Valuation of Plant Genetic Resources

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Plant genetic resources refers to the biological diversity of crops and their wild relatives, encompassing both phenotypic and genotypic variation, including cultivars or varieties recognised as agro-morphologically distinct by farmers and genetically distinct by crop improvement scientists. The value of plant genetic resources is as per the people who depend on it. However, as the costs of conservation mount, it seems to be true that every conservation action needs to be supported with argument that shows tangible and measureable benefits from such action to get the funding needed. In this paper the value of plant genetic resources is briefly discussed, along with the cost of plant genetic resources conserved in genebanks and on farms. This is followed by brief review of literature on economic valuation of plant genetic resources/biodiversity and some issues in such valuation efforts. Some studies on valuation plant genetic resources from different perspectives are discussed. The paper is concluded with a question as to the need for economic valuation of plant genetic resources on which it is difficult to place a value.

Key Words: Biodiversity, Direct use value, Economic valuation, Farmers' perspective, Genebanks, Indirect use value, Plant genetic resources, Uncertainty value

Introduction

Agricultural biodiversity refers to all diversity within and among domesticated crop, tree, aquatic, and livestock systems. Plant genetic resources (PGR) that is the focus of this paper refers to the biological diversity of crops and their wild relatives, encompassing both phenotypic and genotypic variation, including cultivars or varieties recognised as agro-morphologically distinct by farmers and/or genetically distinct by crop improvement scientists.

"Beauty is in the eye of the beholder"– and the value of PGR is as per the people who depend on it. However, as the costs of conservation mount, every conservation action needs to be supported with argument that shows tangible and measureable benefits from such an action to get the funding needed. The genetic variation present in plants has always been considered very valuable and it has been presumed that this natural resource will be available for all time to come to be used by humans. However, it is now realised that the genetic variation present in the centres of diversity could be lost if it is not properly cared for. The problem became pressing with the increased agricultural development required by the rapidly increasing population. This had a profound impact on traditional agriculture, including traditional cultivars. Many factors, natural and human, resulted in the loss of traditional landraces and biodiversity in general which triggered efforts by various national and international organizations to collect and conserve plant genetic resources. The great wealth of genetic diversity still existing in plant genepools holds vast potential for current and future uses of humankind (Harlan, 1992). One end of the conservation spectrum is that the plant genetic resources are irreplaceable and it is essential that we should be concerned with their conservation, at species level, genepool level or at the ecosystem level. Genetic diversity is a natural buffer mechanism against the genetic vulnerability, which has been built into the genetic structure of traditional cultivars (Council, 1972; Anon, 1973; Brown, 1983; Chang, 1994). Countries which still have a significant amount of genetic diversity and species diversity have a responsibility unto themselves as well as to the world at large to conserve it and make it available to for use (Ramanatha Rao *et al*., 1994). At the other end of the spectrum is the argument that the costs of conservation need to be in consummate with its value and hence for providing appropriate support to conservation actions economic evaluation of biodiversity in general and PGR in particular are mooted. In this paper an attempt is made to look at various ways of valuation of PGR and the importance of such a valuation.

Why is Agro-biodiversity Important?

Plant genetic resources is an integral part of agro-ecosystems and agro-biodiversity, whose value has always been assumed, will continue to serve as a direct

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and indirect reservoir of genetic materials and knowledge, required for providing needed requirements of current and future generations of human society. Agro-ecosystems will, therefore, become a battleground where the natural aspects of biodiversity and the societal culture, including the knowledge systems associated with it, will survive or perish in the course of environmental changes and development (Sajise, 2003). In several countries, policy makers have responded to concerns over declining levels of biodiversity in general, PGR in particular and this has led to the introduction of a range of policy measures. Estimating the costs for such measures that promote conservation is relatively easy; however, it is much more difficult to estimate the benefits. Economics can help guide the design of biodiversity policy by eliciting public preferences on different attributes of biodiversity. However, this is complicated by the generally low level of awareness and understanding of what biodiversity means on the part of the general public (Christie *et al*., 2006). Since many of the estimates will be/are based on highly theoretical concepts, assumptions and perceptions, it is important to treat them as guidelines and not standards.

It is also well recognized that the great wealth of plant genetic diversity existing in genepools of economically useful plants, including their wild relatives, has great potential for current and future uses for humankind. It is seen as a defence against genetic vulnerability that results from narrow genetic base, a defence against biotic and abiotic stresses, and also against changing climatic conditions and productions systems. These defence mechanisms result from either through farmers building this defence into the genetic structure of landraces or through modern crop improvement. Both these elements are important in the long run towards sustainable agriculture in spite of numerous obstacles in achieving this. At the same time, there are many examples that have demonstrated the significant benefits arising out of the efforts undertaken in the conservation of PGR and their effective use. For example, rice production in Asia increased by 42% from 1968 to 1981 following the use of high yielding and short duration cultivars derived from genebank collections. The increase was about 110 million tons in one year. At the price of USD 250 per ton, profit of USD 27,500 million per year was generated while the money used for the conservation of rice genetic resources worldwide was estimated to be less than USD 2 million per year. A conservative estimate is that 50% of the profit is due to rice improvement based on the use of rice genetic resources derived from rice genebanks (see Evenson *et al*., 1998). Another example is the hybrid pigeon pea called ICPH 8 developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). This pigeon pea, which requires only 100 days to mature, increases yield by 30 to 40% and can be cultivated under a wide range of conditions. The shorter maturation period required by ICPH 8 meant savings of up to USD 100 million a year to growers as ICPH 8 is resistant to serious damage by fungal and viral diseases (Ramanatha Rao *et al*., 1997). In the seed industry, 6.5% of all genetic research which resulted in a marketed innovation was concerned with germplasm from wild species and landraces compared with only 2.2% emanating from technological approaches of induced mutation (Sajise, 2003). A one-time, permanent yield increase from genetic improvements for five major U.S. crops has generated an estimated $8.1-billion gain in economic welfare worldwide (Rubenstein, 2005). Thus, what plants used on the agro-ecosystems impact on the value of goods produced in these systems and impact on livelihoods of all those that are dependent on them (Ramanatha Rao, 2009).

