Chapter 3

Soil health

Agriculture must, literally, return to its roots by rediscovering the importance of healthy soil, drawing on natural sources of plant nutrition, and using mineral fertilizer wisely

Soil is fundamental to crop production. Without soil, no food could be produced on a large scale, nor would livestock be fed. Because it is finite and fragile, soil is a precious resource that requires special care from its users. Many of today's soil and crop management systems are unsustainable. At one extreme, overuse of fertilizer has led, in the European Union, to nitrogen (N) deposition that threatens the sustainability of an estimated 70 percent of nature[1]. At the other extreme, in most parts of sub-Saharan Africa, the under-use of fertilizer means that soil nutrients exported with crops are not being replenished, leading to soil degradation and declining yields.

How did the current situation arise? The main driver was the quadrupling of world population over the past 100 years, which demanded a fundamental change in soil and crop management in order to produce more food. That was achieved thanks partly to the development and massive use of mineral fertilizers, especially of nitrogen, since N availability is the most important determinant of yield in all major crops[2-5].

Before the discovery of mineral N fertilizers, it took centuries to build up nitrogen stocks in the soil[6]. By contrast, the explosion in food production in Asia during the Green Revolution was due largely to the intensive use of mineral fertilization, along with improved germplasm and irrigation. World production of mineral fertilizers increased almost 350 percent between 1961 and 2002, from 33 million tonnes to 146 million tonnes[7]. Over the past 40 years, mineral fertilizers accounted for an estimated 40 percent of the increase in food production[8].

The contribution of fertilizers to food production has also carried significant costs to the environment. Today, Asia and Europe have the world's highest rates of mineral fertilizer use per hectare. They also face the greatest problems of environmental pollution resulting from excessive fertilizer use, including soil and water acidification, contamination of surface and groundwater resources, and increased emissions of potent greenhouse gases. The N-uptake efficiency in China is only about 26-28 percent for rice, wheat and maize and less than 20 percent for vegetable crops[9]. The remainder is simply lost to the environment.

The impact of mineral fertilizers on the environment is a question of management – for example, how much is applied compared to the amount exported with crops, or the method and timing of applications. In other words, it is the *efficiency* of fertilizer use, especially of N and phosphorus (P), which determines if this aspect of soil management is a boon for crops, or a negative for the environment.

The challenge, therefore, is to abandon current unsustainable practices and move to land husbandry that can provide a sound foundation for sustainable crop production intensification. Far-reaching changes in soil management are called for in many countries. The new approaches advocated here build on work undertaken by both FAO[10-12] and many other institutions[13-20], and focus on the management of soil health.

Principles of soil health management

Soil health has been defined as: "the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive repercussions for soil water and nutrient holding capacity, and ultimately improve crop production"[21]. To that definition, an ecosystem perspective can be added: A healthy soil does not pollute the environment; rather, it contributes to mitigating climate change by maintaining or increasing its carbon content.

Soil contains one of the Earth's most diverse assemblages of living organisms, intimately linked via a complex food web. It can be either sick or healthy, depending on how it is managed. Two crucial characteristics of a healthy soil are the rich diversity of its biota and the high content of non-living soil organic matter. If the organic matter is increased or maintained at a satisfactory level for productive crop growth, it can be reasonably assumed that a soil is healthy. Healthy soil is resilient to outbreaks of soil-borne pests. For example, the parasitic weed, *Striga*, is far less of a problem in healthy soils[22]. Even the damage caused by pests not found in the soil, such as maize stem borers, is reduced in fertile soils[23].

The diversity of soil biota is greater in the tropics than in temperate zones[24]. Because the rate of agricultural intensification in the future will generally be greater in the tropics, agro-ecosystems there are under particular threat of soil degradation. Any losses of biodiversity and, ultimately, ecosystem functioning, will affect subsistence farmers in the tropics more than in other regions, because they rely to a larger extent on these processes and their services.

Functional interactions of soil biota with organic and inorganic components, air and water determine a soil's potential to store and release nutrients and water to plants, and to promote and sustain plant growth. Large reserves of stored nutrients are, in themselves, no guarantee of high soil fertility or high crop production. As plants take up most of their nutrients in a water soluble form, nutrient transformation and cycling – through processes that may be biological, chemical or physical in nature – are essential. The nutrients need to be transported to plant roots through free-flowing water. Soil structure is, therefore, another key component of a healthy soil because it determines a soil's water-holding capacity and rooting depth. The rooting depth may be restricted by physical constraints, such as a high water table, bedrock or other impenetrable layers, as well as by chemical problems such as soil acidity, salinity, sodality or toxic substances.

