Conservation of indigenous livestock: Sustaining biodiversity for current and future generations

CGIAR System Research Priority area 1

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Introduction

Poverty reduction is high on the agenda of both bi- and multi-lateral donors and thus also national governments. Some estimates suggest that livestock is a component of livelihoods for some 70% of the world's rural poor. Moreover, there is a strong correlation between poverty and a high degree of genetic diversity, both for livestock and crop plants. The likely reason is that a range of species and breeds enables rural households to ensure their food security by continuing to produce in uncertain environments. They can therefore manage risk more effectively, as well as making use of a diverse range of outputs with a flexible allocation of labour. The risks induced by natural phenomena such as weather anomalies and insect or disease surges have now been compounded by the increasingly unstable global economic environment, where sudden changes in policy can make their produce uncompetitive. Development agencies have added to the risks by rapid changes in policy and a failure to provide long-term support to introduced species or inputs. There is strong evidence for the gradual erosion of livestock and crop diversity worldwide (Hammond & Leitch 1995) and thus a powerful argument that the poor are being further impoverished and their food security still further undermined.

Local races and breeds of livestock disappear for a variety of reasons, some representing rational responses to changing economic, ecological or social conditions, others pressure from government bodies, development agencies or simply an inappropriate understanding of the trade-offs between short-term gains against long-term viability. Where communities voluntarily replace one breed with another or cease keeping livestock in order to concentrate on other activities such as tree-crops, it would be inappropriate to pressurise these communities into conserving breeds; national institutions should take over this role. Livestock breed conservation is a public good, both nationally and internationally, despite that fact that the great majority of those conserving breeds are in the private sector, in contrast to biodiversity in general. Table 1 presents a summarised list of factors accelerating erosion of livestock biodiversity;

Table 1. Factors accelerating erosion of livestock biodiversity

Factor	Description
Development interventions	Preference given to high-input, high-output breeds developed for benign environments. Commercial interests in donor countries promote use of relatively temperate-adapted breeds and create unrealistic expectations in developing countries
Specialisation	Emphasis on a single productive trait, e.g. dairying, leading to exclusion of multi-purpose animals
Genetic introgression	Crossbreeding and accidental introgression leading to loss of indigenous breeds
Technical change	Machinery replaces work animals
Biotechnology	Cryopreservation equipment inadequate to store germplasm of threatened breeds. Artificial insemination and embryo transfer rapidly displace indigenous breeds.
Economic change	Market for typical outputs is outcompeted by subsidised imports (e.g. milk powder) or replaced by synthetics
Environmental change	Climate or vegetation change makes a breed unviable in a particular habitat
Political instability	Eliminates local breeds owned by vulnerable populations
Natural disaster	Floods, drought and epizootics preferentially affect remote or isolated human and livestock populations

Expanded from Blench (2001)

The major technical issues in the conservation of livestock biodiversity are discussed at length in Blench (2001), Hall (2004) and Gibson & Pullin (2005) and are only summarised rapidly here. The present paper[1]

[1] This version is expanded from the 5-page format presented in Marrakech on December 6th 2005. I would like to thank Rob Chapman for proposing I make a presentation, and to the discussants, particularly Carlos Sere, Director-General of ILRI, for comments and suggestions for further topics. I would also like to acknowledge discussions with Stephen Hall

gives an overview of recent issues and presents a forward-looking view that emphasises the positive in relation to the ten-year strategy of the CGIAR.

Institutional: Conventions and International Agreements

Domestic animals are the one class of living creature largely ignored by international, regional and species conventions. The exhaustive list in Groombridge (1992:479 ff.) lists none and Henson (1992) makes no mention of them. The Rio convention on Biological Diversity of 1992 makes specific mention only of plant genetic resources. Despite this, FAO and more recently ILRI, have begun the process of collating data and creating awareness. FAO organised a series of expert consultations to initiate the 'Global Programme for the Management of Farm Animal Genetic Resources' in 1993 and is developing the Animal Descriptor system used for AGRI (Animal Genetic Resources Information). In 1995, the FAO Conference suggested the mandate of the Commission on Plant Genetic Resources should be widened to include domestic animals. The most recent version of the FAO global assessment and strategy http://www.fao.org/ag/cgrfa/AnGR.htm and forthcoming State of the World's Animal Genetic Resources (2006).