Cost of Plant Genetic Resources Conserved in Genebanks and on Farms

Before going into the question of value of PGR, it may be necessary to look into the cost of conservation. In contrast to the fairly extensive research into the values and benefits of biodiversity and its conservation in general (*e.g.* Pearce *et al*., 1991; Munasinghe and Lutz, 1993; Pearce and Moran, 1994; von Braun, 1994), the costs of PGR conservation have received much less attention (Virchow, 1999). Although, it was estimated that approximately US $ 740 million were spent 1995 in national and multi-lateral activities for the conservation and utilisation of PGRFA (ITCPGR, 1996) (current figures are not known), there is no price for the acquisition of accessions. Although, some genebanks have started charging for the supply of accessions that they conserve, in general, accessions in *ex situ* storage are more or less freely available, with some sort of agreements, to *bona fide* users upon request; only the quarantine and transportation costs are charged occasionally. Access restrictions are being introduced by charging a fee for each requested accession or limiting the access to the whole collection, under the facilitated accesses agreement of the Convention on Biological Diversity. Although, there is not yet a price fixed for PGR, the above mentioned existing expenditures for conservation urge a closer theoretical analysis of the costs and distribution among the players. To identify all involved conservation costs, it is necessary to differentiate the costs from *in situ* and *ex situ* conservation on the farmer level, the national and international levels as well as on the level of the private sector. Very few genebanks have attempted to estimate costs of *ex situ* conservation (Gupta *et al*., 2002) and still fewer efforts have been made on *in situ* conservation (Wale, 2011).

For the purposes of estimating cost of *ex situ* conservation activities may differentiated into: acquisition costs, including the tasks of surveying, inventorying, collecting, and shipping to the genebank as well as multiplication, characterization and the first evaluation of the collected material at the genebank; maintenance costs, including conservation preparations, running-costs and the germination control and regeneration; processing costs, including information record and multiplication costs; and costs for supporting activities, *e.g.* institution and capacity building and the creation of institutional legal frameworks (Virchow, 1999). The cost of conservation is highly crop- and location-specific; therefore, it is imperative to calculate it for estimating the capital required for conserving the germplasm in a given region. Such studies also draw attention towards the critical components, for efficient conservation and would also lead to guide the future conservation strategies as well as in formulating cost-effective approaches. The estimation of cost of conservation helps the International Communities to allocate the appropriate financial assistance to the country for conserving its genetic resources (Gupta *et al*. 2002). Gupta *et al*. (2002), however, indicate several limitations of such estimations. Some limitations include the complex and inter-linked nature of genebank activities and use activities; characterization and evaluation based on local/traditional knowledge; changing conservation technologies associated costs; cost of sharing data with donors and users.

Farmers, especially in many developing countries, maintain traditional crop cultivars and, thus, are often referred to as the custodians of landrace genetic diversity; although some may argue that the custodianship may be a product of production practices. Since such management of on-farm diversity is directly related to their livelihood actions, most farmers maintain them only to the extent that landraces support their livelihood (generate private benefits) and address household concerns. By growing traditional varieties of crops for private benefit reasons, farmers contribute to society. This is sometimes coined as '*de facto* conservation' (Meng, 1997). Although, mainly resource-poor farmers are maintaining PGRFA *in situ* and are not compensated for their work, countries are carrying most of the costs of PGRFA conservation. Without greater international incentives to maintain such biodiversity, countries, especially diversity rich but capacity poor countries, will see little reason for retaining this diversity. International mechanisms and instruments are needed to recompensate national conservation systems for the cost involved maintaining PGRFA. Furthermore, it should be national responsibility to foster the agricultural production increase, especially in marginalised areas, and, simultaneously, to target the *in situ* conservation through an objectives-oriented approach. The combination of production increase by transforming land to high-potential area and a qualitative high, but quantitative low *in situ* conservation is needed to guarantee a sustainable agricultural development (Virchow, 1999). Wale (2011) attempted to estimate on-farm conservation costs based on household-level financial opportunity costs which, in turn, are estimated using sorghum and wheat household survey data from Ethiopia. The results suggest that opportunity costs need to be responsive to agricultural development opportunities, crop types and farmers' characteristics which will all affect the national level conservation costs. Farmers have to be contextually targeted (for on-farm conservation) and treated based on their attribute profiles. Different levels and types of compensation schemes might be required for different groups. Institutionalizing on-farm conservation and optimizing costs calls for fulfilling farmers' expectations based on the opportunity costs they forego (Wale, 2011). On-farm conservation is an important component of the global strategy to conserve crop genetic resources, though the structure of costs and benefits from on-farm conservation differ from those associated with *ex situ* conservation in genebanks. A fundamental problem that affects the design of policies to encourage on-farm conservation is that crop genetic diversity is an impure public good, meaning that it has both private and public economic attributes (Smale *et al*., 2004).

The available information suggests that in most cases the costs of conservation are little understood. The costs of running conservation organizations/agencies may be estimated from their annual budgets, but it may not give a correct picture as such budgets may include several collateral costs that may be unrelated to conservation efforts. In addition, actual *in situ*/on-farm conservation programmes/projects in many countries may be *ad hoc* and may not be institutionalized. Thus, estimating costs of *in situ* conservation of PGR may be very difficult, if not impossible. A better understanding of costs of conservation is necessary to better strategize conservation efforts and may even be important in valuation of PGR, if such valuation is considered necessary for developing policies that cover conservation efforts. In addition, a poor understanding of cost of conservation of PGR can contribute to certain sections of society for looking at PGR purely in terms of their present economic returns.