A shortage of any one of the 15 nutrients required for plant growth can limit crop yield. To achieve the higher productivity needed to meet current and future food demand, it is imperative to ensure their availability in soils and to apply a balanced amount of nutrients from organic sources and from mineral fertilizers, if required. The timely provision of micronutrients in "fortified" fertilizers is a potential source of enhanced crop nutrition where deficiencies occur.

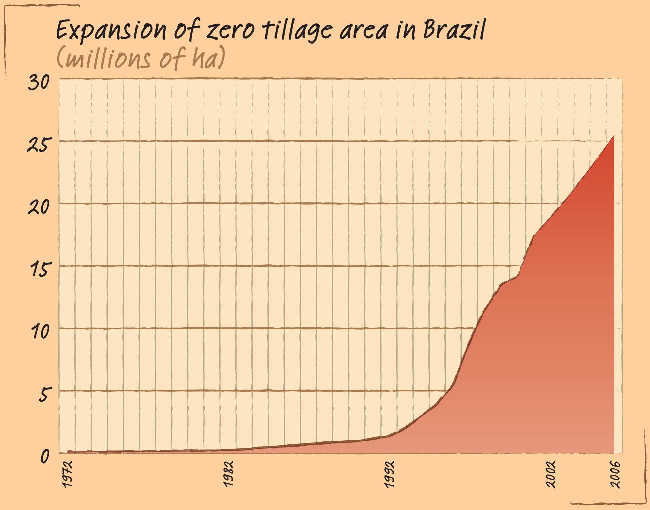
Nitrogen can also be added to soil by integrating N-fixing legumes and trees into cropping systems (see also Chapter 2, *Farming systems*). Because they have deep roots, trees and some soil-improving legumes have the capacity to pump up from the subsoil nutrients that would otherwise never reach crops. Crop nutrition can be enhanced by other biological associations – for example, between crop roots and soil mycorrhizae, which help cassava to capture phosphorus in depleted soils. Where these ecosystem processes fail to supply sufficient nutrients for high yields, intensive production will depend on the judicious and efficient application of mineral fertilizers.

A combination of ecosystem processes and wise use of mineral fertilizers forms the basis of a sustainable soil health management system that has the capacity to produce higher yields while using fewer external inputs.

Technologies that save and grow

No single technology is likely to address the specific soil health and soil fertility constraints that prevail in different locations. However, the basic principles of good soil health management, outlined above, have been successfully applied in a wide range of agro-ecologies and under diverse socio-economic conditions.

Building on soil health management principles, research in different regions of the world has identified some "best-bet" technologies. The following examples describe crop management systems that have high potential for intensification and sustainable production. They address specific soil fertility problems in different agro-ecological zones and have been widely adopted by farmers. They may serve as templates for national partners in devising policies that encourage farmers to adopt these technologies as part of sustainable intensification.



de Moraes Sá, J.C. 2010. No-till cropping system in Brazil: Its perspectives and new technologies to improve and develop. *Presentation prepared for the International Conference on Agricultural Engineering, 6-8 September 2010, Clermont-Ferrand, France (http://www.ageng2010.com/files/file-inline/J-C-M-SA.pdf).*

Increasing soil organic matter in soils in Latin America

Oxisols and ultisols are the dominant soil types in Brazil's Cerrado tropical savanna and Amazon rainforest regions, and they are also widespread in Africa's humid forest zone. Among the oldest on earth, these soils are poor in nutrients and very acidic, owing to their low capacity to hold nutrients – and cations in particular – in their surface and subsoil layers. In addition, being located in regions with high rainfall, they are prone to erosion if the surface is not protected by vegetative cover.

Upon conversion of the land from natural vegetation to agricultural use, special care has to be taken to minimize losses of soil organic matter. Management systems for these soils have been designed to conserve or even increase organic matter by providing permanent soil cover, using a mulching material rich in carbon, and ensuring minimized or zero tillage of the soil surface. These practices are all key components of the SCPI approach.

