



GENES & GENETIC DIVERSITY



EXPLAINING GENETIC DIVERSITY
AND HOW IT CONTRIBUTES
TO OUR LIVES AND FUTURES

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Every **cell** of every individual of every **species** contains **genes**. No two individuals have exactly the same genes – that is, unless they are **clones**. The discovery of genes, what they look like and how they are passed from parent to child, led to a revolution in science in the nineteenth and twentieth centuries.



GENES AND DIVERSITY

It all started with a scientist and monk called Gregor Mendel. In the mid 1800s Mendel experimented on peas in the gardens of the Abbey of St. Thomas in Brno, now in the Czech Republic.



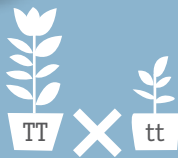
In one experiment, Gregor Mendel selected a tall plant, then crossed (or bred) it with a short plant. He observed how high the plant offspring grew and then how high the next generation of offspring grew. Looking at the pattern of tall-to-short plants, he was able to describe the basic laws of genetics. These laws, roughly summarised, state that when two parents reproduce each will pass on only half of their genetic material to their offspring. Each offspring will have exactly the same number of genes from their mother, and their father. These genes are passed on quite randomly, so all offspring inherit something different and no two siblings are quite the same, as can be seen in the figure on the opposite page. There are exceptions, however. Identical twins are nearly genetically identical, thanks to a rare event in nature where one fertilised egg divides and develops into two offspring. In certain plant families, clones are actually the norm. For instance, when a new bamboo or banana plant shoots up from the side of a parent plant, it is a clone.

OPPOSITE PAGE: FLOWER OF PEA PLANT.
© Giulia Tiddens



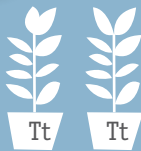


A



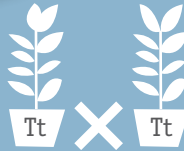
A tall pea plant (TT) is crossed with a short pea plant (tt).

B



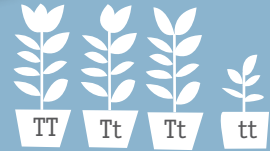
Offspring get one gene for a given trait, like tallness, from each parent. The different traits do not blend. The result of this cross is two tall plants.

C



When these two tall plants are crossed, however..

D



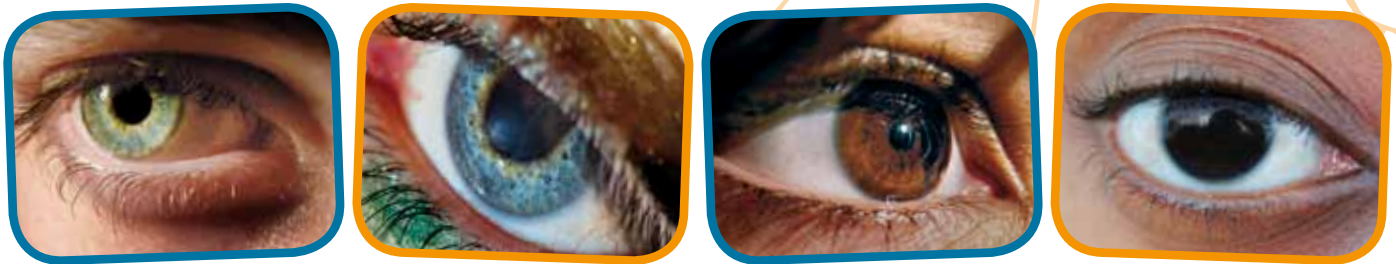
...the result is three tall plants and one short plant because tallness is a dominant trait and shortness is recessive. But recessive traits can crop up in later generations if two copies of a recessive gene are present.



GENETIC DIVERSITY

Putting it simply, genes produce **traits**. A trait is a characteristic such as curly hair, freckles or blood type. Genes act singularly or in combination to produce traits, many of which are very obvious. Human eye colour, for instance, is determined by a combination of genes, giving colours of blue, green, brown, hazel, grey, chestnut and variations inbetween. This is **genetic diversity**.

When you look at the eyes of the population of a town or country in Europe or North America, there may be great variation in eye colour. Elsewhere, for instance in parts of Africa and Asia, eye colour may not vary much at all.



