Erosion of plant genetic resources: causes and effects

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Abstract

The importance of understanding and mitigating the effects of erosion of crop genetic resources has been re-emphasised since the 1992 UNCED conference on Environment and Development. Although it is widely accepted that genetic erosion takes place, its extent has not been technically documented and its definition is contested. Replacement of a diversity of landraces with few unified modern varieties as part of a wider agricultural modernization is the main cause of genetic erosion. There is an inextricable link between cultural and biological diversity at the community level. Genetic erosion has negative developmental effects when the modern varieties which replace local varieties are or become inappropriate for the social, economic and crop-specific conditions and opportunities prevailing among farmers. Two case studies, based on fieldwork in Tanzania, illustrate the causes and its impact on affected communities of erosion of crop genetic resources.

Keywords

Genetic erosion, agricultural diversity, small-scale agriculture.

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Loss of genetic diversity, or genetic erosion, was placed high on the agenda during the UNCED conference in 1992 (in the preamble to the Convention of Biological Diversity (UNCED 1992) and in Agenda 21 (UNCED 1992a)) and, in particular, loss of and threat to animal species has received much attention in recent years. Genetic erosion of agricultural crops on farmers' fields receives less media attention even though it is of far greater importance to the livelihood of millions of farmers in developing countries. Within the international community concerned with conservation and use of plant genetic resources, the causes and effects of the genetic erosion of agricultural crops and possible ways of limiting such erosion have been heatedly discussed in recent years and there are often widely differing views on the issues involved.

A large and growing group of NGOs and grass-roots organisations, which work in a participatory way with farmers, view agricultural modernisation as the primary cause of genetic erosion of crops and emphasise the positive effects of wider utilisation of indigenous knowledge and of diversity of local crop varieties (Berg, 1996). They view a high level of diversity as an aim and state that "without genetic diversity (insitu), options for long-term sustainability and agricultural self-reliance are lost" (RAFI 1997: 7). Mainstream agricultural scientists, on the other hand, regard the effects of genetic erosion of local crop varieties *in situ* as insignificant (Frankel, Brown & Burdon, 1995), provided that the lost genetic diversity is replaced by one or a few modern varieties and that the local crop varieties are collected and conserved *ex situ* (a view which is reflected in most developing countries' agricultural policies and donor supported programs).

This article argues that both groups are wrong, or at least only partially right. A high level of crop genetic diversity *insitu* may be highly beneficial for farmers under low-external input farming conditions, enabling crop varieties to adapt to new pests and diseases and changing environments and climates. However, modern uniform (diversity poor) varieties, under stable, high-input conditions, (*e.g* irrigated rice cultivation in South East Asia) are both high-yielding and yield-stable (Wood, 1996). It is not possible *a priori* to judge whether a high level of crop diversity is positive (or genetic erosion is negative) for farmers livelihood.

While some progress has been made in understanding the complex socio-economic processes involved in genetic agricultural crop erosion, the debate reveals that there is still considerable confusion and a number of unanswered questions regarding the causes and effects of this type of genetic erosion (FAO, 1996). This article seeks to reach beyond the politicised opinions referred to above and to discuss the major causes for genetic erosion and its effects on farmers based on fieldwork in Tanzania.

Towards a useful definition of the genetic erosion of plant genetic resources

In general terms "biodiversity" means "variety of life". For biologists, "biodiversity" refers to the quantity of species and the variety of environments in which species or genes are present (Carroll, Vandermeer & Rosset,1990). "Genetic erosion" is defined as the loss of genetic diversity and commonly refers to the reduction in the quantities of specimens of a species (Solbrig, 1991). For agricultural crops, however, genetic erosion occurs not just by the reduction in the number of plants of a species or in the geographic range of a species, but, more importantly, the loss of genetic variation among the plants, or more precisely, the loss of some of the diverse forms of genes (*i.e. alleles)* that are the primary source of the variation in appearance and in the life cycles of plants.