Such systems are being rapidly adopted by farmers in many parts of Latin America, and particularly in humid and subhumid zones, because they control soil erosion and generate savings by reducing labour inputs. Adoption has been facilitated by close collaboration between government research and extension services, farmer associations and private companies that produce agrochemicals, seed and machinery. Zero-till farming has spread rapidly and now covers 26 million hectares on oxisols and ultisols in Brazil.

Biological nitrogen fixation to enrich N-poor soils in African savannas

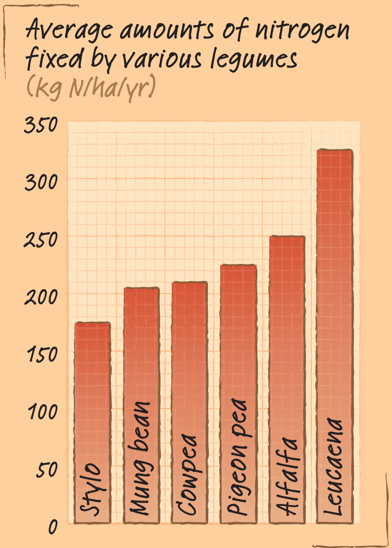
Crop production in the savanna regions of western, eastern and southern Africa is severely constrained by N- and P-deficiency in soils[17, 25], as well as the lack of micronutrients such as zinc and molybdenum. The use of leguminous crops and trees that are able to fix atmospheric nitrogen, in combination with applications of mineral P-fertilizers, has shown very promising results in on-farm evaluations conducted by the Tropical Soil Biology and Fertility Institute, the World Agroforestry Centre and the International Institute of Tropical Agriculture (IITA).

The combination of mineral fertilizer application and a dual-purpose grain legume, such as soybean, intercropped or relay-cropped with maize, increased maize yields in Kenya by 140 to 300 percent[17] and resulted in a positive N-balance in the cropping system. Dual-purpose grain legumes produce a large amount of biomass with their haulms and roots, as well as an acceptable grain yield. Several farming communities in eastern and southern Africa have adopted this system[26]. It has the additional advantage of helping farmers to combat *Striga* – some soybean cultivars act as "trap crops", which force *Striga* seeds to germinate when the weed's usual hosts, maize or sorghum, are not present[10, 27].

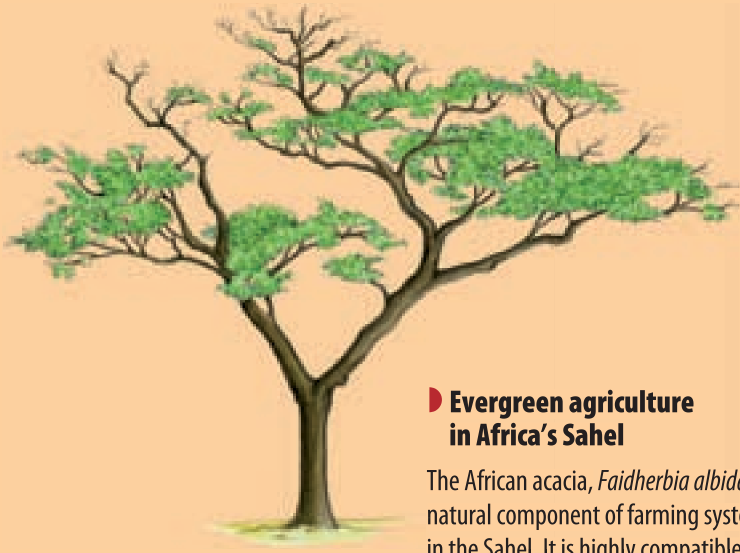
In eastern and southern Africa, N-deficient maize cropping systems have become more productive thanks to improved fallows using leguminous trees and shrubs. Per hectare, species such as *Sesbania sesban*, *Tephrosia vogelii* and *Crotalaria ochroleuca* accumulate in their leaves and roots around 100 to 200 kg of nitrogen – two-thirds of it from nitrogen fixation – over a period of six months to two years. Along with subsequent applications of mineral fertilizer, these improved fallows provide sufficient N for up to three subsequent maize crops, resulting in yields as much as four times higher than those obtained in non-fallow systems.