GENETIC DIVERSITY WITHIN A SPECIES – HUMAN EYES.

(From left to right)

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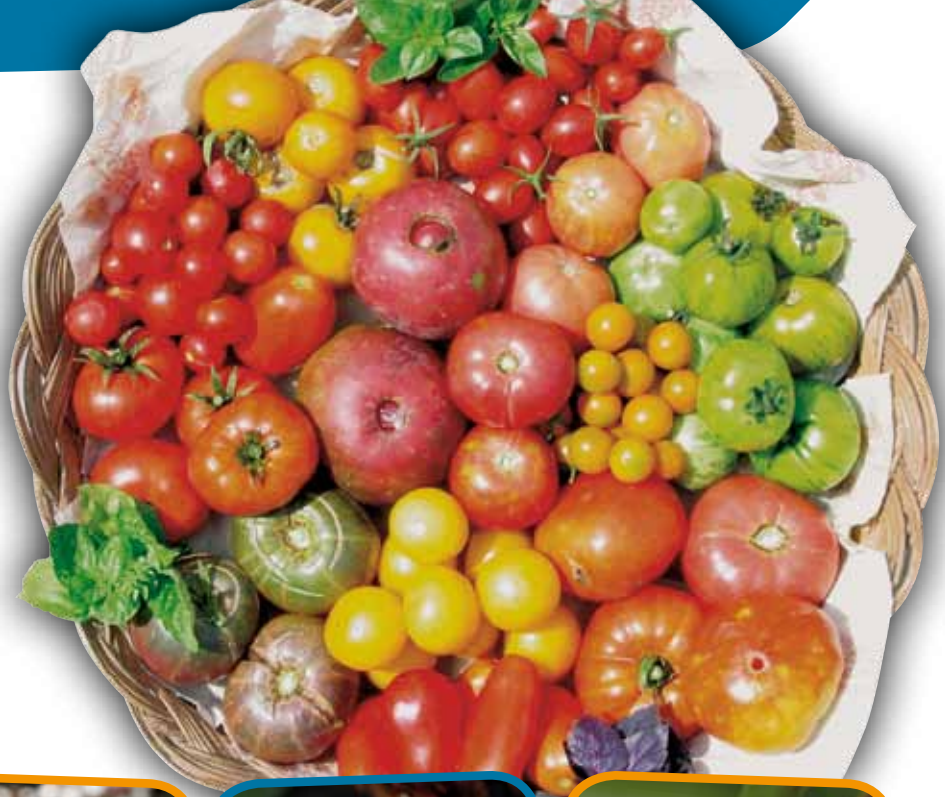
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The eye colour example shows diversity within a single species – the human species. But there's also genetic diversity within a group of species – pigeons, for instance! If you travel to an island or a forest in the tropics, you will almost certainly find pigeons. You will recognise that they are pigeons, but they are not the same as the pigeons you know from back home. They are genetically quite different, although clearly related. There are many more diverse groups of species than pigeons, especially in the insect world!

TOMATOES: THE SAME SPECIES BUT A LARGE VARIETY OF SHAPES, COLOURS, SMELLS AND ESPECIALLY TASTES.

© Reuben Sessa



THERE ARE 4 810 DIFFERENT SPECIES OF FROGS WORLDWIDE. HERE ARE FOUR EXAMPLES.

(From left to right)

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© Diego Adrados (age 14)



In a similar way, we can measure the total genetic diversity of an **ecosystem**. Some ecosystems are more diverse than others. A small area of forest on the Atlantic coast of Brazil contains more plant and animal species, and therefore more genetic diversity, than the entire USA.



