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Review

Addressing the information problem in agriculture via agrobiodiversity: Streamlining the issues, challenges and policy questions

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The purpose of this paper is to show how agrobiodiversity addresses the inherent information problem that agriculture faces and present the issues, challenges and policy questions that need to be addressed to undertake rural development and maintain agrobiodiversity. It has been shown that *ex-situ* and *in-situ* strategies address the different aspects of the information problem in agriculture and farmers' bounded rationality. The various strategies have to, therefore, be taken as a continuum of complementary policy decisions producing different services to society with partly different and partly mutually non-exclusive outcomes. Given that the conservation outcomes, the institutional/technology demands and livelihood impacts are different, presenting the strategies as a choice is as misleading as comparing them with respect to costs, benefits, and (in)accessibility. The size of investment in each conservation strategy essentially depends on the type of genetic materials to be maintained, the level of *de facto* conservation by farmers, the prevailing institutions, the opportunity costs faced, the country's resource endowment and the level of technological progress.

Key words: Agrobiodiversity, agricultural information problem, bounded rationality, conservation strategies.

INTRODUCTION

Biological diversity (or biodiversity in short) is the number, variety and variability of all living organisms in terrestrial, marine and other aquatic ecosystems and their ecological complexes of which they are parts (UNCED, 1992). Agrobiodiversity is a subset of biodiversity relevant for agriculture, covering the diversity and variability of plants, animals and micro-organisms. More broadly, the genetic information, indigenous knowledge, culture and human values therein are all important components of agrobiodiversity.

Agrobiodiversity is not mainly about the physical genetic materials but the information contained therein (Swanson and Göschl, 2000). Encompassing all these components, agrobiodiversity as a source of information has a value in society as new developments occur in technology, agroecosystems, climate and other socio-economic elements of the system. In this paper, agrobiodiversity is defined as the stock and flow of genetic, cultural and indigenous knowledge information embedded in plants and animals that farmers manage.

This paper distinguishes three types of agrobiodiversity – static genetic agrobiodiversity (information A), dynamic genetic agrobiodiversity (information B), and dynamic, genetic and social agrobiodiversity (information C). Information A, B and C are produced by cold room genebanks, field genebanks, and in situ strategies, respectively. While information A refers to the static genetic stock of information maintained, information B is the dynamic genetic flow of information maintained without the human dimension. Information C encompasses agrobiodiversity that captures the flow of information with genetic, indigenous knowledge, and cultural and human values. These three forms of information need not necessarily be mutually exclusive or otherwise, that is, information C is not a sub-set of information B while information B is a sub-set of information A. This classification is used throughout the paper.

Agricultural production involves various biophysical information problems – uncertainties regarding weather, diseases, pests, and drought. Farmers do not have full information on these and other issues while making decisions on the farm. Due to cognitive limitations, complexity of the system and uncertainty, they are bounded rational decisions makers (Simon, 1957). Due to bounds on rationality (Conlisk, 1996), they should be viewed as rational satisficers, not maximizers (Simon, 1957).

Agrobiodiversity has traditionally been conserved *ex-situ* and *in-situ*, *ex-situ* being the dominant strategy. These conservation strategies attend to the different aspects of the information problem in agriculture. While *in-situ* conservation is meant to address the optimal appropriation and use of the flow of information (genetic, cultural, indigenous knowledge and human values), *ex-situ* conservation aims to target the appropriation and use of existing stock of genetic information. This is the information-based justification for the complementarity of these strategies.

For farmers, managing agrobiodiversity (the portfolio of traditional varieties of crops on the farm) is a means not to solve the information problem but to cope with possible undesirable outcomes. Managing agrobiodiversity enables them to better match the possible shocks with the diversity.

One of the purposes of this paper is to show how agrobiodiversity addresses the inherent information problem in agriculture. This is done drawing from the literature on the economics of information and the concept of bounded rationality. As far as the author's knowledge goes, this has not been done before. The other related objectives are to identify the opportunities and challenges in pursuing the various conservation strategies, establish the non-comparability of the different conservation strategies, and present the factors that need to be considered in implementing the "optimal" mix of the different strategies. The following section presents the information problem in agriculture and farmers' bounded rationality. This is followed by a discussion on how different conservation strategies address the information problem in agriculture. After questioning the common practice of comparing the different strategies in terms of costs, benefits and accessibility, the evolving opportunities and inherent challenges in pursuing the conservation strategies are presented. The paper concludes by streamlining the issues, challenges and policy questions.

