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Evolution, plant breeding and biodiversity

S. Ceccarelli
Consultant ICARDA, P.O. Box 5466, Aleppo, Syrian Arabic Republic,
e-mail: s.ceccarelli@cgiar.org

Abstract: This paper deals with changes in biodiversity during the course of evolution, plant domestication and plant breeding. It shows than man has had a strong influence on the progressive decrease of biodiversity, unconscious at first and deliberate in modern times. The decrease in biodiversity in the agricultures of the North causes a severe threat to food security and is in contrasts with the conservation of biodiversity which is part of the culture of several populations in the South. The concluding section of the paper shows that man could have guided evolution in a different way and shows an example of participatory plant breeding, a type of breeding which is done in collaboration with farmers and is based on selection for specific adaptation. Even though participatory plant breeding has been practiced for only about 20 years and by relatively few groups, the effects on both biodiversity and crop production are impressive. Eventually the paper shows how participatory plant breeding can be developed into 'evolutionary plant breeding' to cope in a dynamic way with climate changes.

Keywords: Participatory plant breeding, agrobiodiversity, agricultural research, climate change

Introduction

Evolution and plant breeding are related for two reasons, the first is that plant breeding has been defined as 'evolution guided by man' and the second is that both processes have their basis in, and a major effect on, biodiversity.

The paper discusses the interaction between man and plant evolution. It is divided into three sections: 1) the evolution of plants before crop domestication, which marked the beginning of agriculture, 2) plant evolution from crop domestication until the discovery of Mendel's laws of inheritance, which marks the beginning of scientific plant breeding, and 3) plant evolution after the discovery of Mendel's laws. The reason behind this division is that these three periods differ considerably in the level of interaction between human activity and plant evolution. Man had a negligible effect on plant evolution in the first period; the effect became progressively larger in the second and much larger in the third as technologies became more sophisticated. This, as we will see later, has had a number of negative consequences particularly (but not only) on biodiversity.

Evolution before domestication

Plants are an integral part of human history. It is estimated that between 40,000 and 100,000 species have been regularly used for food, fibres, industry, religion and medicine.

Before domestication which signed the beginning of agriculture, plant evolution followed the principles of adaptation and natural selection; these are treated in detail in several text books and therefore I will only mention them briefly.

If we define biological evolution as the change in the inherited traits of a population from one generation to the next, one of its major driving forces is mutation, with the production of new genes and therefore the creation of new genetic variation. Since mutation is a random and rare phenomenon, only a few individuals are affected, and this leads in the long term (evolution is always long-term) to the development of genetic differences. In some environments these differences are neutral. In other environments they may be associated with varying degrees of advantages, and in others with varying degrees of disadvantages. In evolutionary terms 'advantage' means having more progeny. Therefore, the frequency of genes which give some advantages will increase with time while the frequency of genes associated with disadvantages will decrease, *as long as external conditions do not change*. These changes of gene frequencies may even revert to the original values if there is a reversal of the external conditions and if in the meantime the gene has not disappeared.

Two forces - natural selection and migration - also change the frequency of genes and thus guide evolution. As we will see later, to avoid random changes in gene frequencies it is also important that a minimum population size is maintained.

Before domestication man, the hunter-gatherer was part of the natural order and most likely had, if any, a limited effect on diversity.

Evolution from domestication to Mendel: the origin of agriculture

Agriculture started as a consequence of a major climatic change, the end of the last ice age, about 13,000 years ago. With the end of the last ice age, most of the earth became gradually subject to long dry seasons. This created favourable conditions for annual plants which can survive the dry seasons either as dormant seeds or as tubers.

Agriculture started in that area of the Near East known as the Fertile Crescent around 9,000 BC, and soon after, started in other areas. At least six regions of domestication have been identified, including Mesoamerica, the southern Andes (including the eastern piedmonts), the Near East, Africa (probably the Sahel and the Ethiopian highlands), Southeast Asia, and China. From these regions, agriculture was progressively disseminated to other regions, including Europe and North America.

The Fertile Crescent is still home to several wild progenitors of the first species to be domesticated: these were all annuals that produced edible seeds: wheat, barley, pea, lentil, chickpea and vetch. The first change brought about by domestication was the loss of the ability of wild plants to shatter seed. While this mechanism is essential in the wild, it becomes a nuisance under cultivation.

In addition to being annuals, the first domesticated plants produced seeds which were easy to store and to grow, and grew quickly, providing a ‘regular’ food supply.