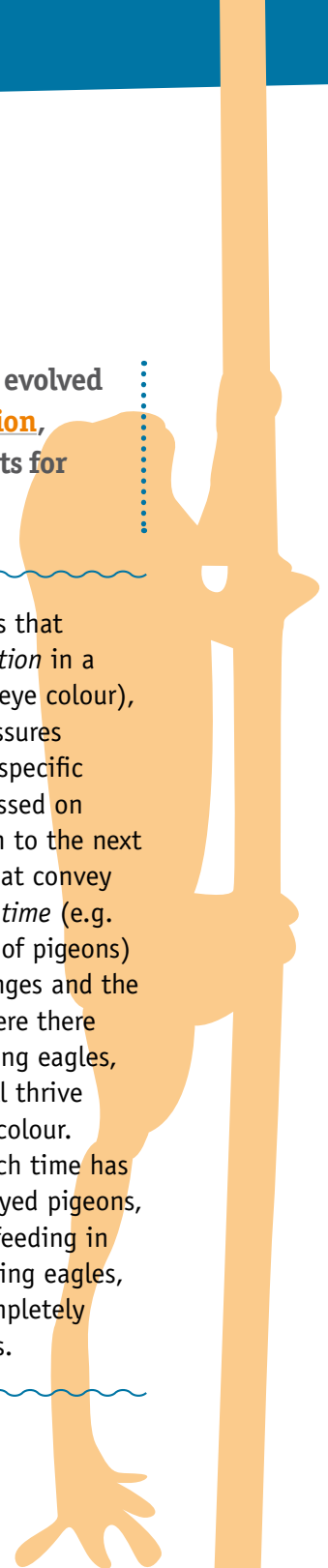
FORCES OF EVOLUTION

There hasn't always been as much genetic diversity on Earth as there is today. It evolved from practically nothing. There are four ingredients to **evolution**: **natural selection**, **variation**, **inheritability** and **time**. The combination of these ingredients accounts for the evolution of species – everything from whales to drug-resistant bacteria!

Let's go back to eye colour, only let's imagine there is a forest that is home to a population of pigeons with different eye colours – let's say some have green eyes and others grey eyes. By chance, the green-eyed pigeons are particularly good at seeing in the dark. In this imaginary forest, the pigeons feed all day on delicious figs only available on a small number of fig trees. During the night, the birds rest. But a change in the climate drives a new species of pigeon-hunting eagle into the area. The eagle's talent for diving from a great height onto pigeons feeding in the fruit trees depends on good daytime visibility.

The pigeons soon begin to hide in the daytime and feed at night. The grey-eyed pigeons have trouble finding fruit at night and are caught by the eagle during the day. The pigeons with green eyes, however, are able to eat without the threat of the eagle because they can feed at night. The green-eyed pigeons' green-eyed offspring are more successful! They live longer and have more offspring. As the grey-eyed pigeons disappear, the pigeon population starts to change. Over time, most of the newborn pigeons have the same eye colour – green!

This story illustrates that where there is *variation* in a population (e.g. in eye colour), new or existing pressures (e.g. eagles) *select* specific *inheritable traits* passed on from one generation to the next (e.g. green eyes) that convey an advantage. Over *time* (e.g. several generations of pigeons) the population changes and the species *evolves*. Where there are no pigeon-hunting eagles, the pigeons can still thrive whatever their eye colour. Eventually after much time has passed, the green-eyed pigeons, with their skills at feeding in the night and avoiding eagles, could become a completely independent species.



WHO'S MORE DIVERSE, HUMANS OR MAIZE?

Although humans may look diverse they are actually genetically very similar. In fact there is more diversity in a single field of maize than there is in the entire human population! Can you imagine the potential for maize to develop into many different types of crops?



MAIZE.
© Global Crop Diversity Trust



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© Richard [www.flickr.com/photos/68137880@N00/3082497758]



© FAO/Riccardo Gangale



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GENETIC DIVERSITY IN USE

Diversity plays a key role in evolution and the survival of species. There are endless examples, from the dinosaur to the dodo, where a species lacked variation or the ability to adapt to pressures in its environment and became extinct. In the case of humans, we have so successfully adapted to our environment that we are now one of the major factors shaping and changing the planet. Despite this fact, we are still highly dependent on diversity at all levels.

Firstly, at an ecosystem level, diversity provides our **habitats** and environments. At the most fundamental level, plants provide the oxygen in the atmosphere. Our diverse habitats provide soils, water, homes, cover from the sun or wind, and many other **services** to support life.

Secondly, species diversity is important because humans eat an **omnivorous** diet and live in diverse environments around the world. Unlike cows and pandas, if we always eat the same, single type of food, we become sick because of a lack of essential nutrients in our diet. Diversity in our food systems is important to keep us alive. Diversity has enabled humans to colonise and thrive in many diverse living conditions around the world. Diversity also provides our medicines, timber, paper, fuel, raw products for manufacturing and just about everything else upon which human civilisation is based.