Value of Plant Genetic Resources

The value of genetic diversity, in its various forms (*i.e.* tangible, intangible etc.), has been extensively discussed in literature (Pearce and Moran, 1994; Brush and Meng, 1998; Evenson *et al.*, 1998; Gollin and Evenson, 1998; Rao and Evenson, 1998; Simpson and Sedjo, 1998; Smale, 2006; Swanson, 1998, Rausser and Small, 2011). Methods employed to estimate value of biodiversity may include one or a combination of various econometric methods that may include: 1. willingness to pay for on-farm diversity; 2. contingent valuation measure; 3. hedonic pricing; 4. other hedonic approaches; 5. option values; and 6. production losses averted. However, the economic valuation of many aspects of agricultural biodiversity remains problematic as these not only have direct value in terms of food and nutrition, but also have indirect uses which include adaptation to low input conditions, co-adaptive complexes, yield stability (reduction of risk), aesthetic value and meeting religious and socio-cultural needs. For crop varieties, three different types of value are distinguished: direct, indirect and option value (Brown, 1990; Brush, 2000; OECD, 2002; Swanson, 1996). Direct or use value is the simplest and most obvious one that refers to the harvest and uses of crop varieties by farmers (Smale *et al*., 2004). Indirect value refers to the environmental services or ecological health the crop varieties contribute to, but which farmers may not observe or notice (Hajjar *et al.*, 2007). Option value refers to the future use of crop varieties (Krutilla, 1967). From the farmers' perspective, the latter two values of crop varieties are secondary, whereas for conservationists the option value is of paramount importance. Nunes and van den Bergh (2001) evaluated the notion and application of economic theories and monetary valuation of biodiversity and concluded that most available economic value estimates only provided incomplete picture. See Drucker *et al*. (2005) for an exhaustive review of literature.

In general terms, agricultural biodiversity provides many goods and services of environmental, economic, social and cultural importance; these environmental goods and services also contribute to sustainable livelihoods in a number of ways (Cromwell *et al*., 2001). The economic value of such goods and services is not well captured by market prices because they are not traded (Brown, 1990) but are valued by local communities often in marginal areas where markets are weak or not present (Smale, 2006). A number studies have been underway to determine the economic bases of farmers' decisions and benefits when using local crop varieties (Smale *et al*., 2004). These studies provide a more concrete understanding of the public and private values that farmers' crop varieties embody. They are: (1) 'private' values in the harvest the farmer enjoys, either directly as food or feed, or indirectly through the cash obtained by selling the produce and purchasing other items; and (2) 'public' values in its contribution to the genetic diversity from which future generations of farmers and consumers will also benefit. The genetic diversity attributes of crop diversity are not fully captured by markets (Brown, 1990) and generally require public investments to provide farmers enough economic incentives to continue growing them. Economic value is important, however, this can be highly contextual and there have to be trade-offs, and the value system varies within the local context and culture (Sthapit *et al*., 2008). Thus, an understanding local culture is essential to visualize the value of PGR and may be difficult or even unethical to look at their value purely in economic terms. However, in these days when every aspect of human activity is measured in terms of economics, it may be difficult to stay away from the questions with regard to economic value of PGR.

Plant genetic resources or agricultural biodiversity in general provides goods with: (1) option value (Brush *et al*., 1992; Rao & Evenson, 1998); (2) direct use value (Johns & Sthapit, 2004); and (3) exploration value (Wilson, 1988; Rausser and Small, 2011). Another classification includes use value, their option value, and their intrinsic value (Dasgupta, 2001).The services offered by agricultural biodiversity can also be categorized into three values: (1) option value (Swanson, 1996); (2) direct use value (Smale, 2006); and (3) indirect use value (Hajjar *et al.*, 2007). (see Table 1). However, it is important to note that any discussion, despite various pressures to put a value on PGR must be tempered taking into account the intrinsic value of biodiversity for local livelihoods and the multiple benefits generated from its use (Table 2). Agricultural ecosystems are completely managed by

Table 1. Goods and services provided by plant genetic resources

Goods	Option value	Adaptive traits	
		Mass selection Parents for breeding Sources of resistance to biotic and abiotic stresses	
		Food	Wild Uncultivated Cultivated
		Nutrition	Wild Uncultivated Cultivated
	Direct use value	Other Utilities	Medicines Timber Energy Utensils/equipment Fodder Natural dyes
	Exploration value (bioprospecting)	Pharmaceuticals Industrial products	
Services	Option value	Portfolio value Exploration value	Use of multiple species/varieties to manage risk Alternate energy
	Direct use value	Dietary diversity Food habits and preferences Religious and research needs Aesthetic value Recreation/agrotourism	
	Indirect use value*	Ecosystem services	Soil retention Pollination Pest management Regulation of natural predators Nutrient recycling
		Carbon sequestration Hydrologic regimes Shade and shelter Nitrogen fixation	

*Note: Indirect value of plant genetic resources is its contribution as a part of larger agricultural biodiversity in given system and realization of these services would depend on how much 'volume' it occupies in a system.

humans and are reported provide services food, fibre, and fuel as per the Millennium Ecosystem Assessment. Provision of these services depends on supporting and regulating services as inputs to production (*e.g.*, soil fertility and pollination, etc.). Agriculture also receives ecosystem disservices that reduce productivity or increase production costs for example, herbivory and competition for water and nutrients by undesired species (Zhang *et al*. 2007). Hence, it is important take into account the how adequately the agricultural ecosystems are managed and upon the diversity, composition, and functioning of remaining natural ecosystems in the landscape. Managing agricultural landscapes to provide sufficient supporting and regulating ecosystem services and fewer disservices will require research that is policy-relevant, multi-disciplinary and collaborative. Some of the agricultural ecosystem disservices include: habitat loss, nutrient run-off, pesticide poisoning of non-target species etc. Zhang *et al*. (2007) discussed how ecosystem services contribute to agricultural productivity and how ecosystem disservices detract from it. They describe the major services and disservices as well as their key mediators and discuss outstanding issues in regard to improving the management of ecosystem services and disservices to agriculture.

Table 2. Plant species and species useful to humans

Use/classification	Plant species
Total number of described species	250,000
Edible species	30,000
Cultivated species	7,000
Species important on national scale	120
Making up 90% of world's calories	30

Source: FAO, State of the World's Plant Genetic Resources for Food and Agriculture (1997)

Studies on Valuation of PGR

Farmers' Perspective

There has been very little economics research carried out to understand the value of rapidly eroding local cultivars/ landraces to the farmers who grow them. This is partly because such varieties are typically found in marginal, isolated environments, where they are traded outside of formal markets (Smale and King, 2005). In addition, economists have only recently challenged the commonly-held assumption that local varieties will inevitably be replaced by modern varieties over time (Brush *et al*., 1992; Meng, 1997).