There is no commonly accepted definition of genetic erosion of plant genetic resources. Conservation biologists define genetic erosion of plant genetic resources as the irreversible loss of genetic diversity, including the loss of individual genes (*i.e.* gene variants or *alleles*) and the loss of particular combinations of genes (*i.e. allele*-complexes), as a result of extinction of the plant variety *in situ* (FAO 1996). From a development point of view there are two problems with this narrow biological definition of genetic erosion. Firstly, it is impractical as it has only recently, with the development of molecular biology based techniques, become possible to measure diversity at the gene level. To date there have been few systematic studies which have provided quantifiable estimates of the actual rates of genotypic or *allelic* extinction of plant genetic resources at the genetic level. Secondly, genetic erosion is a socio-economic process which involves much more than actual loss of particular combinations of genes in plants. It is the by-product of an overall change in farming systems and is often associated with loss of farmers' indigenous knowledge regarding how to manage and use local plant varieties in a productive way.

Practitioners working with communities to conserve plant genetic resources often use the term genetic erosion to mean loss of local landraces within a given community (de Boef et.al., 1993). This is a practical rather than a scientific definition. However, while it is impossible, without scientific genetic analysis, to determine the extent to which one landrace differs genetically from another, the number of landraces within an area will be, in most cases, a good indicator of the level of genetic diversity. Landraces result from centuries of selection by farmers and are a major source of genetic diversity in agriculture providing much of the genetic resources for plant breeding. However, the study of landraces and their use by farmers is problematic in that the vernacular names used for landraces vary greatly and are not consistent. Popular landraces can have several names even within the same village and different landraces may have the same name. The study of erosion in genetic diversity of plant genetic resources therefore has to combine the vernacular names of landraces with the phenotypic and genetic characterisation of varieties and the socio-economic survey of farmers indigenous management of their plant genetic resources.

Defining genetic erosion as the loss of landraces within a community recognises that there is an inextricable link between cultural and biological diversity. Traditionally high levels of cultural diversity have generally been dependent on high levels of biological diversity as livelihood support systems. As traditional farmers numbering in the millions have turned away from their traditional landraces, the knowledge of how to maintain the hand-selected lines that performed well in particular habitats and conditions has fallen victim to an even greater erosion than the germplasm itself. While plant collectors have managed to salvage some of the abandoned genetic diversity, the knowledge that produced and maintained the diversity over many generations remains on-site and has only rarely been recorded in connection with the collection of germplasm for *ex situ* storage (Friis-Hansen, & Guarino, 1995). The erosion of indigenous knowledge which accompanies genetic erosion may be as damaging to the local community as the loss of the genetic material itself. Variety loss at the community or even regional level may not necessarily result in global extinction. However, communities which have lost local landraces have found it difficult to regain access to them even if the varieties have been collected and stored *ex situ*. It is important to distinguish between the *absolute lack of varieties* in any given geographical area and *farmers' inability to access seeds* of *varieties* which exist in the given geographical area, a far more common circumstance in rural areas in developing countries (Sperling et. al., 1993).

Assessment of the current state of genetic erosion of Plant Genetic Resources

It has been estimated that there are up to 500,000 species of higher plants (*i.e.* flowering and cone-bearing plants) of which about 250,000 have been identified or described. Approx. 30,000 of these are edible and approx. 7,000 have historically been cultivated or collected by humans for food. Today, only 30 crops provide 95% of the world's calorie and protein requirements and wheat, rice and maize alone provide more than half the global plant derived energy intake. A further seven crops, sorghum, millet, potatoes, sweet potatoes, soybeans and sugar (cane/beet) bring the total to 75% of the energy intake. While the number of plant species which supplies the world's energy and protein is limited, the diversity within such species is high. There are, for example, more than 100,000 distinct varieties of rice (*Oryza sativa*) (FAO, 1996).

Since the advent of agriculture 10,000-15,000 years ago, farmers have selected varieties based on the traits of the parts of the plants to be consumed including ease of harvest, adaptation to day length, non shattering seed heads, storability, high and reliable regeneration rates, nutritional quality and phenotypic appearance (*e.g.* size, shape, texture). Traditional crop improvement has produced a myriad of landraces, mostly with localised distributions and developed to suit the needs of the farmers who created them. Farmers in environmentally diverse locations have always selected from the germplasm available to them those genotypes that best satisfy their household requirements. Since household requirements vary greatly in different environments and among different cultures and stages of economic development, the landraces selected by farmers over time represent an enormous range of germplasm. Crop diversity, both in terms of growing a number of different crops and different varieties of each crop, plays a crucial role in the maintenance of household food security, the major production goal of resource poor farmers. Such crop diversity allows farmers to adapt their cropping systems to local ecological micro-niches in their fields and to satisfy household food preferences and also provides protection against pathogens. Also, the extent of genetic variation determines how well a population or species can adapt to environmental challenges such as new crop pests, diseases and drought, among others (Simmonds 1991, Simmonds 1991a).