Research indicates that a full agroforestry system with crop-fallow rotations and high value trees can triple a farm's carbon stocks in 20 years[28]. The system has been so successful that tens of thousands of farmers in Kenya, Malawi, Mozambique, Uganda, the United Republic of Tanzania, Zambia and Zimbabwe are now adapting the component technologies to their local conditions.

Sesbania sesban



FAO. 1984. Legume inoculants and their use. *Rome.*



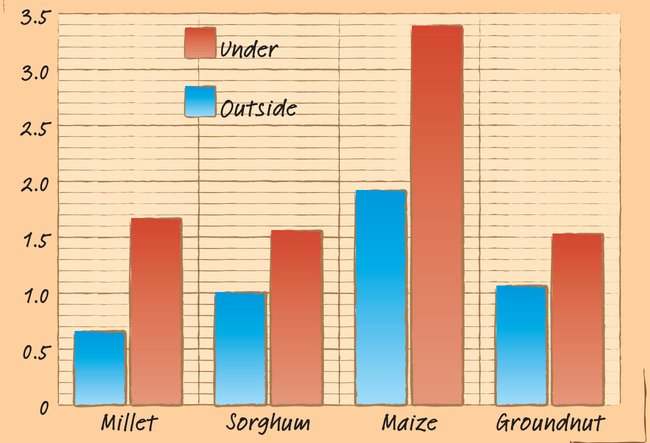
Faidherbia albida

Evergreen agriculture in Africa's Sahel

The African acacia, *Faidherbia albida*, is a natural component of farming systems in the Sahel. It is highly compatible with food crops because it does not compete with them for light, nutrients or water. In fact, the tree loses its nitrogen-rich leaves during the rainy season, thus providing a protective mulch which also serves as natural fertilizer for crops. Zambia's Conservation Farming Unit has reported unfertilized maize yields of 4.1 tonnes per hectare in the vicinity of *Faidherbia* trees, compared to 1.3 tonnes from maize grown nearby, but outside of the tree canopy[29]. Today, more than 160 000 farmers in Zambia are growing food crops on 300 000 ha with *Faidherbia*. Similarly promising results have been observed in Malawi, where maize yields near *Faidherbia* trees are almost three times higher than yields outside their range. In Niger, there are now more than 4.8 million hectares under *Faidherbia*-based agroforestry, resulting in enhanced millet and sorghum production.

Thousands of rainfed smallholdings in Burkina Faso are also shifting to these "evergreen" farming systems.

Crop yields under and outside *Faidherbia albida* canopy (t/ha)

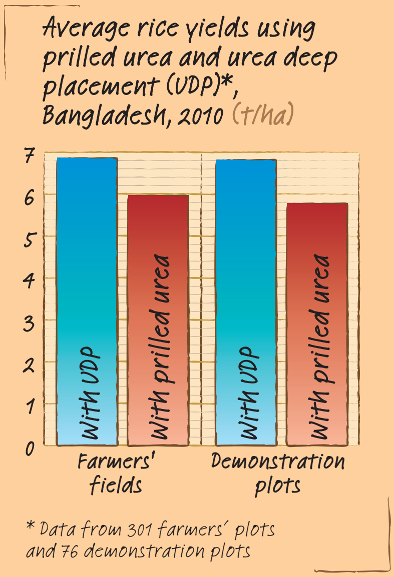


FAO. 1999. *Agroforestry parklands in sub-Saharan Africa, by J.-M. Boffa. Rome.*

"Urea deep placement" for rice in Bangladesh

Throughout Asia, farmers apply nitrogen fertilizer to rice before transplanting by broadcasting a basal application of urea onto wet soil, or into standing water, and then broadcasting one or more top-dressings of urea in the weeks after transplanting up to the flowering stage. Such practices are agronomically and economically inefficient and environmentally harmful. The rice plants use only about a third of the fertilizer applied[30], while much of the remainder is lost to the air through volatilization and surface water run-off. Only a small amount remains in the soil and is available to subsequent crops.