Sthapit *et al*. (2008) discussed three case studies from Nepal and Vietnam in three typical livelihood scenarios: (1) uncultivated and wild food; (2) home gardens; and (3) diversity within species in larger ecosystems. They attempted to demonstrate the scenarios, the value of genetic diversity. They found that there was a common pattern in how farmers valued genetic diversity. The results illustrated that the rationale of managing a large number of cultivars at household levels depending on the value assigned to them based on: (1) the contribution to food security or for the market (income generation), (2) socio-cultural (traditions, religious rituals) purposes, (3) specific abiotic co-adaptive traits (such as being adapted to swamp soils, poor soils, drought), and (4) specific use values to particular families. The degree to which genetic diversity is used and valued by farmers could be measured in the proportion and size of the population planted within the fields of households in a community. These studies revealed that genetic resources are one of the few resources available to resource-poor farmers to ensure their livelihoods and income. However, economic evaluation of these in terms of actual monetary value may be untenable as such an analysis would change the perspective with which valuation exercise may be carried out.

Poudel and Johnsen (2009) carried out a study in Nepal that uses the contingent valuation method to document the economic value of crop genetic resources based on the farmers' willingness to pay for conservation. The study concluded that the rice producing farmers in Kaski district of Nepal were on average willing to pay USD 4.18 for *in situ* conservation and USD 2.20 for *ex situ* conservation of rice landraces per landrace per annum. The respondents were willing to contribute more for *in situ* than *ex situ* conservation because of the additional effect of direct use and direct involvement of the farmers in *in situ* conservation. The values obtained in this study are quantified indications of the value placed by the farming community on the crop genetic resources, specifically rice landraces. As such, they are useful for cost benefit analysis and for debate and decision-making on conservation strategies. The study may contribute to drawing the attention of the policy makers in formulation of appropriate policy mechanisms, raising public and political awareness of the importance of the issue, and helping to set conservation priorities.

Value of Agrobiodiversity in Research Development

Biodiversity prospecting, the search for valuable compounds from plants (and other organisms, mainly wild ones) has been considered as a potential source of finance for biodiversity conservation. However, it has been debated whether revenues from bioprospecting could be large enough to offset the opportunity costs of PGR conservation. Simpson *et al*. (1996) argued that the returns to holding genetic resource assets are unlikely to be large enough to create significant conservation incentives. The claim is based on a model of the research process in which firms sample without replacement from a large set of research leads, incurring a fixed cost per draw. The authors pose the question: supposing that each lead carries a fixed probability of yielding a breakthrough, how much would a private firm be willing to pay to prevent the collection of leads from becoming slightly smaller? In other words, what is the value of the marginal research opportunity, in this R&D process?

Formal analysis confirms what intuition suggests: if the original collection is sufficiently large, then one additional lead is likely either to be infertile (if the probability of success per test is very low) or redundant (if the probability of success is sufficiently high). Given that the number of species in the world is very large indeed, the expected return to the "marginal species" is likely to be vanishingly small. It will, then, exert no genuine incentive towards conservation, in the context of a market for genetic resources. Extensions to cases in which discoveries vary in quality, or in which success rates covary according to an average degree of genetic distance (Polasky and Solow, 1995), generate somewhat higher values, but do not alter the substance of this conclusion. Leads of unusual promise then command information rents, associated with their role in reducing the costs of search. When genetic materials are abundant, information rents are virtually unaffected by increases in the profitability of product discovery, and decline as technology improvements lower search costs. Numerical simulation results suggest that, under plausible conditions, the bioprospecting value of certain genetic resources could be large enough to support market-based conservation of biodiversity (Rausser and Small, 2011).

Generally the value of genetic resources for R&D is placed within the framework of discussions concerning sustainability. Sarr *et al*. (2008) assess the extent to which society is able to invest now in order to prepare for future risks and uncertainties in the arrival of biological problems and they discuss different approaches to valuation within this setting. Weitzman's approach to measurement is seen to be one that considers society's current objectives and information to be little relevant to future risks and uncertainties (Weitzman, 1998). They further note that Sedjo, Simpson and Reids' search-theoretic perspective (Simpson *et al*., 1996) is seen to reduce future uncertainties to highly tractable and known problems and that Goeschl and Swanson's biotechnological approach (Goeschl and Swanson, 2002) also constrains the problem to be one without any real uncertainty, and focuses on the need to maintain genetic resources in order to maintain control over the problem. They note that Kassar and Lasserre (2004) place uncertainty at the core of the problem, and assess the extent to which additional value is added by this feature. In sum all of the approaches to the problem evince a pessimism regarding the capacity of future technological change automatically to resolve these problems. Given this, the value of genetic resources depends on beliefs concerning the ability of current objectives to anticipate future risks and uncertainties (Sarr *et al*., 2008). The question remains whose belief can be regarded as strongest and does it match with the needs of farmers whose livelihoods depend on PGR/agrobiodiversity that is being valuated.

Value of Plant Genetic Resources Based on the Use in Crop Improvement

Many genebanks around the globe conserve several thousands of germplasm accessions. One of the major weaknesses of our conservation efforts has been full characterization and evaluation of the PGR conserved and document information on the useful traits identified in particular accessions. This makes it very difficult to place a value on such PGR and begs the question– what is the expected benefit from using an additional, unimproved genebank accession in crop breeding (Zohrabian *et al*., 2003)? Typically, plant breeders can deduce little about what these accessions have to offer from the existing data describing them. Zohrabian *et al*. (2003) tried to answer this question by combining search theory with a maximum entropy approach, which is particularly suitable for analysis with sparse data. They estimated the marginal value of utilizing prebreeding materials contained in the U.S. National Plant Germplasm System. Data were drawn from trials to screen 573 recently acquired accessions that test for susceptibility to soybean cyst nematode. The present discounted value of benefit streams in the United States was estimated with areas planted to soybean and its prices. The present value of the expected gross research benefits is estimated at about $36,000 to $61,000, which implies that the benefit-cost ratio for investing in an additional accession to prevent losses from a single pest is in the range of 36 to 61. The size of benefits is sensitive to changes in area planted to the crop and to the discount rate because of the time lag between investment in the research and the stream of earnings. The magnitude is also affected by the economic value of the crop, the severity of damage caused by the disease, and the likelihood of future outbreaks requiring a new search. The findings of this study indicate that the lower-bound benefits from utilizing a marginal accession are higher than the upper-bound costs of acquiring and conserving it, justifying the expansion of the U.S. soybean collection.