THE INFORMATION PROBLEM IN AGRICULTURE AND FARMERS' BOUNDED RATIONALITY

Due to the inherent uncertainties involved, the types of genetically coded information that will be required, the time they will be required and the frequency of the need are all future unknowns at a point in time. This is mainly attributed to the impossibility of predicting the types of agricultural production problems that need to be addressed in the future. This has profound implications for agricultural research, that is, the stability of the impacts and desirable attributes of genetic technologies and the diversity of the technology portfolio will have to get priority to have a better chance to address the unknown problem in the future.

Typically, the future demand for agrobiodiversity for breeding is unpredictable to the extent that future agricultural problems that breeders need to address are unpredictable. This ignorance on the future possible outcomes forces decision makers to broaden the diversity so that there will be a better chance to get genetic, cultural and indigenous knowledge to address the problem. Because of the aforementioned inherent uncertainties in agricultural production, there is always a need to maintain agrobiodiversity of future potential agricultural value. Moreover, the pre-cautionary principle would make this need imperative.

There is also information problem for decision makers responsible for making resource allocation decisions for agrobiodiversity conservation. Lack of policy-relevant information on the benefits of conserving and the costs of losing agrobiodiversity is always an important gap negatively affecting the incentives of decision makers to invest in agrobiodiversity conservation and utilization. This problem is further exacerbated by the lack of information on the opportunity cost of investing in agrobiodiversity and the possible conflict with rural poverty. The conflict with poverty emanates to the extent that adopting improved technologies (like improved varieties) reduces both poverty and agrobiodiversity.

All these different facets of the information problem in agriculture affect farmers' and policy decision makers' rational decision making. Rationality issues are confounded with information issues (Conlisk, 1996). In neoclassical economics, being rational means being able to maximize one's utility (Tsang, 2008). Accordingly, optimization behaviour is often enforced with the expectation that there is perfect information (Arthur, 1994). Those decision makers operating in neoclassical world, unbounded rational decision makers, are not constrained by information as they are assumed to have perfect knowledge of their possibility sets (choices) and the respective outcomes. However, in reality, perfect rational decision is rarely the possibility. Farmers and other decision makers have to make decisions with imperfect information or no information at all.

The theory of bounded rationality recognizes the limitations of humans to fully comprehend the fundamental complexity of the environment due to ambiguity and uncertainty (Jones, 1999). As bounded rational actors, farmers' logical apparatus ceases to cope (Simon, 1957). Originally, it is Simon (1957) who suggested that humans are boundedly rational. Accordingly, boundedly rational agents experience limits in formulating and solving complex problems and in processing information. Bounded rationality is a central theme in behavioural economics. It recognizes that even if information is available, it is still impossible to comprehend and analyze all of the potentially relevant information in making decisions due to cognitively limited capacity of human beings (Douma and Schreuder, 1992; Arthur, 1994; Conlisk, 1996).

As such, bounded rationality is a response to the failure of perfect optimality. Economic behaviour is predictable in large part because bounded rationality leads people to adopt rules of thumb; such decision making behaviour due to the information constraint is called optimal imperfection (Conlisk, 1996). For all the aforestated reasons, farmers often exercise optimal imperfection. When decision makers have information problem, they will have to choose among a set of alternative actions the consequences of which are uncertain (Arrow, 1984). In such environments, behaviour is a function of goals and processing limits but the decision maker is intendedly rational, that is, goal-oriented and adaptive subject to resource limits (Jones, 1999).

Productivity and profitability are not often the prime objectives of smallholder farmers operating in marginal environments. Such farmers give more importance to risk, yield stability and environmental adaptability than profit maximization. They fail to benefit from optimization and specialization not because they do not want to maximize profit but because they are not operating in a world of unbounded rationality. Smallholder farmers in developing countries as decision makers are rational victims of imperfect information (Conlisk, 1996).

There is information problem for farmers both on the attributes of the decision making variables (for example, crops, varieties, breeds, etc.) and the respective outcomes (for example, yield, yield stability, environmental adaptability etc.). The ignorance of the farmer about the options and the possible consequences is the key information problem (Arrow, 1974). Lack of information to support decisions on the types and quantities of crops / varieties / seeds / breeds and the consequences of their decisions will force farmers to depend on imperfect information.

Due to the inherent information problem in agricultural production and farmers' bounded rationality, they do not / can not always take one 'best' crop or variety. Instead, they often end up growing multiple "sub-optimal" set of crops / varieties. Farmers value managing a portfolio of crop varieties on-farm to get the flexibility to cope with the uncertain environmental outcomes to their best advantage. They are prepared to pay the opportunity costs of doing so in terms of lost revenues. Agrobiodiversity will continue to be maintained on-farm *de facto* to the extent that it serves as a private insurance against the aforementioned potential agricultural risks to happen at any point in time.