The most comprehensive source of data on endangered livestock breeds is the Worldwatch list maintained by FAO which has been published in book form in three successive editions (most recently FAO, 2000). Originally deriving from (European Association for Animal Production) EEAP data held in Hanover, this is essentially a database of significant genetic and production parameters of global livestock breeds, with particular emphasis on those at risk[2]. Version II of the DADIS database was released on CD-ROM and as a Website in 1998. The electronic version of this, DADIS (Domestic Animal Diversity Information System) database can be accessed on the World-Wide-Web (http://dad.fao.org/home.htm). DADIS is continually updated and a DADIS-NET has been launched to provide a regular channel, of communication between users[3]. DAGRIS (Domestic Animal Genetic Resources Information System) (http://dagris.ilri.cgiar.org/dagris/) has been established on by ILRI (International Livestock Research Institute) to compile information on ruminant breeds in Africa and to serve a more specialised audience than DADIS.

The profile of agrobiodiversity in relation to domestic animals

Agrobiodiversity has never quite attracted the same cachet as 'wild' biodiversity and certainly nothing like the same level of funding or commitment by governments and donors. Indeed, while most governments admit the importance of conservation and Protected Areas, even if the political will to enforce regulations is limited, many governments, donors and NGOs pursue policies that lead to the active erosion of agrobiodiversity. Livestock are generally affected more broadly than crops, partly there are so few domesticated species and partly because most of the species that sustain the developing world are also the subject of intense commercial interest in developed economies. Millet diversity is more likely to be conserved in China than pig diversity, because *Setaria* and *Panicum* play little role in international commerce. Policy-makers, under pressure to feed burgeoning populations, are seduced by the alluring statistics of high-input high-output (HIHO) breeds.

Levels of diversity and the continuing scientific agenda

The uncovering of levels and layers of biodiversity is a dynamic process, especially in terms of genetic research. Phenotypic classifications of diversity often produce results very different from those emerging

and Tashe Dorji that are reflected in the text of the paper. Most important, however, are the many pastoralists and livestock producers who have patiently answered my questions in many countries over many years.

[2] These listings are not without problems (see comments in Gibson & Pullin (2005)).

[3] Other relevant documents on current international efforts can be found at http://dad.fao.org/en/refer/library/reports2/itwg/itwg3.htm

from the laboratory bench. Research on the mitochondrial DNA (mtDNA) of domestic cattle showed that cattle were domesticated twice, once in India and once in the European-African area, very much in contrast to the long-accepted results from osteometry. A similar pattern has been observed with the chicken, originally thought to be domesticated from Indian jungle-fowl. In 1994, an mtDNA analysis seemed to show the chicken was domesticated just once from the races of jungle-fowl found in northern Thailand (Fumihito *et al.* 1994). Still unpublished data from ILRI[4] suggests that this monophyletic origin is certainly incorrect. There were at least two centres of origin (the Indian sub-Continent and 'South China') with Sri Lankan, SE Asia, Eastern and Southern African chickens apparently representing early crosses. Moreover, there has been wild introgression from other wild *Gallus* spp. apparently in India.

Two points emerge from this when considering practical policy implications. Many of the accepted results in textbooks appear to be incorrect, and that phenotypic characterisation can sometimes produce misleading results. Accelerating research is likely to produce further surprises and policy must evolve to reflect this. To put it more concretely, two animals can look the same but in fact turn out to be genetically quite different; in practice it is the genetic resource that should be the focus of conservation, not the animal itself. This in turn implies a science-driven agenda which is far from being adopted at present.

What role does science play?

Recent years have shown that good science is not enough to limit the processes of breed erosion and genetic loss. Those who fund international scientific bodies, both the CGIAR and others, tend to make two contradictory demands, namely that these institutes turn out reputable science (by which they mean papers in highly-rated journals) and that they show 'impact'. Almost by definition, journals such as *Nature Genetics* are not interested in development and to meet the demands of typical referees, authors inevitably move away from the practical world. The usual argument is that the acceptance of such research will induce governments and individuals to turn away from their addiction to high-input, high-output species and breeds. This is fantasy. Donors do not read hard science journals and governments certainly ignore them. They may take a certain pride in the positioning of their citizens in laboratories, or even constructing modern scientific facilities. But policy will not be made on the basis of their results. Moreover, there is a strong argument for saying that this is hardly where international scientific bodies have their comparative advantage as they are then competing directly with universities[5].