It is not possible to determine how much diversity once existed in a particular crop. Historically, no methods of analysis were available and hence no comprehensive surveys of genetic diversity to determine the extent of diversity 100, and much less 1,000 or 10,000 years ago, exist. Because we do not know with certainty what existed, it is impossible to determine with certainty what or how much has been lost or the past or current rate of loss. It is assumed that the introduction of modern agricultural technology and its diffusion during the past three to four decades has greatly accelerated both the *scale* and the *rate* of intra-specific crop genetic erosion. Relatively recently, the "green revolution" in developing countries has promoted the rapid spread of modern varieties. This replacement of landraces on a massive scale, especially in the primary gene centres of many crops, seems to imply that there has been a large scale loss of crop genetic diversity.

Even today, the evidence of genetic erosion of plant genetic resources remains anecdotal, though cumulatively powerful and wholly persuasive. Systematic studies of genetic erosion at farm level would require the study of the genetic diversity of a cultivated area before and after agricultural modernisation has taken place. Such systematic studies has never been undertaken and attempts within FAO to monitor the global genetic erosion of plant genetic resources have not yet produced results (FAO, 1996a). Most evidence of genetic erosion of plant genetic resources is from developed countries and from the relatively high-productivity areas of developing countries where the "green revolution" modern varieties were most successfully introduced. In more marginal areas, there is less clarity although the extent of genetic erosion is almost certainly less, in part because of the limited diffusion of modern agriculture in these areas. While the extent of genetic erosion has not been technically studied and documented, there is widespread acceptance that it is occurring, see Box 1 below.

The causes and effects of the genetic erosion of plant genetic resources are poorly understood

Agricultural modernisation is the major cause of the ero-

Examples of genetic erosion

- A survey of far households in the Republic of Korea showed that of 14 crops cultivated in home gardens, an average of only 26% of the landraces cultivated there in 1985 were still present in 1993.
- In China, in 1949, nearly 10.000 wheat varieties were used in production. By the 1970s, only about 1.000 varieties remained in use.
- In Malaysia, the Philippines and Thailand it is reported that local fruit varieties are gradually being replaced with modern varieties.
- In Ethiopia, traditional barley and durum wheat varieties are suffering serious genetic erosion due to displacement by introduced varieties.
- Large-scale genetic erosion of local varieties of native Andean crops is reported in Equador and Argentina.
- Chile reports genetic erosion of local potato varieties as well as other crops such as oats, barley, lentils, watermelon, tomato and wheat.
- Only 20% of the local maize varieties cultivated in 1930 are now known in Mexico.

Box 1: Examples of genetic erosion. Source: FAO 1996. Report on the State of the World's Plant Genetic Resources. Examples on genetic erosion are mentioned in 81 of the 150 Country Reports produced as part of the preparation of the FAO report.

sion of plant genetic resources. Agricultural modernisation is based on agricultural technology which seeks to control the environment in order to create optimal conditions for growth while modifying the characteristics of crops and animals to enable them to take full advantage of the improved environment. Replacing a wide range of traditional varieties with a few improved varieties has been a significant and productive aspect of agricultural development. Other factors, in addition to the introduction of modern varieties, also contribute to genetic erosion. These include land use changes associated with agricultural development projects, loss of traditional knowledge, disruption of traditional seed exchange mechanisms, and integration and homogenisation of produce markets (Friis-Hansen, 1996).

In the 1970s the international agricultural community realised that the accelerated agricultural modernisation occurring in developing countries, especially in Asia and Latin America, caused massive genetic erosion of local varieties and increasing attention was therefore devoted to collecting endangered crop varieties and storing them in *ex situ* gene banks. The number of gene banks has increased from a handful in the early 1970s to more than one thousand today. The conviction among agricultural scientists and conservation biologists has been that landraces of crops should be replaced by plant breeders' cultivars and that the "present and future role of landraces is to serve as sources of genetic material for plant breeding" (Frankel, Brown & Burdon, 1995:70). While great efforts have been made to collect and store threatened crop varieties, nothing has been done to slow down or reverse the process of genetic erosion *in situ*, as genetic erosion has been viewed as an unavoidable side effect of agricultural modernisation.