Lack of information creates uncertainty that, in turn, forces farmers not to optimize or maximize but to satisfice (Simon, 1957; Conlisk, 1996). Many economic processes under such circumstance are best viewed as imperfectly predictable evolutionary processes (Tisdell, 1996). Satisficing behaviour is the strategy that farmers follow in managing agrobiodiversity.

Information is a commodity (Arrow, 1984). It costs money and time. In a world in which farmers and decision makers know everything, the economics of information would have no place (Douma and Schreuder, 1992). To the extent that we recognize and value the costs of gathering and processing information, there is a need to recognize the role of agrobiodiversity in addressing the information problem in agriculture. One of the utilities of agrobiodiversity to farmers and the nation at large is to avoid the costs of information gathering and managing. Agrobiodiversity makes farmers' life easier by offering them a portfolio of traditional varieties with different attributes in terms of addressing their information-related agricultural problems.

The information problem in agriculture and farmers' bounded rationality would require the supply of agrobiodiversity information in response to a changing environment (agro-ecological, climatic and technological). Agrobiodiversity serves not only local farmers and agroecosystems; it is also an input to R&D in the agricultural breeding industry. The quantity of information supplied would, in turn, depend on the willingness of nations to invest in the different conservation strategies. The utility of agrobiodiversity, as a stock (maintained *ex-situ*) and flow (maintained *in-situ*) of information, cannot be overstated as agricultural problems and environmental changes are always evolving. That is why information is an important concept for understanding the role of agrobiodiversity in agriculture (Swanson and Göschl, 2000). The following section further explains as to how different agrobiodiversity conservation strategies address different facets of the information problem in agriculture.

HOW DO CONSERVATION STRATEGIES ADDRESS THE INFORMATION PROBLEM?

Ex-situ strategies

Starting with the ground breaking collection activities of N.I. Vavilov, until recently, most agrobiodiversity conservation efforts have focused on *ex-situ* strategies. The following two are the most common types:

i) Cold room gene banks, also called suspended *ex-situ* (Soulé, 1991), include seed banks, tissue culture collections, and cryo-preserved collections. How does it address the information problem? Suspended *ex-situ* aims to address future foreseeable problems using the genetic information contained in the currently existing stock. There, however, will be a mismatch between the problem and the way it is to be addressed to the extent that the static genetic information (information A) is irrelevant to the dynamic agricultural problems.

ii) The second *ex-situ* strategies are living *ex-situ*. These are programs that involve maintaining traditional varieties using botanical gardens, experimental fields, field gene banks and so on. They are often established in agro-ecologically representative fields. Compared to cold room gene banks, living *ex-situ* strategies are more dynamic and connected to nature but still miss the human element compared to *in-situ* strategies, that is, they fail to maintain indigenous knowledge, the dynamics of culture, and human values. They produce information B. These strategies address the inherent information problem in agriculture better than cold room gene banks, to the extent that the strategies can result in agrobiodiversity information outcomes that are dynamic enough to respond to dynamic agricultural problems.

***In-situ* strategies**

According to the Convention on Biological Diversity, the fundamental requirement for the conservation of biological diversity is the *in-situ* conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural surroundings (Ibisch et al., 2010). *In-situ* conservation strategies, which produce information C, aim to support farmers' livelihoods, minimize the welfare loss they face when engaged in conservation, and ensure the continuous existence of traditional varieties of crops.

In-situ activities are of recent innovations in many developing countries and they are of limited nature in both coverage and scope. Only a small number of countries (such as Ethiopia, Nepal, Turkey, and Vietnam) have active *in-situ* conservation programmes (Heywood and Dulloo, 2005). In the investment decision in *in-situ* strategies, the evolution under the natural environment is an important factor. The faster the evolution, the more appealing will be *in-situ* conservation because then there will be enough difference between the stock and the flow to justify *in-situ* investment costs. In this regard, it can be concluded that climate and technological changes make *in-situ* conservation more appealing. *In-situ* approaches are more attractive in circumstances where they are likely to have minimal impacts on the profitability of modern agricultural activities (Bardsley, 2007).

On-farm conservation

On-farm conservation, a sub-set of *in-situ*, refers to the use and management of traditional varieties of crops on farmers' fields. Farming itself is the original method of conservation linked with utilization (Engels and Wood, 1999). The history of on-farm conservation can, therefore, be traced back to the history of farming. Farmers maintain some level of agrobiodiversity *de facto* to the extent that it addresses their private livelihood concerns such as risk reduction, yield stability, environmental adaptability, and seed security.