Genetic diversity and the variation of traits that it provides allow individual species to adapt to changes in the environment. All species, such as humans, are under the constant threat of a new flu or other disease, as well as weather and temperature changes. Food may turn up reliably in supermarkets and shops but behind the scenes scientists and farmers are working constantly to keep up yields to meet the demand. Genetic diversity is the basis on which crops adapt and evolve in the face of challenges.

Over the past 12 000 years, farmers have selected individual plants that yield more, taste better, or survive well under pressure. In different places or times, thousands of farmers used the seed from their preferred plants to sow the next season's crop. In this way people have shaped crops to meet their needs under specific conditions. Thousands of crop varieties have been developed around the world. Modern-day breeders similarly select plants with specific traits, using various techniques or tools to speed up the process and to produce the high-yielding varieties that we are likely to buy in supermarkets. The box "The Making of Our Daily Bread" illustrates the importance of genetic diversity to wheat farmers.

THE MAKING OF OUR DAILY BREAD

In the 1940s, farmers were losing much of their wheat crop to a fungus known as stem rust. The fungal spores are carried by the wind from field to field. The spores can land on any part of the wheat plant and infect it, forming pustules on the stem and leaves, and causing the plant to produce much less seed, if not to die altogether.

Breeders screened wheat **genebanks** – storehouses of genetic diversity – for plants that do not appear to get the symptoms of the disease when grown in the presence of the fungal spores. They crossed popular wheat varieties that die from stem rust with the **wild relatives** that seem to resist the

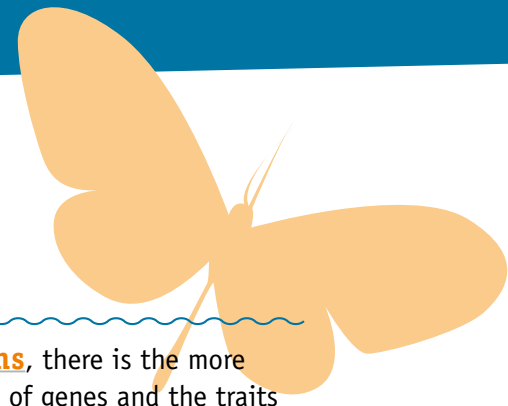
disease to breed new forms of disease-resistant wheat that produce good yields. The new varieties were taken up enthusiastically by farmers, and spread worldwide. One of the scientists responsible, Norman Borlaug, went on to win a Nobel Prize for his efforts. There is probably not one single reader of this book who has not benefited from Norman Borlaug's work.

In 1999, a new stem rust appeared in Uganda and spread into the Middle East. Plant breeders are screening all their genetic resources once more to find wheat varieties with resistance to the new disease.

It is important to realise that a new devastating disease in a major crop is not news – this is business as usual in the world of agriculture! So it's important to keep a large genetic diversity to be able to produce new varieties which are resistant to these new diseases.

WHEAT GROWING IN SPAIN.
© Bernat Casero





GENETIC DIVERSITY UNDER **THREAT**

A place without genetic diversity is chronically fragile and poised for disaster. In 1845, a deadly disease destroyed the potato crop, the main crop of the rural poor in Ireland, leading to the starvation or migration of two million people. There have been many events like this in human history.

Apart from dramatic famines or **extinctions**, there is the more gradual threat of **genetic erosion** or loss of genes and the traits that they produce. Present-day agricultural, forestry or aquaculture systems are more **homogeneous** (similar) over wide geographical areas than ever before, cultivating a smaller number of the same species and varieties. But diversity is still very much appreciated and used, especially in areas where people depend entirely on their crops throughout the year as a source of food. How else does a family eat if one crop fails? A very rich source of crop diversity is also hidden in remaining wild habitats, where the **wild relatives** of crop species can still be found.



THE FLOWERS OF CULTIVATED POTATOES (left) AND WILD POTATOES (right).

© Martin LaBar
© Arthur Chapman

In the volatile world in which we live, diversity is an important factor. A large number of scientists, breeders and farmers are working to safeguard biodiversity to allow humans to meet the challenges of an unpredictable future. This can be achieved in different ways.