Crop domestication occurred independently in geographically distant regions: in China rice and millet were domesticated by 7,500 BC followed by mung beans and soybeans, the latter about 4,000 BC. Potato and cotton were domesticated in the North of Latin America 4,500 BC and 7,500 BC, respectively, while Sunflower was domesticated in North America about 3,000 BC. In the Sahel local rice and sorghum were domesticated by 5,000 BC.

Domestication was a long process, and full dependency on domesticated crops and animals did not occur until the Bronze Age.

The so called Neolithic Revolution marked an increase of man’s ‘control’ over nature. It was accompanied by the formation of what we now call ‘indigenous or local knowledge’ – a type of science without records that can be recognized by informal discussions with farmers in areas where modern plant breeding has not yet arrived.

Local knowledge: three examples

The explorers of Eritrea

Eritrea, a newly independent country, has a several thousand year old agricultural history. In many villages there are a few farmers who operate quite differently from others: they actually explore what other farmers are growing and what is available on the markets, sometimes walking up to 40 km per day. They may come back from their travel with a handful of seed, or a few spikes or panicles. They then space-plant this seed in a very small piece of land, chosen among the best of the village; the plants are carefully observed and, if considered sufficiently new and interesting, harvested separately or in bulk depending on the variability present. The harvested seed is then distributed to other farmers for further testing in different conditions. At the end of the process a new variety may have been produced. One of the leading wheat varieties in Eritrea is said to have originated in this way.

The rice breeder in Sikkim

Sikkim is the northernmost part of India, between Nepal and Bhutan. It is a highly mountainous region with a great variety of crops and wild life. In a village south west of Gangtok (the state capital), in a high-rainfall area, I met a farmer who expressed his community's disappointment with all the new rice varieties introduced by the Ministry of Agriculture, because of their poor taste. For this reason, he said, each farmer keeps his own variety, maintaining it by carefully selecting (before harvesting) the best panicles, which are then stored for the next planting season, while the rest of the crop is consumed. As all the farmers follow this methodology, and because the original populations were highly heterogeneous, each farmer probably has a different heterogeneous variety, thus maintaining very high levels of biodiversity in the village fields.

Coco: the Cuban bean germplasm expert

Coco (this is how everybody calls him) is a Cuban farmer in the mountains north of Havana. He maintains a collection of over 100 different varieties of beans (*friolles*), one of the staple foods of Cuban farmers. Each variety is grown in a separate plot, with a small peg and a label (with name and number). Visitors come (even from outside the country) to see the different types and to choose one or more to grow on their own farms. In addition to the large 'collection' plots, Coco grows a few plants of most of the same varieties in his regular field (between rows of corn, to best utilize the little land he owns) for his own consumption; Coco knows each variety as a father knows his children, and can tell the colour of the seed without opening the pods and which kind of dishes each variety is good for. He also keeps at home few seeds of each variety in small, carefully labelled glass bottles, so that in the case of very bad climatic events nothing gets lost - a rudimentary but effective gene bank (see later).

When asked why he does all this, Coco says: 'when I feel upset, or sad or worried, I come here and as soon as I look at all this diversity I feel better!'

One of the major differences between 'traditional knowledge' and modern science is that the first is based on repeated observations over time while the second is based on repeated observations in space (replications). Another difference is the way in which they are communicated: while 'traditional knowledge' is largely shared in an informal, mostly unwritten way, modern science is communicated almost always in a written and highly formal way. Therefore, it is difficult for scientists to elicit 'traditional knowledge' using the forms of communication of modern science.

Local knowledge and biodiversity: lessons

The three examples in the last section - and there are many more that could be quoted - tell us that long before Mendel and long before plant breeding as we know it today, farmers planted, harvested, stored and exchanged seeds, and fed themselves and others, and in doing all this they built a considerable amount of knowledge about crops, their characteristics and possible uses, and their interactions with the surrounding environment.

All this knowledge has been largely ignored by modern plant breeding.

While slowly and steadily improving their crops farmers also maintained a large amount of biodiversity. As in the case of local knowledge, the deliberate maintenance of diversity can only be inferred from what we observe in the so called 'primitive' agricultural systems still practiced by poor farmers in remote and/or marginal conditions.

A careful observation of these systems shows that farmers tend to dilute the risk associated with practicing agriculture in difficult conditions using various combinations of three levels of biodiversity: different crops, different cultivars of the same crop, and/or heterogeneous cultivars to retain adaptability and to maximize adaptation *over time* (stability or dependability), rather than adaptation *over space*. Diversity and heterogeneity serve to disperse or buffer the risk of total crop failure due to unpredictable environmental variation. As we will see later this is in sharp contrast with the trend of modern plant breeding towards uniformity over space.