Culture, religion and indigenous knowledge play important role in the *de facto* production of agrobiodiversity by farmers. For instance, the status of rice traditional diversity in Nepal is determined based on farmers' preferences, cultural practices and religious values (Pant and Ramisch, 2010). A case study from Himalaya (India) shows that the use of agrobiodiversity also maintains socio-cultural traditions and local identities (Nautiyal et al., 2008). Nazarea (2005) has shown the link between the geographic origins of diverse domestic food types from diverse crop varieties and their development in various cultures. Indigenous knowledge is also a milestone in conserving agrobiodiversity (Al-Quran, 2011; Nautiyal et al., 2008).

If agrobiodiversity is left to the farmers, the *laissez-faire* equilibrium remains inefficiently low (Baumgartner and Quaas, 2010). Farmers might abandon some traditional varieties that no longer support their livelihoods. Important components of agrobiodiversity can be lost due to: agricultural intensification and monoculture, habitat loss, market globalization and climate change (Rudebjer et al., 2011). According to Nazarea (2005), industrial agribusiness and orientations of modernity perpetrate the homogenization of the global agricultural gene pool, resulting in loss of agrobiodiversity, mono-cropping, uniformity in cultivation, and ultimately becoming prone to disaster. Such a change also erodes the associated indigenous knowledge (Rudebjer et al., 2011).

Economic development policy interventions often lead to more specialisation and uniformity (Göschl and Swanson, 1996). Unless mitigating policy measures are put in place, specialization and comparative advantages in agricultural production (Fafchamps, 1992) will take-over diversification and the consequences thereof. That is why, in industrialized countries, the majority of the original agrobiodiversity is lost.

In Nepal, improved crop varieties replaced landraces on three-quarters of the land area cultivated to rice between 1960 and 2000 (Rudebjer et al., 2011). Countries as well as international organisations have to, therefore, supplement farmers' contribution *de facto*. Government-supported on-farm conservation is one means of filling this gap.

On-farm conservation was initially dismissed altogether because it was assumed that financial compensation (to farmers) was always a necessity (Love and Spaner, 2007). Moreover, at the policy level, encouraging farmers to maintain indigenous crop varieties was (and still is) considered as promoting continued rural poverty (Brush, 1992). However, on-farm conservation does not necessarily call for financial compensation and it need not promote traditional farming. Its aim is to maintain agrobiodiversity (produce information C) and at the same time enhance farmers' wellbeing. Its strategy is to engage local communities. It works through targeted group of farmers to whom government will have to create incentives (commercialisation and value adding to farmers' products, technological support, financial compensation, etc.) equivalent to the opportunity costs.

This is to reward farmers and local communities for their public contribution to sustainable agriculture (Swaminathan, 1996). If it is implemented after stratifying farming systems and targeting few farmers, the cost (compared to the benefit) will be far too small.

As the farming environment (for example, climate) and farmers' constraints change, new diseases, pests and other environmental constraints emerge. Increasing environmental risk increases farmers' dependence on agrobiodiversity (Baumgartner and Quaas, 2010). The nature of agrobiodiversity maintained by farmers is a reflection of this natural evolution. The combination of crop varieties maintained on the farm and their diversity evolve with the emergence of new and successful crop varieties and the depreciation and obsolescence of old ones. Such evolution has continued to produce agrobiodiversity on-farm over generations. This is what economists view as the flow of information (Swanson and Göschl, 2000).

So far, only fragmented and often project-based, on-farm conservation programs and initiatives, are underway. One example comes from Kenya where a program was established in 2005 by the FAO in conjunction with the Government of Kenya which worked with local communities (Rudebjer et al., 2011). Another example is the project in Ethiopia undertaken from 1995 to 2002 and supported by GEF and UNDP (Balcha and Tanto, 2008). The GEF project in Turkey is another example (De Boef, 2008).

How does on-farm conservation as a conservation strategy address the inherent information problem in agriculture? This strategy maintains, stimulates, and enhances the dynamic management of agrobiodiversity. What is conserved is not just genetic diversity but also indigenous knowledge management that goes with it (Bertuso et al., 2008). It aims to address future information problems in agriculture through information C produced in response to environmental and socio-economic changes.

Enhancing farmers' varieties

Variety enhancement involves improving the productive and income generating capacity of farmers' varieties and processing them into value-added products. Enhancing indigenous varieties can produce information C and enable farmers benefit more from their varieties. That is how it links conservation and development (Alteiri and Merrick, 1987; Hardon and Boef, 1993). A recent report by the Secretariat of the Convention on Biological Diversity emphasizes the need to integrate biodiversity and development programmes (Ibisch et al., 2010).