A single wild relative of the tomato contributed genetic resources that increased the solids content of processing tomatoes by 2.4%. This has been worth US$ 250 million a year in the state of California alone, because it reduces energy needs in processing (Stolton *et al*., 2006). Three different wild peanuts have been used to breed commercial varieties resistant to root knot nematodes. It is helping to save peanut growers around the world an estimated $100 million a year *(http://www.unep.org/documents.multilingual/default.asp?DocumentID=399&ArticleID=4542&l=en).*

As one of the use values, genetic diversity available to us in PGR has economic value related to the potential benefits it can bring through the breeding of new varieties of global crops. Through crop improvement programmes (of which plant breeding is an essential component) useful genetic traits can be incorporated into existing plant cultivars, for instance in order to increase yields, improve the quality of the crop, or breed disease resistance. Plant breeding based on traits derived from crop wild relatives is quite common for most global crops, and makes an important contribution to increasing global welfare (Morris and Heisey, 2003). As noted earlier, the economic value of genetic diversity is widely recognized, however, there are relatively few experiences with the actual valuation of PGR. Hein and Gatzweiler (2006) carried out an analysis of the economic value of *Coffea arabica* genetic resources contained in highland forests of Ethiopia. The valuation was based on an assessment of the potential benefits and costs of the use of *C. arabica* genetic information in breeding programmes for improved coffee cultivars. The method is based on the assumption that the value of coffee genetic information equals the benefits that can be obtained from applying this information in a breeding programme. The study considered the breeding for three types of improved cultivars: increased pest and disease resistance, low caffeine content and increased yields. Costs and benefits are compared for a 30 years discounting period, and result in a net present value of coffee genetic resources of 1458 and 420 million US$, at discount rates of 5% and 10%, respectively. The value estimate is prone to considerable uncertainty, with major sources of uncertainty being the length of breeding programmes required to transfer valuable genetic information into new coffee cultivars, and the potential adoption rate of such enhanced cultivars. Nevertheless, the study demonstrated the high economic value of genetic resources, and it underlines the need for urgent action to halt the currently ongoing, rapid deforestation of Ethiopian highland forests.

More examples of PGR contribution to crop improvement in crops like wheat, maize etc can be found in Hoisington *et al*. (1999). Also see Box in Esquinas-Alcázar (2005) and Evenson *et al*., 1998).

Value of Plant Genetic Resources Conserved in Genebanks

Broadly speaking, PGR can be conserved *ex situ* (out of their place of origin) by any one of several technical means, or managed *in situ* (in their place of origin), on farms or in wild reserves. Economics is a utilitarian discipline focusing on human society rather than biological systems. The economic value of PGR, therefore, derives from human use, although human use can refer not only to food, fibre, and medicinal production but also to aesthetic, ecosystem, and social-support functions (Brown, 1991).

The theory of valuing and managing PGRs is reasonably well understood and has been surveyed before. These genetic resources are an impure public good, and markets typically do not give the right incentives for conservation to the farmers, herders, hunters, and gatherers whose actions may have a large impact on the conservation of species, landraces, breeds, and varieties. There is thus *prima facie* support for public actions that promote conservation (Gollin and Evenson, 2003). Simpson *et al*. (1996) show that the marginal value of large collections gets very small, because if a trait is common, a marginal accession will seldom be useful, and if it is rare, it will be difficult to collect. However, this can change with any chance discovery within genebank accessions which can make the value of conserved accessions soar.

With the progress that is being made in molecular biology and molecular tools that are becoming available, in the future, collections may be screened for the presence of new alleles at a given locus (Graner *et al*., 2004)). These alleles could later be assayed for their functional value. This approach would require the prediction of a gene's phenotype from its DNA sequence, a capacity that is still to be reached. However, recent advances in the analysis of linkage disequilibrium may help identify genes underlying traits of interest by association mapping (Rafalski, 2002). This approach obviates the requirement for experimental populations, and genetic studies could be performed directly on the plant material available at a genebank. The time span from identifying a target gene to its deployment in a breeding programme might be reduced, thus, further increasing the value of germplasm collections. Developing countries are not able to take advantage of the full range of biotechnology tools to harness the value of their genetic resources and efforts must be made to bridge the gap that is widening in this field of speciality.

Valuing Biodiversity – Public Perception

Determining value of biodiversity in general, of which PGR is a subset, may not tell us directly the value of PGR but they are indicative of their value in a boarder context. Even with fairly well established theoretical basis for estimating the value of biodiversity in economic terms, research efforts have yet to provide a comprehensive assessment of the value attached to the components of biological diversity such as anthropocentric measures (*e.g.* cuteness, charisma, and rarity) and ecological measures (*e.g.* keystone species and flagship species). Christie *et al*. (2006) addressed this issue of valuing the ecological and anthropocentric diversity of biological resources. Their study also stands out in that it is one of the few studies that attempt to value the diversity of biodiversity. They attempted to, rather than simply estimating the value of a biological resource such as a particular species or habitat, explored in detail values for the ecological and anthropocentric concepts that can be used to define and describe the diversity that exists within biological resources. Policy makers may benefit from information on the economic value of different actions aimed at biodiversity protection, but also on which aspects of biodiversity are most valued by taxpayers. Stated preference methods can provide both types of value estimates, but implementing these methods is difficult in this particular case since the general public has a rather low level of understanding of what biodiversity is and why it matters. In this study authors made use of a novel way of conveying information to respondents, information which is consistent with ecological understanding of what aspects of biodiversity might be considered. Authors then used choice experiments to estimate the relative values people place on these attributes, and contingent valuation to look at the value of specific policy programmes. The study concluded that the public had positive values for biodiversity, but may be indifferent as to how biodiversity is actually protected. Christie *et al*. (2006) also investigated the extent to which valuation workshop approaches to data collection could overcome some of the possible information problems associated with the valuation of complex goods, such as diversity of biodiversity. The key conclusion was that the additional opportunities for information exchange and group discussion in the workshops helped to reduce the variability of value estimates. How policy makers might choose to use such information is something that was not addressed in their study. One option could be to use economics to set overall budgets for biodiversity conservation, but ask ecologists to determine how this money could be utilized on the ground. Another option could be to use the kind of evidence presented to use more economic information in this targeting different conservation actions. Some economists might argue that, in a world of scarce resources and conflicting demands, some information on public preferences for biodiversity conservation is better than no information if society wishes to make sensible and politically-inclusive choices.

