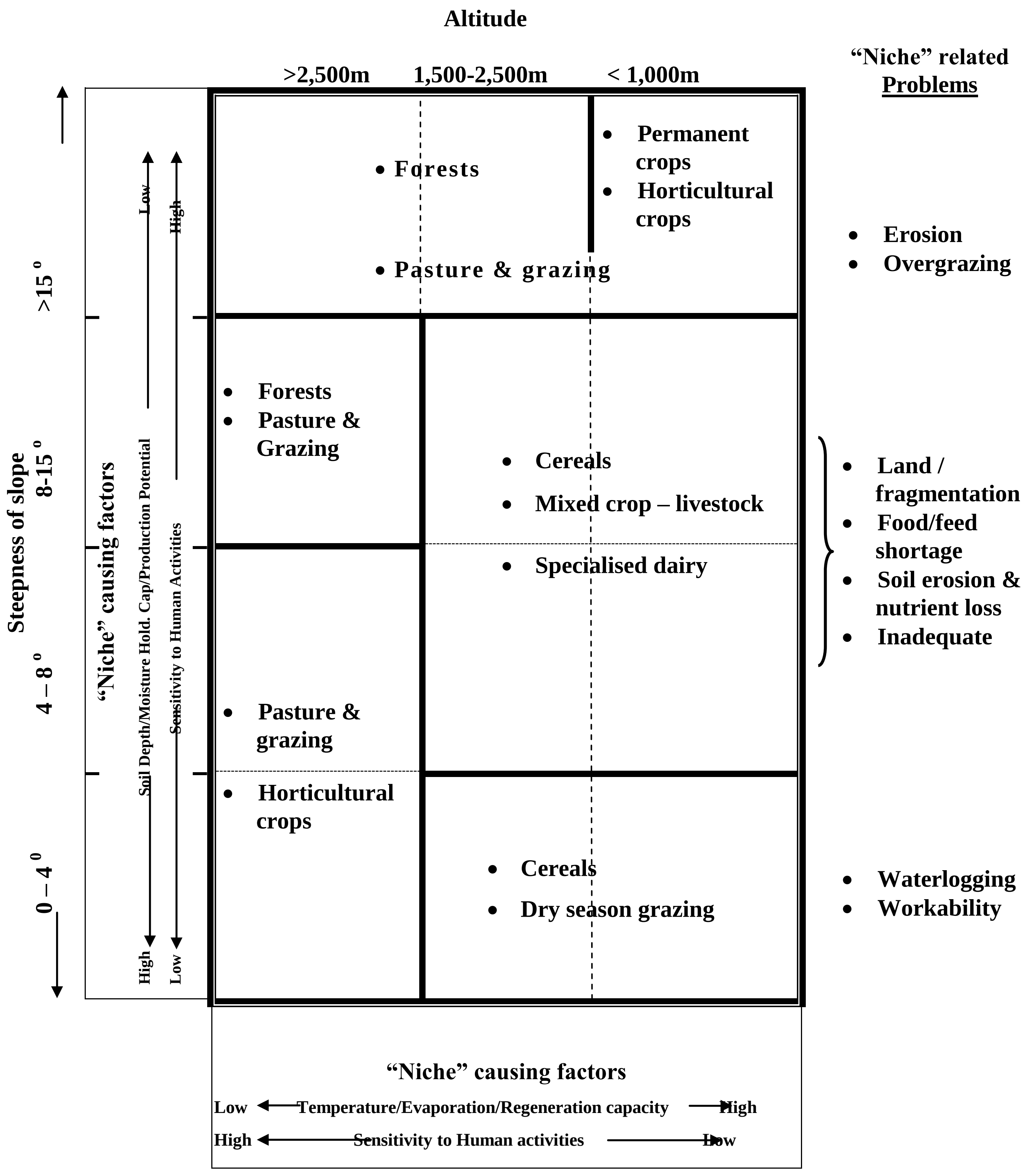
Current research : From Vertisols management to integrated resource management

Apart from the BBM package, the JVP also conducted on-station and on-farm research on technological solutions to other problems e.g. animal feed, nutrition, soil fertility management etc. However, these component technologies have been mainly tested at the scale of plot, animal or farm, often separately. Multiple interventions and their integrated effects were not assessed. The highland ecosystems, like any other ecosystem, have been viewed primarily as biophysical systems with geo-chemical and biological functions or at best, as human production systems with product yields or economic returns as the focus. In reality, farmers have many enterprises and in any year, they may cultivate many small plots that are spread across a landscape. Sharp and sudden changes in landforms within short distances (steep slopes, moderate slopes, flatlands and valleys) are very specific to the highlands. Rugged terrain limit accessibility, and soils along higher slopes are normally shallow. Combination of land forms and soils types within short distances create “niches”. Land potential and land-use practices, their constraints are different when the gradient and altitude are combined to divide a landscape (Figure 2). Consequently, potential solutions will also be different for different niches.

However, changes occurring in one part or “niche” of a highland ecosystem have impact on other parts. Individuals and communities decide to use different parts of a landscape in particular ways and such use may be complementary or competitive. They also have environmental implications both at site and beyond, for short as well as long run. For example, technology interventions in the Vertisols dominated part of an ecosystem may generate changes in the pattern of use in other parts of the landscape. Therefore, inter-relationships between biophysical and human dimensions need to be integrated both spatially and temporally to identify ways to improve conditions of the ecosystems and human welfare. Bioeconomic modeling is a useful tool for integrating the biophysical and socioeconomic aspects of a landscape, e.g. a watershed, and for assessing the multidimensional consequences of several technology and policy interventions.

The JVP has recently expanded its watershed research agenda to include more holistic and farmer participatory assessment of the consequences of multiple technology interventions as well as development of a bioeconomic model of the watershed to assess, in an integrated manner, the longterm consequences of different technology and policy interventions. It is expected that the model, once fully developed, will be useful for evaluation of integrated watershed development projects elsewhere.

Figure 2. Land-use practices and major constraints for production improvements in the highlands



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