Recent examples that enhance the value added benefits of neglected and underutilized crops include leafy vegetables in Kenya, quinoa (an Andean grain), farro (an ancient wheat variety in Italy) and the participatory domestication of tropical fruits (such as *Dacryodes edulis*) in West Africa (Rudebjer et al., 2011). Pant and Ramisch (2010) have shown that cultural preferences in India enable farmers to get price premiums for their traditional varieties with particular aromas and grain characteristics. Such price premiums can motivate farmers to better maintain agrobiodiversity.

Enhancing farmers' varieties reduces the opportunity cost to farmers of agrobiodiversity conservation to the extent that the extra productivity and the value added benefits farmers. Due to its desirable features, it is argued here that this strategy is, perhaps, one of the most feasible strategies that can be followed in areas where local varieties are in dominant use. Building on the resilience of agrobiodiversity to survive under stress conditions and considering agro-ecological, and socio-economic factors, this strategy has to be further explored to address both development and conservation issues.

Community seed/gene banks

Community seed/gene banks (CGBs), managed by the local community, are a simple process of community agriculture designed to function as community-based seed supply networks for locally adapted crops and enhanced farmers' varieties (Feyissa, 2002). As village-level facilities and gardens, they have seed storage, market, and germplasm repository components. The banks collect and buy seeds and potentially valuable crop varieties from farmers after establishing networks to facilitate seed exchange and supply. Every member farmer gets seeds of his / her choice for planting and returns the agreed amount of seeds during harvest.

CGBs work in small quantities of seeds and target seed security of local varieties and crops (de Boef et al., 2010). Like the aforementioned two *in-situ* strategies, they link agrobiodiversity conservation and development (livelihood strategies, food security and community empowerment) (Sthapit et al., 2008). Seeds lost from one community can be recovered from other cluster of community members (Maharjan et al., 2011).

Experiences from Nepal suggest that community seed banks are reliable and effective rural institutions not only to conserve agrobiodiversity but also to strengthen local seed systems against the odds of climate adversity (Shrestha et al., 2006). In Ethiopia, for instance, through the GEF/UNDP pilot project, a network of twelve CGBs were established across the country (Tanto and Balcha, 2003; Sthapit et al., 2008). Another example comes from Western Terai of Nepal (Maharjan et al., 2011). They work through community-managed Dedhi system, a system of returning (at harvest) one and half of the