Genetic erosion before Mendel

Despite what was discussed in the previous sections, genetic erosion started even before modern plant breeding, due mostly to two causes - both associated with human action. The two causes have a common denominator, known as the 'bottle neck effect' which is an evolutionary event in which a significant percentage of a population or species is killed or otherwise prevented from reproducing, and the population is reduced by 50% or more, often by several orders of magnitude.

The two main causes of the early genetic erosion are known as the 'Domestication Syndrome' and the 'Columbian Exchange'.

'Domestication Syndrome' indicates the process of reduction of genetic variability associated with the fact that the Neolithic man used a limited number of wild progenitors to select for those traits, such as the reduction or loss of seed dispersal mechanisms (brittle rachis in cereals, shattering pods in legumes), reduction/loss of seed dormancy, a more compact growth habit, earliness, gigantism, photoperiod insensitivity, and reduction/loss of toxic compounds. It is believed that traits associated with those selected against during domestication may have been lost.

The second cause, known as the 'Columbian Exchange', derives its name from Columbus, but it refers to the enormous and widespread exchange of plants, animals, foods, human populations (including slaves), diseases and ideas between the Eastern and Western hemispheres that occurred after 1492 - perhaps the first example of globalization of agriculture and of adaptation of crops to new environments and climates. The Columbian Exchange moved crops from the place of domestication to other areas through the early great explorations. Plants domesticated in the Americas, such as maize, cotton, tomato, tobacco, cacao, potato, sweet potato, beans, pepper, pumpkin, pineapple, papaya, went to Europe. Plants domesticated in Europe, Africa or Asia, such as wheat, barley, coffee, rice, citrus, cabbage, garlic, onion, sugarcane, apple, pear, peach, went to the Americas. Similarly with animals: cats, dogs, donkeys, horses, sheep, goats, cattle and camels went from Europe to the Americas, while alpacas, guinea pigs and lamas went from the Americas to Europe.

In both cases there was a bottleneck effect due to the small number of individuals which were transported.

The best known (and most disastrous) consequence of the Columbian Exchange is the potato famine, which caused widespread misery in Ireland between 1845 and 1849 and is now recognized as the worst human disaster of 19th century Europe.

In 1841 the population of Ireland was 8.5 million people. In 1845 a disease called late blight, caused by the fungus *Phytophthora infestans* destroyed half the potato crop. This was the first of three consecutive failures of the potato crop. When the 1847 crop failed also, the whole nation was faced with starvation. This was when the first wave of immigration began. By 1851, at least a million Irish were dead while another 1.5 million had arrived in America to start a new life (Miller and Wagner, 1994).

Evolution after Mendel

The interaction between people and plants took on a completely new dimension after the discovery of Mendel's laws about a century ago, with man assuming a dominant role over evolution with the help of progressively more sophisticated technologies. This is evident from the comparison of events in the last 150 years with those during the period from the origin of agriculture to Mendel, and the even longer period which ended with the origin of agriculture. Some of the key events after Mendel published the results of his experiments on pea in 1886 are:

1902 Mendel's principles were discovered and verified, marking the beginning of modern genetics;
1953 Crick and Watson solved the three-dimensional structure of the DNA molecule;
1966 Nirenberg and Khorana cracked the genetic code;
1972 Berg and Boyer produced the first recombinant DNA molecules;
1977 The first genetic engineering company (Genentech) was founded;
1993 FlavrSavr tomatoes, genetically engineered for longer shelf life, were marketed.

Two major changes took place in this period which profoundly affected the evolution of plants, particularly of domesticated crops. Firstly, plant breeding was moved from farmers' fields to research stations and from farmers to scientists. What was done by very many farmers in many different places was now done by relatively few scientists in a few places. Secondly, plant breeding gradually went from publicly to privately funded: as a consequence not all crops were treated equally, and some became 'orphan crops', neglected by science. They include some important food crops such as banana, cassava and yam. In these changes there is no evidence that any use was made of, or any attention was paid to, the local knowledge accumulated over thousands of years.

It is interesting to note that in the early part of the 20th century a number of scientists were actually advocating an environmentally friendly type of plant breeding. In 1923 H.K. Hayes wrote 'The importance of plant breeding as a means of obtaining varieties which are adapted to particular environmental conditions is becoming more generally recognized.' In 1925, F.L Engledow added 'We can no longer hope, as breeders once did, for the new form which everywhere and in all years will excel. Our hope is of breeding for every locality the form best adapted to the environment it offers'.