Types of diversification

A paradox noted by several authors is that breeds are most numerous in developed agricultural societies with intensified production systems, and that societies with a specialisation in livestock, typically pastoralists, may have relatively few breeds. However, herders tend to be responsible for species-level adaptation, the gradual capacity for livestock to withstand hostile environments, both in terms of climate and diet. Pastoralists have thus been responsible for the breeding of animals adapted to very high or low temperatures as well as extreme humidity. Farmers exchange gene pools over a very restricted geographical area with the result that marked breeds are more numerous and more distinct in diverse agricultural societies, especially as breeding control develops. Pastoralists move over very long distances and make limited efforts to control breeding (less in Africa than Central Asia). Indeed, introgression from other herds may be a key strategy in building up resistance to a wide spectrum of pathogens. This is another argument for moving away from a narrow focus on breed towards a broader view of genetic diversity and in particular, the spectrum of adaptation found in pastoral societies.

[4] Han Jianlin and Olivier Hanotte (p.c.)
[5] Indeed the funding squeeze can mean that the science is done by university-funded graduates.

Winning the argument: some case studies

The argument for the conservation of agrobiodiversity is largely won in the scientific community but its impact remains diffuse in the real world. Often this is because the partners are unequal; science is not up against science but against the pervasive influence of large commercial enterprises. Ministry offices are flooded by well-produced colour leaflets illustrated with fat and happy cattle, adorned with impressive output data. Such documents are not obliged to include a health warning, although there is every argument for saying that the alluring fantasies these promote can do considerable damage to economies and threaten livelihoods. The examples below provide some concrete field-based examples of the importance of the conservation of livestock biodiversity and the direct role it plays in sustaining livelihoods in uncertain environments.

We had one but the wheels fell off. **Decollectivisation in Central Asia.**

In terms of area, the grasslands of much of Africa and Eurasia are unsuitable for agriculture and any type of intensive livestock production, but have historically been used by pastoralists for extensive production. As a consequence, herders have developed a range of breeds with extreme tolerance of harsh conditions, disease challenge and other types of stress. Mongolian cattle, for example, regularly survive on natural grazing outside in winters that drop below -40 C° (Bynie 2004). Soviet dominance in Central Asia following 1917 led to rather distorted production strategies, whereby HIHO breeds were imported from European Russia, kept in heated sheds throughout the winters and fed on mechanically cut hay (see Humphrey & Sneath 1999:11 ff. for a description of these systems in Buryatia). Needless to say, this was not economically viable and was also very environmentally destructive, and when the USSR broke up, the system of collective farms was dropped and infrastructural support for HIHO breeds similarly collapsed. All through Central Asia, herders are now seeking to rebuild their herds using traditional breeds, which may be lower output, but which survive the winters without supplementary feed. The long years of collectivisation has meant that stocks of some of these breeds are now quite rare and much in demand; a strong argument for ensuring that agrobiodiversity is maintained, whatever production strategy is entertained by the state of the moment.

How now brown cow? **Livestock development in Bhutan**

The Bhutanese government has had a well-structured programme of modernising the livestock sector since the 1960s, heavily influenced by experiences from Switzerland and indeed, often funded by Swiss aid. Swiss Brown and Jersey cattle have been introduced and given out to farmers for cross-breeding. The government wishes to encourage herders to settle down and use planted pastures to feed stock; much research effort has gone into the most appropriate species and rotation patterns to produce suitable fodder crops. However, adoption has remained at low levels over four decades and herders continue to migrate. Their reasons are various, but factors are typically the high labour and financial costs of planted pastures, the space requirements of larger herds, where land is increasingly going under rice in the valleys. If migration is essential to subsistence, then only breeds that can tolerate the cold, the climatic variation animals are subjected to in extreme vertical movements and the disease challenges presented by subtropical forest (Arbenz & Tshering 2000). So herders continue with yaks and the local *Siri* cattle, as well as an elaborate crossbreeding strategy making use of the mithun, a bovid imported from northeast India (Gupta & Gupta 2000). Despite collaboration with ILRI, genetic characterisation of local breeds and the manifest failure of households to adopt intensive production, administrative pressure to continue work on exotic breeds remains strong and takes up the majority of resources.