GENETIC DIVERSITY FOREVER

Conserving seeds is more complicated than you might imagine. The easy option involves packing materials into airtight containers and storing them at low temperatures. For plants that don't produce seeds, the materials are conserved as miniature plantlets in glass tubes in the laboratory or as tissue samples frozen to ultra-low temperatures in liquid nitrogen. In both cases, the materials may remain dormant for several decades although they still need to be checked regularly to ensure that they are not deteriorating.

A genebank is not like a library where browsers can come and read the books or ask for particular titles or authors. You cannot tell from a seed how the plant will grow, whether it will deal with diseases or certain climates, nor how the harvested crop will taste. One of the most important aspects of genebanking is to test the plants and document meticulously their traits and characteristics. Genebanks keep thousands of samples. For instance, there are more than 250 000 entries for maize in different genebanks around the world. That is a lot of seeds to look through to find the maize that may work for you!

The ultimate safe place for crop diversity is the Svalbard Global Seed Vault in Norway. Here, within the Arctic Circle dug into a frozen mountainside, safe from hurricanes, floods, electricity blackouts and wars, the genebanks of the world are depositing samples from their collections as a safety backup. So far, more than 500 000 seed samples are in storage. Whether these seeds will ever be needed is anyone's guess. This diversity represents a multitude of options that we can provide to the people of the distant or maybe not-so-distant future.



Communities or individual farmers have been safeguarding their seeds and animal breeds since organised agriculture began. With a better knowledge of genetics and evolution, scientists began to recognise the significance of diversity and collect rare breeds and crop varieties. Today there is a worldwide network of institutes that conserves the seeds, roots and tubers of crops in genebanks.

THE SVALBARD SEED VAULT CUT WITHIN THE MOUNTAIN IN NORWAY.

© Global Crop Diversity Trust

ENTRANCE TO THE SVALBARD SEED VAULT IN NORWAY.

© Svalbard Global Seed Vault/Mari Tefre



The International Maize and Wheat Improvement Center (**CIMMYT**) is a research and training center with the objective to sustainably increase the productivity of maize and wheat systems to ensure global food security and reduce poverty.

The Tropical Agricultural Research and Higher Education Center (**CATIE**) works on increasing human well-being and reducing rural poverty through education, research and technical cooperation, promoting sustainable agriculture and natural resource management. One of its areas of work is improving coffee production systems.

THE WORLD'S LARGEST EX SITU COLLECTIONS

This map shows a selection of the important international crop collections.

Source: Global Crop Diversity Trust.



Maize
© Jayegirl99



Coffee
© Rex Bennett

Mexico

Colombia

Peru

Brazil



Beans
© Roger Smith



Potatoes
© Philippa Willitts



Cassava
© CIAT

The International Center for Tropical Agriculture (**CIAT**) has the world's largest genetic holdings of beans (over 35 000 materials), cassava (over 6 000), and tropical forages (over 21 000), obtained or collected from over 141 countries.

The International Potato Center (**CIP**) is a root and tuber research-for-development institution delivering sustainable solutions for the pressing global problem of hunger. It has a large gene bank of potato varieties and other root species.

The Brazilian Agricultural Research Corporation (**EMBRAPA**) develops technologies and identifies practices to improve agricultural production. It is a major research institution for cassavas as well as other tropical fruits such as pineapples, acerolas, bananas, citrus fruit, papayas, mangos and passion fruit.

Bioversity International uses agricultural biodiversity to improve people's lives by researching solutions for three key challenges: sustainable agriculture, nutrition and conservation. Bioversity maintains the international Germplasm Collection of both improved varieties and wild species of bananas.

The Vavilov Research Institute of Plant Industry (**VIR**) undertakes research and development for numerous types of crops and varieties. It supports the collection and maintenance of gene banks for numerous crop species, including barley.

The World Vegetable Center (**AVRDC**) works in four main areas: germplasm, breeding, production and consumption. AVRDC maintains the world's largest public vegetable genebank with more than 59 294 entries from 155 countries, including about 12 000 of indigenous vegetables.