However, the dominant breeding philosophy which eventually emerged as a consequence of what is known as the 'Green Revolution' was based on Wide Adaptation, i.e. the selection of varieties able to perform well in many different locations and countries, having lost photoperiod sensitivity and vernalization requirement.

The term Green Revolution was coined in March 1968 by William S. Gaud, the director of the U.S. Agency for International Development (USAID) to indicate the outcome of a development strategy based on a) new crop cultivars, b) irrigation, c) fertilizers, d) pesticides and e) mechanization. Within that strategy, the new varieties were obtained by selecting for wide adaptation. Not only was this exactly the opposite of what farmers had done for millennia, but the term wide adaptation was somewhat misleading because it indicates wide 'geographical' adaptation rather than wide 'environmental' adaptation (Ceccarelli, 1989). In fact the agricultural environments in which these 'widely adapted' varieties were successful were actually very similar (high rainfall and good soil fertility) or were made similar by adding irrigation water and fertilizers when farmers can afford them. This caused three major problems. First, the heavy use of chemicals soon began impacting the environment. Second, the poorest farmers and particularly those living in marginal environments were bypassed because they could not afford to purchase the chemicals needed to create the right environments for the new varieties - not all scientists agree on this, but most of the poor farmers do. The father of the Green Revolution, Norman Borlaug, pointed out recently, 'despite the successes of the Green Revolution, about two billion people still lack reliable access to safe, nutritious food, and 800 million of them are chronically malnourished' (Reynolds and Borlaug, 2006). Third, there was a dramatic decline in agricultural biodiversity because on one hand hundreds of genetically diverse local varieties selected by farmers over millennia for specific adaptation to their own environment and uses were displaced, and on the other hand the new varieties (despite having different names) were all very similar in their genetic constitution.

Diversity and suicide

The decline in agricultural biodiversity can be quantified as follows: while it is estimated that there are approximately 250,000 plant species, of which about 50,000 are edible, we actually use no more than 250 - out of which 15 crops give 90% of the calories in the human diet, and 3 of them, namely wheat, rice and maize give 60%. In these three crops, modern plant breeding has been particularly successful, and the process towards genetic uniformity has been rapid - the most widely grown varieties of these three crops are closely related and genetically uniform (pure lines in wheat and rice and hybrids in maize). The major consequence is that our main sources of food are more genetically vulnerable than ever before, i.e. food security is potentially in danger.

The two best known examples of the consequences of genetic uniformity are the southern corn leaf blight epidemic of 1970, and Ug99, a virulent strain of stem rust which attacked wheat for the first time in Uganda in 1999.

The southern corn leaf blight epidemic of 1970 was caused by a new race of the fungus *Helminthosporium maydis*, which reduced corn yield by 15% nationwide. The widespread use of Texas male-sterile cytoplasm (T) in the production of hybrids was an important factor in the severity and spread of the epidemic because it made all the hybrids equally susceptible. Losses were over 700 million bushels (a bushel of corn corresponds to 25.4 kg). Reserves of corn and other grains eased the impact on the economy and food supplies but there were important domestic and foreign effects.

Ug99 is a virulent strain of the black stem rust fungus *(Puccinia graminis)*, which was first discovered on wheat in Uganda in 1999. Because of the genetic similarity of the wheat varieties grown globally, the disease was found in Kenya in 2001 and in Ethiopia in 2003. In January 2007 spores blew across to Yemen, and north into Sudan. From Yemen and Sudan the spores could easily blow into Egypt, Turkey and the Middle East, and on to the Indian subcontinent where a billion people depend on wheat. In February 2008 the presence of UG99 has been officially reported in Iran.

Erosion of genetic diversity affects not only crops but the entire ecosystem: during the last 20 years population has increased by 34% (from 5 to 6.7 billion); land per person is 2.02 ha from 7.91 ha in 1900 and will drop to 1.67 in 2050; 250% more fish are being caught than the sea can produce; species are becoming extinct a hundred times as fast as the rate in the fossil records.

The situation is so serious that the hypothesis has been formulated that we are perhaps moving towards a sixth mass extinction (Novacek, 2007) judging from the recent human-induced extinctions and today's threats to species. Limiting the rate of extinction will be difficult: considering that already in 2007, 25% of corn production in U.S.A. was used for biofuel. If USA's 2017 target for biofuels will be met, and if additional land will be brought under cultivation to replace lost food production, twice as many species will be driven to extinction through habitat loss as would be saved by mitigating climatic changes.