Changes in climate and environment are altering selection pressures on natural plant populations, but, it is difficult to predict the novel selection pressures to which populations will be exposed. As noted earlier, there is heavy reliance on plant genetic diversity for future crop security in agriculture and industry, but the implications of genetic diversity for natural populations receives less attention. Jumpt *et al*. (2008) examined the links between the genetic diversity of natural populations and aspects of plant performance and fitness. They argue that accumulating evidence demonstrates the future benefit or ‘option value’ of genetic diversity within natural populations when subject to anthropogenic environmental changes. Consequently, the loss of that diversity will hinder their ability to adapt to changing environments and is, therefore, of serious concern. Bosselmann *et al*. (2008) showed that the economic value of genetic diversity in forests goes beyond the risk reducing effects and includes, *e.g.* option values when several clones are mixed in the same forest stand.

Climate change is pacing new demands on agrobiodiversity and there is a need for change in conservation use efforts and attitudes towards it; along with valuing it for the future. As noted earlier, the concerns for economic evaluation place a bit too high value on their current and immediate future. Thus, a good question to ask is how these various changes will affect different *in situ* conservation efforts of landraces and wild species. Although, ecosystems have adapted to changing conditions in the past, current changes are occurring at rates not seen historically. In general, the faster the climate changes, the greater the impact on people and ecosystems. There is a significant research gap in understanding the genetic capacity to adapt to climate change (Ramanatha Rao, 2009). This appears to be corroborated by the recent fluxes in the food prices and collapsing production systems are a reminder of how rapidly climate change can affect global food markets erasing geographical boarders with a common pain: how do we feed ourselves (Havalgi, 2009)? This changing scenario may have serious implications on the methods used for the valuation of PGR. Plant breeders, farmers and food production systems, including monocultures all depend on the wide genetic base of the wild relatives to develop crops that adapt and produce well under different climatic conditions, especially when the changes are occurring dramatically and drastically as they are now. Agricultural biodiversity, however, is under severe threat due to habitat loss and environmental degradation, exacerbated by climate change, leading to significant loss of these critical genetic resources, threatening global food security. Placing further stress on it through funding restrictions due to improperly estimated value and inflated costs of conservation can further impede the conservation efforts. The use and conservation of agrobiodiversity is the central means in assuring adaptation of humanity to climate change challenges and to provide global food security. Agricultural trading policies, systems and organizations are critical in providing means to trade, recognize and reward farmers working as stewards of agricultural biodiversity. For farmers, policy makers and governments to realize the critical role of agrobiodiversity in climate change, and for paving a path for use of agrobiodiversity as an essential adaptation tool; it is critical that the agrobiodiversity should wear the mantle of economic success capable of bargaining for its care-takers. This requires changes in our thinking on placing a definite value on agrobiodiversity. However, some of this problem can be overcome by putting a price on agrobiodiversity used and conserved by the farmers and designing ways for payment and trade of agroecosystem services such as control of natural enemy population, genetic source for insect, disease or drought tolerance and others. Havalgi (2009) strongly argues that farmers and farming communities must benefit and be able to trade through agrobiodiversity conservation credits for their needs without compromising on conservation goals. The role of trade and policies that govern trade are critical here. It is this role of trade in agrobiodiversity conservation that will be explored in this paper. Putting a price or value on agrobiodiversity through taxation or share-and-trade systems is a starting point. Given the urgency of early and widely covered agrobiodiversity conservation and rescue interventions, it is critical that agrobiodiversity share-trade programmes be understood and monitored carefully.

Limits of Economic Valuation of Biodiversity of Plant Genetic Resources

We have seen so far various ways to view and estimate economic value of PGR and biodiversity. The value of PGR appears to vary greatly depending on the values perspective, economic theory adapted and assumptions made. In practice, monetary valuation of biotic resources by the concept of total economic value is a powerful tool for a rational treatment of this fraction of natural capital and for its conservation. Beyond methodological limits to monetarisation with regard to its marginal character there are also moral limits. Adopting the weakest and least controversial assumptions regarding both human dependence on biodiversity and environmental ethics, one is led to the conclusion that the impossibility of communicating with future generations forbids us to value biodiversity only in monetary terms. Fairness towards future demands that we consider conservation as a constraint on economic activity (Hampicke, 1999). As noted earlier, PGR basically are irreplaceable and it is essential that we should be concerned with their conservation, at species level, genepool level or at the ecosystem level and genetic diversity is a natural defence mechanism against the genetic vulnerability, which has been built into the genetic structure of traditional cultivars. The adoption of biodiversity-based practices for agriculture, however, is partly based on the provision of ecosystem goods and services, since individual farmers typically react to the private use value of biodiversity, not the 'external' benefits of conservation that accrue to the wider society, a society that often ignores the small farmer. Evaluating the actual value associated with goods and services provided by agrobiodiversity, especially to the farmers, requires better communication between ecologists and economists, and the realization of the consequences of either overrating its value based on 'received wisdom' about potential services, or underrating it by only acknowledging its future option or quasi-option value. Partnerships between researchers, farmers, and other stakeholders to integrate ecological and socioeconomic research help evaluate ecosystem services, the tradeoffs of different management scenarios, and the potential for recognition or rewards for provision of ecosystem services (Jackson *et al*., 2007).