Feeding the megacities

An argument that comes up with predictable regularity is the importance of feeding the cities, especially the very large cities that have sprung up in Asia since the 1950s. This goes roughly as follows; city populations have significant protein requirements which cannot be met by 'traditional' production systems and in

particular not by the wasteful processes that are associated with ruminants. Intensive and semi-intensive operations involving monogastrics, particularly chickens and pigs, are therefore the preferred option, since they take relatively less space and can be supplied predictably by feeds by the private sector. To a certain extent this transformation is already happening, with intensive poultry production the norm on the periphery of large cities across the world. However, this business has an important additional consequence; the vast international trade in standardised, tasteless chickens is also penetrating rural areas of the developing world and putting small-scale producers out of business[6]. The risk, needless to say, is that such industries are highly vulnerable to epizootics, as the evolving succession of poultry diseases is currently demonstrating; a risk which actually a greater burden for small-scale village producers, whose livelihoods can be wiped out.

Another side of this argument is that since the cities now contain a large proportion of the poor in certain countries, while the concentration on rural producers ignores their needs. This contains two sub-questions; should we place greater emphasis on the urban poor and how will their protein requirements be met? One striking feature of urban livestock demand is that it is almost entirely for meat; the typical multi-purpose rural breed that supplies work, fibre, manure, milk and meat is irrelevant when the dominant require is for protein with some dairying.

Disease

There is little argument concerning the dangers of narrowing the genetic base of domesticated plants; present problems with rust in wheats show how rapidly yields can fall when a new pathogen takes hold. However, the situation with livestock is less clear. Are disease outbreaks such as avian influenza related to replacing diverse breeds with those more genetically uniform? This cannot entirely be the case, because not only have there been many previous outbreaks, but also because wild birds are equally affected. Nonetheless, in broad Darwinist terms, this must be the case; a wide range of subspecies will have a range of tolerance of pathogens and some will suffer preferentially higher mortality. The survivors will reproduce more effectively and a subsistence producer will more likely to preserve the nucleus of future breeding stock. However, disease cycles are unpredictable and outbreaks may only occur at long intervals; the most viable strategy may be to keep more of the most productive breeds and take a risk on an epizootic not occurring within an economic cycle. As information systems improve, this may be more common. For example, African pastoralists have been known to convert their herds into cash when they hear of the outbreak of epizootics such as rinderpest, and then rebuy stock after the disease has passed. No definitive recommendation can be made, because of great uncertainties as to the speed at which new disease strains will emerge. However, human diseases such as malaria are adapting ever faster to new drugs and strains of hospital-related infections arise ever more rapidly, both situations with clear parallels in livestock production. The responsibility for maintaining diverse livestock breeds as a strategy against serial disease mutations may fall increasingly to international bodies and national governments in coming decades.

What role should High-input High-output breeds play?

It can sometimes seem that advocates of the conservation of livestock biodiversity take up a fundamentalist position that proposes the elimination of all High-input High-output (HIHO) breeds. While it is certainly the case that the argument for maintaining biodiversity includes a thread that regards their indiscriminate promotion as responsible for long-term damage to the environment and a likely incubator for a series of epizootics, HIHO breeds are now integral to feeding the world and therefore need to have a defined place. The principle economic characteristics of HIHO breeds is that they function best when input supply chains are short and where long-term socio-political stability is assured. This is because they depend heavily on reliable infrastructure and relative predictability of the price of inputs. For this reason, they have typically been more successful in Europe and Asia than in Africa, and around cities rather than in rural areas. Indeed the long-term failure of HIHO breeds in most of sub-Saharan Africa is a direct reflection of the problems of

[6] Ghana, for example, admits the import of Brazilian frozen chickens under WTO regulations, and these now reach the cold stores of most small towns, outcompeting local producers.

input supply and unreliable veterinary services. In Central Asia, the former command economies delivered unsustainable inputs for nearly seventy years before collapsing and causing production systems to revert to pre-Soviet breeds. Future livestock polices will therefore depend on a stratification of breeds, developing those that respond most effectively to degrees of infrastructure effectiveness. This is very contrary to typical livestock production analyses, where inputs are typically assessed in technical terms and will require a new nexus of co-operation between social scientists and animal breeds.