There are several other examples of disasters caused by genetic uniformity: often the damage caused is on relatively unknown crops, such as Napier grass or Taro, in distant places and affect a few thousand people - not enough to reach the front pages of newspaper. And, after all why should we worry about loss of diversity? A large amount of genetic diversity has and is being collected and stored in gene (or germplasm) banks, in which every sample (usually of seed) is kept in airtight containers at -10 to -200C and 5 to 7% humidity for 50 to 100 years (Damania, 2008). From time to time a given amount of material is taken out of the gene bank, planted in the field and 'rejuvenated': the fresh seed is then stored again. Worldwide, 1308 gene banks are registered and conserve a total of 6.1 million accessions, including major crops, minor or neglected crop species as well as trees and wild plants. Of the 30 main crops, more than 3.6 million accessions are conserved *ex situ* (FAO, 1996). In 2008 a new international gene bank, the Svalbard Global Seed Vault (SGSV), has been constructed on a mountain deep inside the Arctic permafrost on Norway's Svalbard archipelago. The vault is a facility capable of preserving the vitality of seed for thousands of years and therefore is a repository of last resort for humanity's agricultural heritage.

On one hand these collections serve a very important purpose - avoiding the loss of individuals and species, and of the genes, which may be unique, they carry. On the other hand by 'freezing' seeds they also 'freeze' evolution at the time of the collection. Therefore, many advocate that together with the conservation in gene bank - *ex situ* -, the diversity should also be conserved in its original locations - *in situ* -, where the plant populations can continue to evolve.

Participatory plant breeding

In the last two sections I will address the question of whether the evolution of plants guided by man could have gone along a different direction; and more specifically whether we could have fed ourselves without destroying the planet.

To address this question I will first question some of the basic assumptions of plant breeding (Ceccarelli and Grando, 2002) and then describe a model of plant breeding which combines modern science with the 'local knowledge' of which some examples were given earlier, brings plant breeding back into farmers' hands -which is different from bringing farmers back into breeding as a recently publication suggests (Almekinders 2006), and also encourages a return to diversity. This model is known as Participatory Plant Breeding (PPB) and can be considered as a type of evolutionary plant breeding because of its beneficial effects on biodiversity (Ceccarelli and Grando, 2007).

PPB is first of all a type of participatory research. In participatory research farmers (or in general, users) are involved in designing and developing technologies – not just in testing the final products of scientific research as done in conventional (non-participatory) research. Specifically, there are several differences between conventional and participatory plant breeding: in conventional plant breeding new varieties are selected on research stations by breeders and the final products are tested on farm. Adoption occurs at the end of the breeding process. In PPB new varieties are selected in farmers' fields jointly by breeders and farmers and adoption occurs during the breeding process. Actually there are some breeding programs which are conducted in farmers' fields, but without genuine farmer involvement.

Scientifically, conventional plant breeding and PPB are the same process but they differ in three key organizational aspects:

- Trials are conducted in farmers' fields and managed by farmers;
- Farmers participate as equal partners in the selection process;
- The process can be duplicated independently in a large number of locations and of countries, with different methodologies depending on the crop and the country.

At ICARDA, PPB was first initiated with barley in Syria in 1996 in nine villages. It expanded to 11 villages in 2001 and eventually to 24 villages in 7 provinces in 2003. It is important to note that, depending on farmers' preferences, different villages test different types of breeding material – in each cycle of selection we start with more than 400 lines and populations. The program is very flexible and can easily and rapidly incorporate changes in farmers' preferences as well as changes in agronomic practices. From 2003 to 2008 it was conducted in collaboration with the Ministry of Agriculture in an attempt to institutionalize it. In 2008 the Ministry of Agriculture has declared this work 'a threat to the National food security' and therefore it is now conducted only with the collaboration of the farmers in a reduced number of villages.

From Syria, PPB has spread to Morocco, Tunisia, Yemen, Jordan, Egypt, Eritrea, Algeria and Iran and from barley to wheat, lentil, chickpea and faba bean, usually following requests from farmers. The plant material differs from country to country, and between villages within the same country. In addition, and again following specific requests from farmers, these programs largely use old varieties - landraces - that often have disappeared from the field but are still available in gene banks. Therefore, with PPB what we do - and here I quote an old Eritrean farmer who on his very first day of participation told the Director General of the Research Institute - is ‘to bring back into farmers’ hands that science which was taken from them many years ago’.