One way of reducing N losses is to compress prilled urea to form urea super granules (USG) which are inserted 7 to 10 cm deep in the soil between plants. This "urea deep placement" (UDP) doubles the percentage of nitrogen taken up by plants[31-35], reduces N lost to the air and to



IFDC. 2010. Improved livelihood for Sidr-affected rice farmers (ILSAFARM). *Quarterly report submitted to USAID-Bangladesh, No. 388-A-00-09-00004-00. Muscle Shoals, USA.*

surface water run-off, and has produced average yield increases of 18 percent in farmers' fields. The International Fertilizer Development Center and the United States Agency for International Development are helping smallholder farmers to upscale UDP technology throughout Bangladesh. The goal is to reach two million farmers in five years[36]. The technology is spreading fast in Bangladesh and is being investigated by 15 other countries, most of them in sub-Saharan Africa. The machines used to produce USG in Bangladesh are manufactured locally and cost between US$1 500 and US$2 000.

Site-specific nutrient management in intensive rice

The International Rice Research Institute (IRRI) and its national partners have developed the site-specific nutrient management (SSNM) system for highly intensive rice production. SSNM is a sophisticated knowledge system focused on double and triple rice mono-cropping. Tests at 180 sites in eight key irrigated rice domains of Asia found that the system led to a 30 to 40 percent increase in N-use efficiency, mainly thanks to improved N management. Across all sites and four successive rice crops, profitability increased by an average of 12 percent.

In several provinces of China, SSNM reduced farmers' use of N-fertilizer by one third, while increasing yields by 5 percent[37]. A site-specific N-management strategy was able to increase uptake efficiency by almost 370 percent on the North China Plain[9]. Since the average plant recovery efficiency of nitrogen fertilizer in intensive rice systems is only about 30 percent, those are remarkable achievements that contribute substantially to reducing the negative environmental effects of rice production. The complex SSNM technology is being simplified in order to facilitate its wider adoption by farmers.

rice

The way forward

The following actions are required to improve current land husbandry practices and provide a sound basis for the successful adoption of sustainable crop production intensification. Responsibility for implementation rests with national partners, assisted by FAO and other international agencies.

Establish national regulations for sound land husbandry. A supportive policy framework should aim at encouraging farmers to adopt sustainable farming systems based on healthy soils. Leadership is required to establish and monitor best practices, with the active participation of smallholder farmers and their communities. Governments must be prepared to regulate farming practices that cause soil degradation or pose serious threats to the environment.

Monitor soil health. Policymakers and national institutions responsible for the environment are demanding methods and tools to verify the impact of farming practices. While monitoring soil health is a very challenging task, efforts are under way to implement it at global[38], regional and national scales[39]. Monitoring the impact of agricultural production has advanced in developed countries, but is just beginning in many developing countries. FAO and its partners have developed a list of methods and tools for undertaking assessments and monitoring tasks[40]. Core land quality indicators requiring immediate and longer term development should be distinguished[41]. Priority indicators are soil organic matter content, nutrient balance, yield gap, land use intensity and diversity, and land cover. Indicators that still need to be developed are soil quality, land degradation and agrobiodiversity.

Build capacity. Soil health management is knowledge-intensive and its wide adoption will require capacity building through training programmes for extension workers and farmers. The skills of researchers will also need to be upgraded at both national and international levels, in order to provide the enhanced knowledge necessary to support soil management under SCPI. Policymakers should explore new approaches, such as support groups for adaptive research cooperation[42], which provide technical support and on-the-job training for national research institutions and translate research results into practical guidelines for small farmers. National capacity to undertake on-farm research must also be strengthened, and focused on addressing spatial and temporal variability through, for example, better use of ecosystems modelling.

Disseminate information and communicate benefits. Any large-scale implementation of soil health management requires that supporting information is made widely available, particularly through channels familiar to farmers and extension workers. Given the very high priority attached to soil health in SCPI, media outlets should include not only national newspapers and radio programmes, but also modern information and communication technologies, such as cellular phones and the Internet, which can be much more effective in reaching younger farmers.

Chapter 4

Crops and varieties

Farmers will need a genetically diverse portfolio of improved crop varieties, suited to a range of agro-ecosystems and farming practices, and resilient to climate change

Sustainable crop production intensification will use crops and varieties that are better adapted to ecologically based production practices than those currently available, which were bred for high-input agriculture. The targeted use of external inputs will require plants that are more productive, use nutrients and water more efficiently, have greater resistance to insect pests and diseases, and are more tolerant to drought, flood, frost and higher temperatures. SCPI varieties will need to be adapted to less favoured areas and production systems, produce food with higher nutritional value and desirable organoleptic properties, and help improve the provision of ecosystem services.