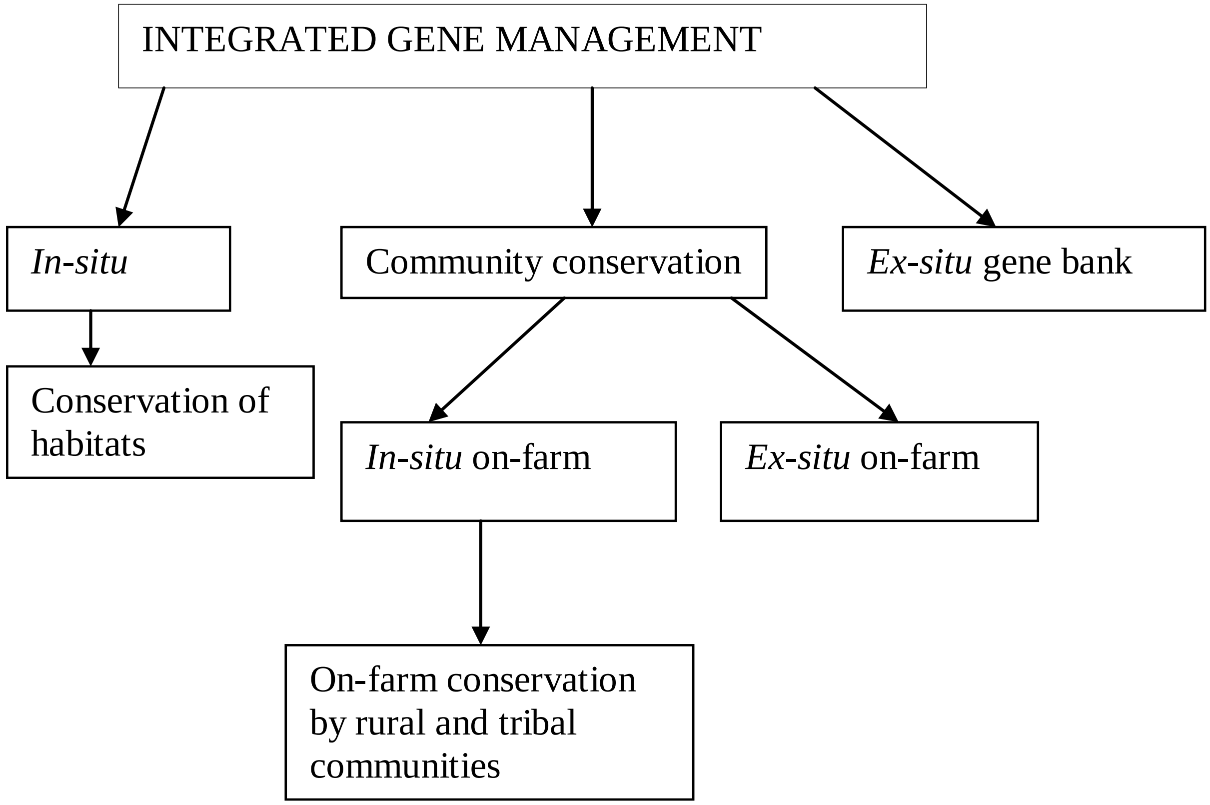

Figure 1. Conservation strategies as a continuum (Swaminathan, 2000).

quantity of seeds distributed to the farmers (during planting).

How do community seed/gene banks address the inherent information problem in agriculture? These conservation and development strategies typically produce information C and enhance agrobiodiversity exchange, seed security and local community ownership. Community seed banks play important role in marginal farming communities in terms of: sustaining livelihoods and securing local food, ensuring seed security, reducing dependence of farmers to external inputs, and conserving the rare and threatened but socio-culturally important agrobiodiversity (Maharjan et al., 2011).

Given the differences in conservation outcomes and the different aspects of the information problem in agriculture that the conservation strategies address, the following section questions the common tradition of comparing the different conservation strategies in terms of costs, benefits and (in) accessibility.

CONSERVATION STRATEGIES: ARE THEY COMPARABLE?

Soulé (1991) and Swaminathan (2000) have presented conservation strategies as a continuum. Swaminathan's presentation involves integrated gene management composed of *in-situ*, community conservation, and *ex-situ* (Figure 1).

The premise behind this approach is to avoid the 'artificial' *ex-situ* / *in-situ* dichotomy and recognize the availability of a diversity of strategies within each broad category suited to different circumstances. The optimum investment in the different combinations of strategies will depend on the extent to which each strategy:

1) Is suited to different plants / animals / genetic materials,
2) Addresses the same or different aspects of the information problem (stock and flow) in agriculture,
3) Results in mutually exclusive / complementary conservation outcomes (genetic information A, B and C), and
4) Is linked to the rest.

Conservation strategies need to take into account a complex range of factors (Rudebjer et al., 2011). To take advantage of their synergies and allocate resources among the different strategies, decision makers have to consider the features of the respective conservation strategies (Table 1).

Considering the country's resource endowment (for example, finance, technology, institutions etc.), finding the "right" mix of the various strategies will be indispensable. Even though the conservation outcomes are not completely disjoint, *ex-situ* and *in-situ* strategies will still remain imperfect substitutes (Smale et al., 2001).

Decision makers have to recognize that these strategies are serving society different purposes: conservation at a point in time (suspended *ex-situ*) and conservation over time (*in-situ* and living *ex-situ*). The strategies could result in information A, B or C. They are not alternative strategies to achieve the same objective.

Hammer et al. (2003) have distinguished ex situ, in situ and on-farm conservation strategies in terms of focus, purpose, method, institutional requirement, networking and limitations. Table 1 provides additional differences among the different conservation strategies based on author's research and drawing from the literature. Given such fundamental differences, it is not uncommon to find cost efficiency comparisons being made (Brush, 1991; Worede, 1997). According to Brush (1991), for instance, *in-situ* conservation is less expensive than *ex-situ*. Such comparisons are unwarranted as the outcomes are essentially not comparable.

While discussing the cons and pros of different conservation strategies, some authors have taken logistical and institutional issues as disadvantages of *in-situ* (Jarvis et al., 2000). However, these issues are not inherent disadvantages of *in-situ* strategies. They are rather infrastructural / institutional barriers that need to be addressed to materialize any conservation or rural development strategy.

Some studies (Love and Spaner, 2007) have taken ready availability and accessibility of conserved materials (to plant breeders) as the advantages of gene banks. However, inaccessibility is not the innate feature of gene bank conserved materials. Why would materials maintained *in-situ* not be accessible? As long as the institutional arrangements, incentives and rules are in place, accessibility and availability may not be sources of concern for *in-situ* conserved materials. Thus, making such a comparison is inaccurate.