In other words, we are reversing the change that has occurred in the last 100 years or so, when ‘breeding’, done by many farmers in many different places, was taken over by a few scientists at a few places.

PPB can impact positively on biodiversity because, being a highly decentralized process, it produces varieties which are different – from country to country, from village to village within a country, and even within the same village depending, among other factors, on the age, wealth and gender of the farmers. In addition, these varieties are often not homogenous, i.e. they are still genetically variable – in contrast to the majority of varieties produced by conventional breeding in which all the plants are genetically identical.

It is because of its beneficial effect on these different levels of biodiversity – which often co-exist within the same farm - that PPB can also be defined as ‘evolutionary breeding’. From this point of view it is the ideal complement to the collections held in gene banks because it allows crops to continue to evolve and to adapt to new agronomic techniques, new uses and eventually new climates.

Even though PPB has been practiced for only 20 years, there are already indications of impacts at various levels:

- Adoption: many new varieties have already been adopted by farmers even though the program is relatively new;
- Institutional: in several countries, policy makers and scientists are showing much more interest in PPB as it is expected to generate more relevant results more quickly and at a lower cost;
- Farmers’ skills and empowerment: the interactive nature of the PPB programs has considerably improved farmers’ knowledge, their ability to negotiate, and their dignity. It is because of their skills and their increased self-confidence that farmers in a number of countries will start exploiting the additional advantages of evolutionary plant breeding as described earlier;
- Biodiversity: different varieties have been selected in different areas in each country, in response to different environmental constraints and users’ needs. Interest in landraces has increased as indicated by the request of farmers in

Syria, Jordan, Algeria, and Iran to have access and to evaluate their landraces kept in gene banks.

Evolutionary plant breeding

Evolutionary plant breeding is an old concept introduced by Suneson more than 50 years ago (Suneson, 1956), and its 'core features are a broadly diversified germplasm, and a prolonged subjection of the mass of the progeny to competitive natural selection in the area of contemplated use'.

As we have seen above PPB does not follow the methodology described by Suneson but it allows some degree of adaptation of the genetic material and more importantly builds the capacity of local communities to handle populations of the type described by Suneson.

At the moment of writing we are in the process of deploying a population resulting from mixing an equal number of seeds of nearly 1600 F2 obtained by crosses done at ICARDA in a number of locations in Syria, Jordan, Iran, Algeria, Egypt and Eritrea. We have already discussed with farmers that the handling of this complex population is very simple, as it only needs to be planted and harvested for the years to come in locations affected by either abiotic (drought, high and low temperatures, salinity, soil deficiencies) or biotic (diseases and insect pests) or a combination of both, and let natural selection slowly increase the frequency of the most adapted genotypes. With the experience and the skills developed through PPB, farmers and breeders can superimpose artificial selection for traits which are of importance in each specific location. Different farmers may well select different plants and grow the progenies in their own field and this can be repeated over the years; the expectation is that the varieties derived from this evolving population at any time will be better adapted that those derived earlier - for this reason I described the method to a group of Iranian farmers as plant breeding for their children rather than themselves.

There are many additional ways of using this population; in addition to single plant or single spike selection - which may be developed into pure lines or can be mixed to form a superior mixture - the population grown in a given location initially by one farmer, can be subdivided into sub-populations to be grown by other farmers who might have very specific conditions. Not all the seed harvested in any one year is needed to maintain the population and the extra seed can be used to sow the regular crop particularly in those situations in which uniformity is not required. In some extreme locations the rainfall can be occasionally so low that nothing will survive: in those cases it is advisable to have access to supplementary irrigation in order to save the population and with it all the adaptation which has accumulated up to that year.

One major advantage of evolutionary breeding is its simplicity and its enormous potential to adapt crops - any crop - to climatic changes as well as all other agronomic changes which might occur in the future.

Conclusions

We have shown that it is possible to organize plant breeding programs, and therefore to guide plant evolution, in a way that combines modern science and local knowledge. The experience gained working with different crops in a number of countries indicates that:

- Farmers are excellent partners. The quality of participation is unrelated to race, gender, wealth, literacy, religion, and they readily share their knowledge with scientists;
- Participatory and evolutionary plant breeding are able to increase crop biodiversity, promotes the use of landraces and wild relatives, and allows crops to continue to evolve - and therefore are the most dynamic way to cope with climatic changes.

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