Genetic resources for food and agriculture are the biological basis of world food and nutrition security; and they directly or indirectly support the livelihoods of over 2.5 billion people. For resource-poor farmers, adaptive animal breeds, crop varieties and cultivars adapted to particular micro-niches, stresses or uses are the main resources available to maintain or increase production and provide a secure livelihood. During the last decade, there have been significant number of studies that attempt to estimate the economic value on PGR. However, as noted earlier it is difficult to value many other aspects of agricultural biodiversity as these have both direct and indirect values in terms of qualitative traits such as food, nutrition and environmental uses that include adaptation to low input conditions, co-adaptive complexes, yield stability and the consequent reduction of risk, specific niche adaptation, and in meeting socio-cultural needs. These values vary according the context and location and to outguess the value that the poor farmers place on agrobiodiversity available for their livelihoods seems to be unethical. Together, the direct and indirect values of genetic resources for resource-poor farmers are expressed in a range of options in the form of the crop varieties and species they use for managing changing environments (Sthapit *et al*., 2008). Given this premise, viewing their value in purely monetary terms may not be right strategy. After all there are not strategies for the conservation of the so called high economic value items like gold, rare minerals etc. It must also be noted that the current value of agrobiodiversity estimates generally tend to be low. If when the private value of a good rises, potential owners will agitate to change property rules so that it becomes easier for them to seize the added value.

Concluding Remarks

Plant genetic resources are the raw material used by plant breeders to create improved crop cultivars. Due to socio-economic-cultural complexities involved, it is exceedingly difficult to ascribe a purely economic value to any particular PGR. While the market value of a new variety of rice or wheat is fairly easy to calculate, it is almost impossible to estimate the value of any one characteristic derived from an individual accession would always be, at best, an estimate based on several assumptions and would heavily depend on one's perspective. At the end of the debate, the question that would loom large is – what use can we put such an estimate to which may turn out to be purely and estimate with large range of plus or minus. No doubt, it can help the conservationists to argue for more funding for PGR conservation, research and use efforts. However, is it necessary to make any such argument for PGR conservation and use – on which all of our current needs for food and other needs depend? I leave it at that and for the reader to decide on the future course of action.

References

Anon (1973) Genetic vulnerability of Crops. A world wide problem of raising concern. *Agrl. Sci. Rev.* **11:** 49–55.

Bosselmann AS, JB Jacobsen, ED Kjær (2008) Climate change, uncertainty and the economic value of genetic diversity: A pilot study on methodologies. Forest & Landscape Working Papers No. 31-2008. Forest & Landscape Denmark, Hørsholm, 58p.

Brown GM (1990) Valuing genetic resources. In: GH Orians, GM Brown, WE Kunin and JE Swierzbinski (eds.) Preservation and Valuation of Biological Resources, Seattle: University of Washington Press, pp 203–226.

Brown WL (1983) Genetic diversity and genetic vulnerability an appraisal. *Econ. Bot.* **37:** 4–12.

Brush SB (2000) Genes in the Field: On-Farm Conservation of Crop Diversity. Canada: IDRC; Rome: IPGRI, pp 3–26.

Brush SB and E Meng (1998) Farmers' valuation and conservation of crop genetic resources. *GRACE* **45:** 139–150.

Brush SB, JE Taylor MR Bellon (1992) Technology adoption and biological diversity in Andean potato agriculture. *J. Dev. Econ.* **39:** 365–387.

Chang TT (1994) The biodiversity crisis in Asian crop production and remedial measures. In: CI Peng and CH Chou (eds.) Biodiversity and Terrestrial Ecosystems. Institute of Botany, Academia Sinica, Monograph Series No. 14, Taipei. pp 25–41.

Christie M., N Hanley, J Warren, K Murphy, R Wright and T Hyde (2006) Valuing the diversity of biodiversity. *Ecol. Econ.* **58:** 304–317.

Cromwell E, D Cooper and P Mulvany (2001) Agriculture, biodiversity and livelihoods: Issues and entry points for development agencies. In: I Koziell and J Saunders (eds.) Living off Biodiversity: Exploring Livelihoods and Biodiversity Issues in Natural Resources Management. London, UK: International Institute for Environment and Development, pp 79–112.

Dasgupta P (2001) Economic Value of Biodiversity, Overview In: SA Levin (ed.). Encyclopedia of Biodiversity. pp 291–304.

Drucker AG, S Melinda and P Zambrano (2005) Valuation and Sustainable Management of Crop and Livestock Biodiversity: A Review of Applied Economics Literature. Published for the CGIAR System-wide Genetic Resources Programme (SGRP) by the3International Food Policy Research Institute (IFPRI), the International Plant Genetic Resources (IPGRI), and the International Livestock Research Institute (ILRI).

Evenson RE, D Gollin and V Santaniello (1998) Agricultural Values of Plant Genetic Resources. Wallingford, UK: FAO and CAB, pp 1–25.

Esquinas-Alcázar J (2005) Protecting crop genetic diversity for food security: political, ethical and technical challenges. *Nature Reviews/Genetics* **6:** 947–953.

Gollin D and RE Evenson (1998) Breeding values of rice genetic resources. In RE Evenson, D Gollin and V Santaniello (eds.) Agricultural Values of Plant Genetic Resources. Wallingford, UK: FAO and CAB, pp 179–196.

Gollin D and R Evenson (2003) Valuing animal genetic resources: lessons from plant genetic resources. *Ecol. Econ.* **45:** 353–363.

Graner A, KJ Dehmer, T Thiel and A Börner (2004) Plant genetic resources: benefits and implications of using molecular markers. In: M Carmen de Vicente (ed.) The Evolving Role of Genebanks in the Fast-developing Field of Molecular Genetics. IPGRI, Rome, pp 26-32.

Goeschl T and T Swanson (2002) Social value of biodiversity for R&D. *Envtl. Resou. Econ.* **22:** 477–504.

Gupta AK, S Saxena, C Vikas, B Gosh Shrabani, S Riya and N Jain (2002) Cost of conservation of agrobiodiversity. IIMA Working Papers WP2002-05-03, Indian Institute of Management, Ahmedabad, Research and Publication Department.

Hajjar R, DI Jarvis and B Gemmill-Herren (2007) The utility of crop genetic diversity in maintaining ecosystem services. *Agric. Ecosyst. Envt.* **123:** 261–270.

Hampicke U (1999) The limits to economic valuation of biodiversity. *Intl. J. Social Econ.* **26:** 158–173.

Harlan JR (1992) Crops and Man, 2ed. American Society of Agronomy, Inc. Madison, WI.

Havalgi N (2009) Implication for International Trade on Agrobiodiversity Conservation and Food Security in

Climate Change Scenario. http://www.nccr-climate.unibe.ch/conferences/climate_policies/working_papers/Havaligi.pdf.