OPPORTUNITIES AND CHALLENGES IN PURSUING THE STRATEGIES

Ex-situ conservation strategies remove the genetic material from its natural environment. The other problem with *ex-situ* strategies is that the materials have to be regenerated regularly. Stored seed is not viable indefinitely (Rice et al., 2006). Moreover, a gene bank has to regularly account for agro-ecological dynamics as it is not meant to be a museum (Hammer, 2003). However, financial resources are often limited to regularly carry out the required regenerations (Frisvold and Condon, 1998). The other most important problem is that cold room gene banks can't maintain information B and C. *In-situ* and on-farm conservation strategies are less appealing and politically controversial because they are perceived to have high opportunity costs in terms of development and there are yet no clear principles to follow. This has been noticed, for instance, in Ethiopia during stakeholders' meetings as part of Bioversity's participatory policy research project – Genetic Resources Policy Initiative. Competing vested interests of the different stakeholders clash on objectives and strategies mainly due to their failure to understand the cross-cutting nature of agrobiodiversity conservation policy. The remaining challenge is mainstreaming on-farm conservation with policies aimed at enhancing agricultural productivity.

The 'right' mix of investment in these strategies will depend on the nature of agrobiodiversity to be conserved and the country's endowments, institutions, technology, and resources available for investment. Because *ex-situ* conservation needs setting up 'artificial' conservation facilities, its modern technology demand is high, especially for seeds with special features (such as recalcitrant seeds).

While technology and finance are the most important constraints for *ex-situ* strategies, institutional development, transaction costs and incentive design will remain to be the prominent issues for *in-situ* strategies. The size of investment in each strategy has to be decided collectively considering all these factors.

To implement targeted and incentive-based on-farm conservation interventions, there is a need to: assemble reliable information on opportunity costs that farmers face when managing agrobiodiversity on-farm, identify agrobiodiversity hotspots and endangered species, and stratify farming systems based on their agro-ecological heterogeneity. The other gap is lack of understanding of farmers' attitudes and willingness to get involved in public on-farm conservation activities (Cromwell and van Oosterhout, 2000). Most *in-situ* activities are not established with full understanding of farmers' preferences, motivations, expectations, perceptions, and endowments.

Lack of experience and absence of well-established institutions and principles to align these strategies to mainstream policy are the other forefront challenges (Wood and Lenne, 1997). This is critically important to institutionalize *in-situ* conservation and make it convincing for policy makers, farmers and other stakeholders. Policy makers in agrobiodiversity conservation can draw from design economics (King, 2012) in their quest for the right institutional mechanisms for community-based conservation schemes.

Even though the complementarity of *ex-situ* and *in-situ* strategies is recognized, there are few examples of projects / programs that have implemented integrated approaches (Love and Spaner, 2007). Though both conservation strategies are in the policy documents of most countries, only few employ both (Maxted et al., 1997). Establishing effective linkage among these conservation strategies is the remaining challenge (Frisvold and Condon, 1998; Demissie and Arega, 2000).

Neither *ex-situ* nor *in-situ* strategies alone will be enough (Rice et al., 2006). The weaknesses of *ex-situ*

Table 1. Discerning differences among the conservation strategies.

Criteria	*Ex-situ*	*In-situ*	On-farm
Responsibility	Mainly a public activity	Both private and public contribution	Mainly private activity but the public is also contributing to supplement
Political appeal	High	Medium	Low
Modern technology requirement	High	Low	Low
Local community engagement and human influence	Low	Medium	High
Connection to farmers' livelihoods	Low	Medium	High
Link to nature	Low	High	High
Conservation outcome	Agrobiodiversity – only the genes	Agrobiodiversity in its entirety – indigenous knowledge, culture and human values	Agrobiodiversity in its entirety – indigenous knowledge, culture and human values
The contribution of the strategy to the information problem	Information A and B	Information C	Information C

Source: Own compilation.

strategies are often the strengths of *in-situ* and vice versa. As the conservation outcomes, their institutional/technology demands, and livelihood impacts are different, presenting them as a choice is as misleading as comparing their costs, benefits and (in) accessibility. There is little doubt that in situ and ex situ approaches are complements rather than substitutes, but they are too frequently discussed as competing alternatives (Wright, 1997).

The participatory policy research undertaken under the auspices of GRPI, where the author was involved as an economist, suggests that payments for farmers engaged in *in-situ* conservation have not been well received by policy makers. However, considering the public benefits of agrobiodiversity conservation as environmental services, farmers have to get rewards for engaging in *in-situ* and on-farm conservation (Rudebjer et al., 2011).