Changing demand

A typical impact of globalisation is ever more rapid changes in demand for livestock products. This is most visible in the market for fibres; as artificial fibres take over for mass-market products, especially in cold countries, the incentive to breed particular species and breeds for their hair or wool can suddenly drop. For example, the single most important factor in the decline of the camel in Mongolia is the lack of market for its wool; Chinese cold-weather clothes now dominate the market. Similarly in Bhutan, sheep production is in steep decline because of imported clothing. Sometimes new 'luxury' demand can provide a counterweight; demand for Mongolian cashmere and thus goat production is on the increase.

Demand for meat is also undergoing striking changes. Most dramatic is simply individual consumption; although increased meat intake is not really nutritionally necessary in many food economies it is a typical symbol of growth and status. Meat consumption, especially in China's cities has risen sharply over the last two decades, reflecting the burgeoning urban economy. Moreover, the species of livestock preferred increasingly mimics global taste trends rather than local traditions. Thus in Mongolia and China, demand for beef is rising sharply in the cities, replacing the more traditional mutton and pork and producers inevitably respond. In the countries of the Middle East, increasing distaste for camel meat is leading to precipitous declines in the numbers of camels herded, despite its huge symbolic importance in Arab culture.

International agencies should not be seduced away from long-term strategic thinking by this type of local change. Officials of national ministries are naturally concerned to reflect more ephemeral changes in demand, since they must deal with these on daily basis. But to allow the gene pool of the Bactrian camel to dwindle irreversibly because of temporary trends in clothing manufacture would be a very shortsighted policy. Natural fibres and low-fat meat can become popular again in quite a short period and the maintenance of livestock biodiversity is a long-term insurance policy against this type of economic fluctuation.

Convincing policy-makers

Coherent policies on livestock biodiversity are still uncommon, and often ill co-ordinated. Large livestock companies have significant political influence, especially in the United States, and approaches which run counter to their commercial philosophies often get short shrift in international decision-making. The primary task, then is to co-ordinate approaches, propagating an understanding of the parameters of long-term sustainability in livestock projects and their distinctive time-scales, which are ill-adapted to typical project cycles. The key task remains to convince policy-makers to;

a. have a policy on livestock biodiversity that is coherent with regional policies
b. not to also have a contradictory policy on improved breeds
c. to have a framework that allows input from evolving science
d. to put significant resources behind the policy and to ensure donor projects and NGOs comply

The two main strategies pursued by advocates of the conservation of livestock biodiversity appear to be lab-based genetic research and modelling the economic valuation of Animal Genetic Resources (e.g. Drucker, Smale & Zambrano 2005). The problem, however, is relevance for the situation on the ground. If government policy advisers plough through these papers would they then make different policies? Clearly

not. Government policies are made on much more pragmatic grounds. Another possible audience is the donors, perhaps the GEF. But it would be hard to find a project document that used these techniques to justify livestock biodiversity conservation. Donors are busy people and on the whole take advice from in-country consultants.

What must be developed are a series of case studies, looking at real examples, where the conservation of livestock biodiversity has proven of long-term value to a country or economy. Similarly, follow-up studies, showing the fate of HIHO breeds after the closure of donor projects, would also be valuable. These need to be presented in an easily assimilable form and distributed widely to decision-makers in governments, donors and NGOs.

Hotspots

The conservation of biodiversity in the wild has benefited considerably from the identification of 'hotspots', regions where the natural biodiversity of all organisms or some particular classes, reaches very high levels. Costa Rica, the Niger Delta and the Solomon Islands are distinctive examples. Such hotspots have never been characterised for domestic stock, but the concept is surely useful in helping to prioritise the allocation of scarce resources. Ethiopia, China and the British Isles would appear to be evident examples of high genetic diversity and as such might be assigned high priority. Obviously, this would be mediated through knowledge of existing policies and practice; enough interest in rare breeds already exists in Britain for development intervention to be irrelevant.