Banana
© Ian Ransley



Barley
© Ian Britton



Vegetables
© AsiaDHRRR

Italy

Syria

Russia

Taiwan

India

Philippines

Nigeria



Yam
© IITA



Chickpea
© Mink



Sorghum
© Global Crop Diversity Trust



Rice
© Siebe

The International Institute of Tropical Agriculture (**IITA**) works on enhancing crop quality and productivity. It works on assessing the growing properties and nutritional content of new varieties of yam and works with other crops such as cowpeas, soybeans, bananas/plantains, cassavas and maize.

The International Center for Agricultural Research in the Dry Areas (**ICARDA**) contributes to the improvement of crops such as chickpea, bread and durum wheats, kabuli, pasture and forage legumes, barley, lentil and faba bean. Other work includes supporting improvement of on-farm water-use efficiency, rangeland and small-ruminant production.

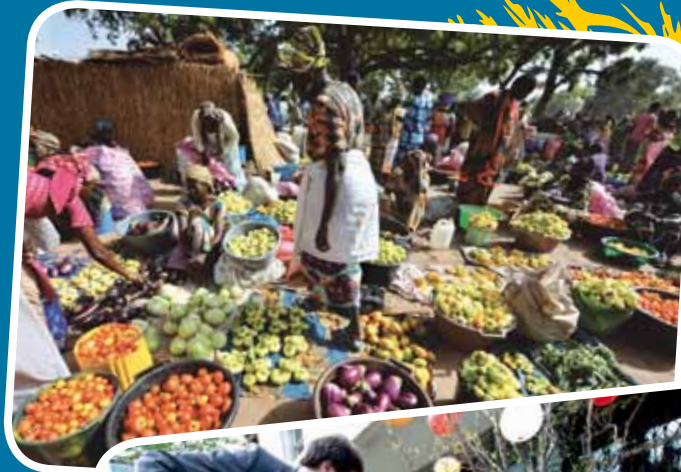
The International Crops Research Institute for the Semi-Arid Tropics (**ICRISAT**) conducts agricultural research for development in Asia and sub-Saharan Africa. Its genebank serves as a world repository for the collection of germplasm of a number of crops including sorghum.

The International Rice Research Institute (**IRRI**) develops new rice varieties and rice crop management techniques that help rice farmers improve the yield and quality of their rice in an environmentally sustainable way. IRRI maintains the biggest collection of rice genetic diversity in the world, with more than 113 000 types of rice, including modern and traditional varieties, as well as wild relatives of rice.



WHAT CAN YOU DO TO CONSERVE GENETIC DIVERSITY?

- ⌘ Visit a local Farmers' Market. The farmers usually grow and sell local varieties of fruits and vegetables that you won't find in the supermarket. By buying their products you are encouraging the farmers to continue growing genetically distinct varieties.
- ⌘ Try growing local fruits and vegetables at home. If you grow two different types of tomatoes, you may see how they sprout, flower and fruit at different times. You will also see how they taste different too!
- ⌘ You can grow plants native to your area in your garden.
- ⌘ You can encourage your school or neighbourhood to set up community gardens.



LOCAL MARKET IN GAMBIA.
© FAO/Seyllou Diallo

TREE PLANTING CEREMONY AT FAO HQ IN ITALY.
© FAO/Alessandra Benedetti

SCHOOL GARDEN IN PERU.
© FAO/Jamie Razuri

❖ Turn vacant or abandoned areas into green lots, where everyone can plant fresh fruits and vegetables, flowers and any other plants they would like to grow. For inspiration visit www.nybg.org/green_up.

❖ You can join a group that helps to conserve diversity or to protect the environment. For example, look for groups that plant trees, take care of animals or run urban farms or gardens.

❖ Reducing waste, recycling garbage and using environmentally-friendly cleaning products all help to protect the environment and reduce the threat to endangered species.

❖ Give a presentation about genetic diversity at your school. You can, for example, talk about the Svalbard Global Seed Vault, where hundreds of thousands of food seeds are being kept safe for the future. You can read more about it at www.croptrust.org.



COMMUNITY SCHOOL GARDEN IN HAITI.
© FAO/Thony Belizaire

SCHOOL ORCHARD IN INDIA.
© FAO/Jon Spaul

STAFF CAMPAIGN TO ENCOURAGE GREEN HABITS AT FAO IN ITALY.
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GROUP WORK IN THE CENTRAL AFRICAN REPUBLIC.
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