Agricultural modernisation means much more than the provision of a technical package of external inputs enabling farmers to increase agricultural productivity. Agricultural modernisation policies, as they have been practised in many developing countries, have been based on a number of largely implicit assumptions. One such basic assumption is that science-based modern agricultural techniques are always better than traditional techniques. A common approach to agricultural modernisation in many areas in developing countries has been to replace traditional farming techniques and crop varieties with modern ones, without considering the effects on the overall farming system. A broad range of government policies, implemented by public institutions and private companies and supported by donor organisations, supports this approach. Such modernisation policies include (i) government price subsidies of modern seed varieties and associated chemical inputs; (ii) linking credit for small scale farmers directly to their purchase of modern varieties and associated chemical inputs; and (iii) marketing institutions discriminating against the purchase of local varieties (Cromwell, 1996).

There is growing evidence that the process of adoption of modern varieties by small-scale farmers is a non-linear process in which modern varieties are replacing local landraces. Slow diffusion of modern varieties into the farmers' portfolio of varieties is common, although there are examples of successful large scale introductions of modern varieties. The variability in conditions of plant growth in small-scale rainfed agriculture is high and individual modern varieties are not likely to perform optimally in all micro-niches. Adoption and allocation of part of a farmer'sfields to a modern variety often involves compromises (*e.g.* the modern variety may yield more grain but less starch, or may take a longer time to mature and demand more inputs (leaving less resources for other varieties and often increasing the vulnerability of crop production)). There are many examples of the adoption of modern varieties resulting in a reduction of the area cultivated with landraces and eventually their replacement within a specific area.

However, intensification of smallholder crop cultivation does not necessarily lead to a reduction in genetic diversity. Some researchers argue that indigenous intensification in some situations may promote farmers to select positively to higher levels of crop diversity (Guyer & Richards 1996). The central argument is that local knowledge about plant genetic resource management is sometimes highly dynamic and farmers use this knowledge to internalise modern varieties in their farming strategies. Local knowledge may be defined as cultural knowledge, producing and reproducing mutual understanding and identity among the members of a farming community, where local technical knowledge, skills and capacities are inextricably linked to non-technical ones, (*e.g* cultural, ecological and sociological factors) (Scoones & Thompson, 1994).

The modern varieties that replace the diversity of local varieties are often not appropriate for the social, economic, agronomic and crop specific conditions and opportunities prevailing among farmers. The successful adoption and use of modern varieties requires that a whole range of structural conditions is satisfactory (*e.g.* timely availability of affordable appropriate seasonal inputs, supportive agricultural policies and relevant support from research and extension services). If farmers' access to such agricultural services diminishes within a few years after their adoption of modern varieties and, during that period, farmers have lost their local crop diversity, serious consequences for farmers' ability to sustain their cropping systems arise.

The following are two examples of the processes of genetic erosion and their effects on farmers. Both examples are based on field work conducted in Tanzania.

Rice cultivation on Usangu Plains: continuous replacement of varieties in a context of commercial market-oriented production

Usangu Plains is a semi-arid area situated in the Southern Highlands of Tanzania, comprising 1,500 square kilometers. Usangu Plains has experienced a dynamic demographic change over a 30 year period with a rapidly increasing population resulting from immigration from surrounding areas. Commercialisation has transformed the area from a traditional pastoral society to an intensive irrigated rice based economy with broad social differentiation and a well-developed labour market.

Rice cultivation was introduced in the Usangu plains by immigrants from India as early as the 1930s and expanded dramatically after the construction of a main irrigation canal in 1964 and farmers' subsequent construction of additional informal irrigation canals. Farmers on Usangu Plains have cultivated a high number of rice varieties over the past three decades and once dominant rice varieties have frequently been replaced after farmers adoption of new varieties. While some of the cultivated varieties have been landraces from areas in Tanzania with long traditions of rice cultivation, most have been modern varieties (mostly based on releases from the International Rice Research Institute in the Philippines). Three main variety selection criteria were identified during fieldwork among farmers on Usangu Plains. They are: (i) productivity, (ii) household requirements and (iii) market demand.