Relevance for other types of biodiversity

Livestock biodiversity does not exist in a vacuum, but interacts with policies and practice in relation to other types of biodiversity. A straightforward example of this is the conflict between livestock and wildlife in Protected Areas (PAs), especially East Africa. Livestock of any type are held to damage the environment and are generally excluded, which is often a source of conflict with adjacent pastoral populations. More dramatic is the burning off of large swathes of rainforest for low-grade cattle ranching in Brazil, representing a destruction of biodiversity which hardly represents a good argument for livestock production. In many ways, such conflicts are to be resolved in the political arena rather than through science. However, subtler and more challenging are the relationships between biodiversity conservation and livestock breeds in pastoral areas. In global terms, rangelands are a 'resource under siege' and much of the threat arises from the types of livestock that graze them. Central Asian grasslands, for example, have historically conserved high levels of biodiversity, because of the diversity of breeds and species that exploit them and because periodic blizzards have kept stock numbers in balance. Too many animals and the introduction of 'modern' uniform breeds has quickly resulted in overgrazing, loss of species diversity and plagues of voles and grasshoppers, competing with herders for forage resources. State responses, for example in the grasslands of China, has been aerial spraying of toxins and then aerial reseeding. Instead of engaging in this type of 'arms race', a more constructive response would be to make more effective use of the biodiversity of existing domestic animals and the range they graze.

Policy re-orientation

The policy re-orientation required of decision-makers can be summarised as follows (Box 1);

Box 1. Policy re-orientation to support livestock biodiversity

- Support to the conservation, free use and international exchange of animal genetic resources, with due attention to IPR issues
- Support the re-orientation of National Research institutes towards research on indigenous livestock breeds

- ❖ Support a re-orientation of research from a focus on individual traits to lifetime and herd productivity
- ❖ Support a re-orientation of research and extension towards species and uses relevant to poor people, i.e. micro-livestock and work animals
- ❖ Support a switch to more responsive, participatory methods of determining selection goals
- ❖ Support innovative initiatives such as co-conservation, co-exploitation, exploration of new domesticates, and improved management of existing semi-domesticates
- ❖ Support new marketing initiatives to add value to unusual or niche livestock products
- ❖ Support to inventory projects that add value through cross-border and regional co-operation
- ❖ Support to the implementation of the CBD and its COP extensions
- ❖ Develop awareness of the importance of 'joined-up' policy, i.e. not allowing two different government bodies to promote contradictory policies
- ❖ Focus science more directly on issues of importance to donors and policy-makers

Research

Much of the research recommended (Box 2) follows directly from the policy re-orientation proposed;

Box 2. Research and project re-orientation proposed to support livestock biodiversity

- ❖ Support national programmes of breed characterisation, both at the genetic and phenotypic level, but linked to and feeding into international research databases
- ❖ Extend inventory projects to identify breed conservation status
- ❖ Monitor, characterise and support the conservation of wild relatives of domestic animals, where these exist
- ❖ Focus more attention on genetic traits such as disease resistance which may be regional rather than breed-centred
- ❖ Develop technical parameters for experimental domestications and co-conservation initiatives
- ❖ Extend mtDNA characterisation to all domestic animal species and improve techniques for monitoring degree of homozygosity
- ❖ Base selection criteria on realistic modelling of environmental stress
- ❖ Better develop understanding of the relationship between livestock breed conservation and socio-economic variables (i.e. more effective poverty focus)

National programmes of breed characterisation are highly variable between countries and typically suffer from inconsistent political support and thus funding, as well as differing scientific capacity. The CG system, through more extensive networking and cross-centre policy development, could assist in raising the profile of livestock breed characterisation and develop standards in national and regional centres. Such centres could then become foci of inventory projects to identify breed conservation status as well as identifying issues in the conservation of wild relatives. A high is then to develop a smooth relationship between the investigation and publication of results from the field and their integration into international databases such as DADIS and DAGRIS, especially where such materials are in languages other than English. In addition, the typical national focus of livestock biodiversity research has often had the effect of duplicating results or promulgating contradictory information an issue which can be resolved by appropriate regional initiatives.

The science base of the CG must play a more in-depth role in promoting laboratory work at the national level, especially in terms of the molecular characterisation of breeds and focusing attention on genetic traits such as hardiness and disease resistance. At present this remains highly centralised, but collaborations, particularly with Asian countries, illustrate how skills can spread into national institutions.

The CG system should also extend its policy work, both at the political level and in relation to socio-economic studies. The coming decade will require more efforts to harmonise national and regional structures and develop evidence-based policies. International bodies such as the CG institutions have a comparative advantage in this area and the international research system should benefit from their familiarity with regulatory frameworks and their ability to adduce evidence from a wide range of sources. The poverty focus of many international donors should concentrate efforts on linking socio-economic work with high-quality laboratory science to benefit poor rural households through the re-orientation of national and regional policies.

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