Heina L and F Gatzweiler (2006) The economic value of coffee (*Coffea arabica)* genetic resources. *Ecol. Econ.* **60:** 176–185.

Hoisington, DM Khairallah, T Reeves, JM Ribaut, B Skovmand, S Taba and M Warburton (1999) Plant genetic resources: What can they contribute toward increased crop productivity? *Proc. Natl. Acad. Sci.* USA **96:** 5937–5943,

International Technical Conference on Plant Genetic Resources (ITCPGR) (1996) Current expenditures for the conservation and utilisation of plant genetic resources for food and agriculture'', Document: ITCPG/96/Inf/1, FAO, Rome.

Jacksona LE, U Pascualb and T Hodgkin (2007) Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agric. Ecosys. Envt.* **121:** 196–210.

Johns T and BR Sthapit (2004) Biocultural diversity in the sustainability of developing country food systems. *Food Nutrition Bull.* **25:** 143–155.

Jump AS, R Marchan1 and J Peñuelas (2008) Environmental change and the option value of genetic diversity. *Trends in Plant Sci.* **14(1):** 51–58.

Kassar I and P Lasserre (2004) Species preservation and biodiversity value: a real options approach. *J. Envl. Econ. Manag.* **48:** 857–879.

Krutilla JV (1967) Conservation reconsidered. *Am. Econ. Rev.* **57:** 777–786.

Meng EC (1997). Land allocation and in-situ conservation of crop genetic resources: The case of wheat landraces in Turkey, PhD Thesis, University of California.

Morris ML and PW Heisey (2003) Estimating the benefits of plant breeding research: methodological issues and practical challenges. *Agrl. Econ.* **29:** 241–252.

Munasinghe M and E Lutz (1993) Environment economics and valuation in development decision making. Environment Working Paper No. 51, The World Bank, Washington, DC.

National Research Council (1972) Genetic Vulnerability of Major Crops. National Academy of Sciences. Washington DC.

Nunes PALD and JCJM van den Bergh (2001) Economic valuation of biodiversity: sense or nonsense? *Ecological Econ.* **39:** 203–222.

OECD (2002) Handbook of Biodiversity Valuation. A Guide for Policy Makers. Paris, France: Organization for Economic Cooperation and Development.

Pearce D and DMoran (1994) The economic value of biodiversity. Earthscan Publications, London.

Pearce DW, BE Barbier, A Markandya, S Barrett, RK Turner and T Swanson (1991) Blueprint 2, Earthscan, London.

Polasky S and A Solow (1995). On the value of a collection of species. *J. Envl. Econ. Manag.* **29:** 298–303.

Rafalski A (2002) Applications of single nucleotide polymorphisms in crop genetics. *Curr. Opinion Pl. Biol.* **5:** 94–100.

Ramanatha Rao V (2009) *In situ*/on-farm conservation of crop biodiversity. *Indian J. Gen. Pl. Breed.* **69:** 284–293.

Rao KPC and RE Evenson (1998) Varietal trait values for rice in India. In: RE Evenson, D Gollin and V Santaniello (eds.) Agricultural Values of Plant Genetic Resources, Wallingford, UK: FAO and CAB, pp 151–156.

Rausser GC and AA Small (2011) Valuing research leads: Bioprospecting and the conservation of genetic resources. *J. Political Economy* **108(1):** 173–206.

Rubenstein KD, P Heisey, R Shoemaker, J Sullivan and G Frisvold (2005) Crop Genetic Resources–An Economic Appraisal. A Report from the Economic Research Service, USDA, 39p.

Sajse PE (2003) Agrobiodiversity and sustainable development: what, why and for whom? In: Xu Jiancho and Stephen Mikesell (eds). Proceedings of the III Symposium on MMSEA 25-28 August 2002, Lijang. PR China, Kunming.

Simpson DR, RA Sedjo and JW Reid (1996) Valuing biodiversity for use in pharmaceutical research. *J. Political Economy* **104:** 163–185.

Simpson RD and RA Sedjo (1998) The value of genetic resources for use in agricultural improvement. In: RE Evenson, D Gollin and V Santaniello (eds.) Agricultural Values of Plant Genetic Resources Wallingford, UK: FAO and CAB, pp 55–66.

Smale M (2006) Valuing Crop Biodiversity On-Farm Genetic Resources and Economic Change. UK: CABI.

Smale M, M Bellon, D Jarvis and BR Sthapit (2004) Economic concepts for designing policies to conserve crop genetic resources on-farms. *GRACE* **51:** 121–135.

Smale M and A King (2005) What is Diversity Worth to Farmers? Research at Glance series – Briefs 13-18. I

Stolton S, N Maxted, B Ford-Lloyd, B, S Kell and N Dudley (2006) Food Stores: Using protected areas to secure crop diversity. WWF and University of Birmingham, Gland, Switzerland and Birmingham, UK.

Sthapit BR, R Rana, P Eyzaguirre and D Jarvis (2008) The value of plant genetic diversity to resource-poor farmers in Nepal and Vietnam. *Intl. J. Agrl. Sust.* **6:** 148–166.

Swanson T (1996) Global values of biological diversity. *PGR Newslet.* **105:** 1–7.

Virchow D (1999) Conservation of plant genetic resources for food and agriculture: main actors and the costs to bear. *Intl. J. Social Econ.* **26:** 1144-1161.

von Braun J (1994) Genes and biodiversity: new scarcities and rights challenge agricultural economics research. *Quarterly J. Intl. Agri.* **4:** 345-348.

Wale E (2011) Costing on-farm conservation of crop diversity: The case of sorghum and wheat in Ethiopia and implications for policy. *Afr. J. Agri. Res.* **6:** 401-406.

Wilson EO (1988) Biodiversity. Washington, DC: National Academy Press.

Weitzman ML (1998) The Noah's ark problem. *Econometrica* **66:** 1279-1298.

Zhanga W, TH Rickettsb, C Kremenc, K Carneyd and SM Swintona (2007) Ecosystem services and dis-services to agriculture. *Ecol. Econ.* **64:** 253-260.

Zohrabian A, G Traxler, S Caudill and M Smale (2003) The marginal value of an accession. Biotechnology and Genetic Resource Policies – What is a Genebank Worth? Brief 9. International Food Policy Research Institute, Washington.