(i) Productivity of grain production, while important, is not the only variety selection criteria for farmers. Farmers seek to maximise their total household rice production by using a range of varieties which together enable them to optimise the use of their resource base. If a farmer's fields, for example, have early access to water (located up-stream in the local hierarchy of water distribution canals), the farmer may select varieties with longer time to maturity and a higher water requirement (which commonly means higher yield potential). The balance between access to land and availability of labour also influences farmers' choices of varieties: large land owners tend to sow late maturing rice varieties by broad casting after early tractor ploughing, while farmers with limited land transplant early maturing varieties following ox-ploughing or hand hoeing.

(ii) Suitability of individual varieties to satisfy household requirements and preferences is an important selection criteria although its importance has been reduced as rice production has increasingly become commercialised. Local

landraces such as "shinga ya mwali" (neck of an young unmarried women), which farmers describe as having "good appearance, taste and smell, but low yield", are close to becoming extinct locally as they have been replaced by modern varieties which are higher yielding but less palatable.

(iii) Market demand has increasingly become the most important variety selection criteria. In the 1970s, the Mbeya Primary Cooperative Union (the state-controlled monopoly marketing organisation) encouraged the purchase of modern varieties. This policy, which was based on a crude modernisation ideology, resulted in the loss of several local landraces. During the 1980s the blanket price policy of the Mbeya Primary Cooperative Union resulted in the increased use of high yielding but relatively poor tasting varieties. Trade liberalisation which occurred in 1988 had a dramatic impact on farmers' selection and cultivation of rice varieties. Dar es Salaam consumer preferences now determined the market demand and price for rice varieties. Today, given that there is no longer any demand for previously cultivated rice varieties, there is either absolute or relative lack of seed for most of such varieties. Three rice varieties dominate on Usangu Plains: Kilombero (medium maturing, medium yield potential, high price, good taste), Fiya (late maturing, high yield potential, low price, poor taste) and Supa Mati (early maturing, medium yield potential, medium price, poor taste). Today, a trade-off between price and volume determines farmers' choices of the variety mix they cultivate.

No immediate negative effect on farmers results from the genetic erosion on Usangu Plains as the decision to concentrate on three rice varieties was taken by the farmers themselves in order to adjust to market demand. Because of the relatively high profitability of rice cultivation and the relatively easy access to new varieties from outside the local area, the negative effects of genetic erosion are likely to remain limited even in the medium to long term.

Sorghum cultivation in Ismani: Replacement of a diversity of landraces by one modern variety in the context of subsistence production

Mkulula village is situated in Ismani Division approximately 3 hours drive on a poor quality dirt road from Iringa in the Southern Highlands of Tanzania which is 500 kilometers from Dar es Salaam. The area is today characterised as semi-arid, with a mean annual rainfall of 431 mm (6 year mean). The distribution of rainfall is highly variable from year to year as well as within the agricultural season.

Only 50 years ago Ismani was densely covered with natural forest. Cultivation has since gradually expanded into the area from neighbouring highland areas. Large scale forest clearing occurred in the 1950s and 1960s during which time "slash and burn" agriculture was practised with maize, sorghum and millet as the major crops. In the 1970s, in connection with the forceful resettlement of the population into nuclear villages, maize became the main crop. By the mid-1980s deforestation was widespread, soil fertility was low and this, in combination with rainfall levels, meant that maize was no longer sustainable. During the 1980s and 1990s sorghum gradually became the main crop now covering more than half the total cultivated area.

The increased cultivation of sorghum has primarily been based on farmers' use of indigenous landraces acquired through exchange with traditional sorghum growing farmers such as the Gogo tribe living in the neighbouring semi-arid Dodoma Region. Approximately 16 sorghum varieties representing a diversity of crop traits and well adapted to local production conditions and household requirements were cultivated in Mkulula village in the beginning of the 1990s. All such landraces produce tall plants which provide supplementary fodder for livestock and have broad tolerance to pathogens (disease, insects, fungi and virus). Some of the landraces are particularly tolerant of drought stress. The landraces cover a wide spectrum with regards to time to maturity of the individual varieties.