Provision of ecosystem services in agro-ecosystem (Hajjar et al., 2008; Baumgartner and Quaas, 2010) is one important contribution of agrobiodiversity that has not received adequate attention. Pascual et al. (2011) and Narloch et al. (2011) have proposed voluntary reward mechanisms called payment for agrobiodiversity conservation services (PACS). This proposal is timely and justified as agrobiodiversity conservation benefits society at large well beyond the boundary of the farm. It is immoral to expect farmers to contribute to a public good at the expense of their livelihoods. It is also the recognition of agrobiodiversity to address the information problem in agriculture (MEA, 2005; emphasis added). The Swiss government, for instance, has supported multifunctionality of agriculture by providing direct payments for more ecologically sustainable practices (Lehmann and Stucki, 1996).

Modern and traditional agriculture differ in various ways: risk, market access, nature dependence, resilience to environmental shocks, focus on profit maximization, diversification or risk, sustainability outcomes (agrobiodiversity versus monoculture; standardization or specialization versus diversification; scientific versus indigenous knowledge), external input requirements and so on. Such differences have important implications for farmers' incentives to manage agrobiodiversity. They are by and large the reasons why most of the remaining agrobiodiversity is found in the developing world.

The role of agrobiodiversity to agriculture and farmers' incentives to maintain it are more important for traditional agriculture and marginal environments. For instance, the value of agrobiodiversity to alleviate risk within a marginal agricultural community in Nepal is found to be substantially greater than in Turkey, where, again, it is much greater than in Switzerland (Bardsley, 2007). In socio-ecologically fragile and vulnerable environments, agrobiodiversity provides farmers with greater agroecosystem resilience and natural insurance to reduce vulnerability (Jackson et al., 2007; Rudebjer et al., 2011; Pascual et al., 2011).

Increasing crop diversity is very useful in pest and disease management (Hajjar et al., 2008). Moreover, empirical evidence is emerging which shows that higher level of agrobiodiversity is associated with a decrease in yield variance (Di Falco and Perrings, 2003; Di Falco et al., 2007). Future agrobiodiversity conservation strategies have to not only address these challenges but also take advantage of the emerging opportunities.

CONCLUSIONS AND IMPLICATIONS

The purpose of this paper has been to show how agrobiodiversity addresses the inherent information problem that agriculture faces and present the issues, challenges and policy questions in implementing rural development strategies without compromising on agrobiodiversity. It has been shown that the different agrobiodiversity outcomes of *in-situ* and *ex-situ* strategies address the different aspects of the information problem in agriculture and farmers' bounded rationality. The paper identifies the relevant policy issues (strategic investment, conservation outcomes, institution development, and opportunity costs) related to various agrobiodiversity conservation strategies.

The problem of 'optimal' mix of agrobiodiversity conservation strategies requires the 'optimal' use of agrobiodiversity information (A, B and C) within the context of a changing agro-ecologic and socio-economic environment. While *in-situ* and living *ex-situ* strategies are meant to address the optimal appropriation and use of the flow of information (B and C), suspended *ex-situ* is meant to target the appropriation and use of existing stock (information A). That is how these strategies attend to the different aspects of the information problem in agriculture.

The paper has questioned comparisons commonly made among the different conservation strategies (for instance, in terms of costs, benefits, and (in)accessibility). Comparing these strategies on cost basis, which has been a common practice in the literature, is assuming that the conservation outcomes are the same which is not the case.

Since *in-situ* and *ex-situ* agrobiodiversity conservation strategies attend to the different aspects of the information problem in agriculture, presenting them as a choice is as misleading. The policy objective has to rather be to invest in a continuum of conservation strategies and take advantage of the areas of potential cost savings in implementing the strategies.

It is imperative to recognize their differences in terms of conservation outcomes, institutional/technology demands, and livelihood impacts in making investment decisions. Decision makers and stakeholders have to recognize that *ex-situ* and *in-situ* strategies are neither substitutes nor mutually exclusive in outcomes.

Establishing the necessary link among the conservation strategies, ensuring supportive and non-redundant outcomes, and coordination of the efforts is the daunting task ahead for sustainable agriculture.

The size of investment in each conservation strategy to be decided collectively depends on the type of genetic materials to be maintained, the nature of the conservation outcomes, the level of *de facto* conservation by farmers, the prevailing institutions, the opportunity costs encountered, and resource/technology endowment. While technology and finance are the most important constraints for *ex-situ*, institutional development, transaction costs, opportunity costs and incentives are the important issues for *in-situ* strategies.

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