As a response to the 1991/1992 drought in Southern Africa, which also affected Ismani, an NGO distributed 40 tons of an improved sorghum variety by way of emergency seed supply to Ismani. The NGO had no knowledge about the performance of the modern variety, PN3, which was purchased in Zimbabwe. PN3 was developed by ICRISAT (International Crop Research Institute for the Semi Arid Tropics) with the participatory involvement of farmers in the breeding process. PN3 has been successful in Mkulula village for the following reasons: (i) it has a short time to maturity and yet a yield level similar or slightly higher than the local long-season landraces; (ii) it is white and farmers are content with its palatability as food as well as for local beer; and (iii) it is easier to process than the local landraces.

While the introduction of PN3 was highly successful, it resulted in widespread genetic erosion among the local landraces. After its introduction and cultivation on a small scale in the 1992/93 season, the PN3 variety expanded to cover almost half of the sorghum area in the 1993/94 season. During the 1994/95 season the PN3 variety was cultivated on between 75% and 90% of the farmers' sorghum fields and only 11 out of the 16 local varieties were still present in the village and confined to the remaining area. Several of the remaining landraces were cultivated in such small quantities that they were threatened by extinction.

While farmers' adoption of PN3 has had an immediate positive impact on farmers' household food production and security, the long-term effects of the farmers' increased dependency on one variety is unclear. It is likely that most of the remaining sorghum varieties will be abandoned and the community will be highly vulnerable in the event PN3 falls victim to a disease or pest. In 1995 some farmers in Mkulula reported that PN3 had begun to change certain characteristics (*e.g.* increasing its length to maturity as a result of cross-pollination with local sorghum varieties). The absence of access to "pure" PN3 seed (PN3 is not produced by Tanzanian seed companies) will increasingly create problems for farmers who have become dependent on PN3 for their subsistence.

Conclusions

Erosion of plant genetic resources is not simply the replacement of a diversity of land races with one or a few modern varieties, but involves the loss of farmers' indigenous knowledge of and ability to manage their own plant genetic resources.

The extent to which diffusion of modern varieties results in genetic erosion depends on the strength and quality of local plant genetic resource management and the comparative ability to satisfy the farmers' household requirements of local landraces *vis a vis* the modern varieties introduced. In the case of Ismani, genetic erosion was caused by the introduction of an appropriate modern variety which better satisfied household requirements. In the case of Usangu, genetic erosion was first caused by changes in household requirements (from subsistence to production for the market) and later by changes in the market demand.

The focus of the debate (and of most conservation efforts) has been on the consequences of genetic erosion for future modern plant breeding, while little attention has been given to the consequences for farmers. The extent to which genetic erosion has negative effects on farmers in the medium to long term depends on the stability and efficiency of the market's and the state's provision of agricultural services. In the case of Ismani, the negative effects of genetic erosion are likely to be serious if or when the PN3 variety develops problems, as the farmers have no access to physiological pure seed. In the case of Usangu, the negative effects of genetic erosion are likely to be limited, as the Usangu is not a centre for genetic diversity of rice and the varieties lost are not well adapted local varieties but old modern varieties being replaced with new ones.

One could argue that the process of crop genetic erosion could be better illustrated using more "extreme" examples than the two relatively and unclear examples from Tanzania. However, most farming communities, like Usango and Ismani, are likely to have experienced a mixture of positive and negative effects from genetic erosion. To understand the developmental impact of genetic erosion of crop genetic diversity in a given area, it is necessary to assess the socio-economic conditions under which the genetic erosion takes place. The mere assessment of the underlying biological processes of erosion does not provide a complete or accurate picture.

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While farmers' adoption of PN3 has had an immediate positive impact on farmers' household food production and security, the long-term effects of the farmers' increased dependency on one variety is unclear. It is likely that most of the remaining sorghum varieties will be abandoned and the community will be highly vulnerable in the event PN3 falls victim to a disease or pest. In 1995 some farmers in Mkulula reported that PN3 had begun to change certain characteristics (*e.g.* increasing its length to maturity as a result of cross-pollination with local sorghum varieties). The absence of access to "pure" PN3 seed (PN3 is not produced by Tanzanian seed companies) will increasingly create problems for farmers who have become dependent on PN3 for their subsistence.

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