Those new crops and varieties will be deployed in increasingly diverse production systems where associated agricultural biodiversity – such as livestock, pollinators, predators of pests, soil organisms and nitrogen fixing trees – is also important. Varieties suitable for SCPI will need to be adapted to changing production practices and farming systems (see Chapter 2) and to integrated pest management (see Chapter 6).

SCPI will be undertaken in combination with adaptation to climate change, which is expected to lead to alterations in timing, frequency and amounts of rainfall, with serious droughts in some areas and floods in others. Increased occurrence of extreme weather events is probable, along with soil erosion, land degradation and loss of biodiversity. Many of the characteristics required for adaptation to climate change are similar to those needed for SCPI. Increased genetic diversity will improve adaptability, while greater resistance to biotic and abiotic stresses will improve cropping system resilience.

Achieving SCPI means developing not only a new range of varieties, but also an increasingly diverse portfolio of varieties of an extended range of crops, many of which currently receive little attention from public or private plant breeders. Farmers will also need the means and opportunity to deploy these materials in their different production systems. That is why the management of plant genetic resources (PGR), development of crops and varieties, and the delivery of appropriate, high quality seeds and planting materials to farmers are fundamental contributions to SCPI.

Principles, concepts and constraints

The system that will provide high-yielding and adapted varieties to farmers has three parts: *PGR conservation and distribution*, *variety development* and *seed production and delivery*. The stronger the links among these different parts, the better the whole system will function. Conserved and improved materials will need to be available for variety development, and new varieties will have to be generated at a pace that meets changing demands and requirements. Timely delivery to farmers of suitably adapted materials, of the right quality and quantity, at an acceptable cost, is essential. To work well, the system needs an appropriate institutional framework, as well as policies and practices that support its component parts and the links between them.

The improved conservation of PGR – *ex situ*, *in situ* and on-farm – and the enhanced delivery of germplasm to different users depend on coordinated efforts at international, national and local levels[1]. Today genebanks around the world conserve some 7.4 million accessions. These are complemented by the *in situ* conservation of traditional varieties and crop wild relatives by national programmes and farmers, and by the materials maintained in public and private sector breeding programmes[2]. Strong national conservation programmes, combined with the improved availability and increased distribution of a wider range of inter- and intra-specific diversity, will be critical to successful implementation of SCPI.

Technical, policy and institutional issues influence the effectiveness of programmes for crop improvement. A wide range of diverse materials is needed for the pre-breeding of varieties. Molecular genetics and other biotechnologies are now widely used by both national and private sector breeding programmes and can make an essential contribution to meeting SCPI breeding objectives[3]. The policy and regulatory dimension needs to include not only variety release, but also provisions for intellectual property protection, seed laws and the use of restriction technologies.

The benefits of PGR conservation and plant breeding will not be realized unless quality seeds of improved varieties reach farmers through an effective seed multiplication and delivery system. Variety testing of promising materials from breeding programmes needs to be followed by the prompt release of the best varieties for early generation seed multiplication. Certified seed production, along with quality assurance provided by the national seed service, are essential next steps before seed is sold to farmers. Both the public and private sectors should support this value chain and, where possible, local seed enterprises should produce certified seed and market it to farmers.

Smallholder farmers around the world still rely heavily on farmer-saved seed and have little access to commercial seed systems. In some countries, well over 70 percent of seed, even of major crops, is managed within the farmer seed system. Both formal and saved seed systems will be essential in the distribution of SCPI-adapted materials. The various practices and procedures adopted to support SCPI will need to take account of how farmer seed systems operate, and strengthen them in order to increase the supply of new materials.

Ensuring that the different parts of the PGR and seed supply system are able to meet the challenges of SCPI requires an effective policy and regulatory framework, appropriate institutions, a continuing programme of capacity development and, above all, farmer participation. A strong programme of research, aimed at providing information, new techniques and materials, is also important. Ideally, the programme will reflect farmers' knowledge and experience, strengthen the linkages between farmers and research workers from different areas, and serve dynamic and changing needs.

Approaches that save and grow

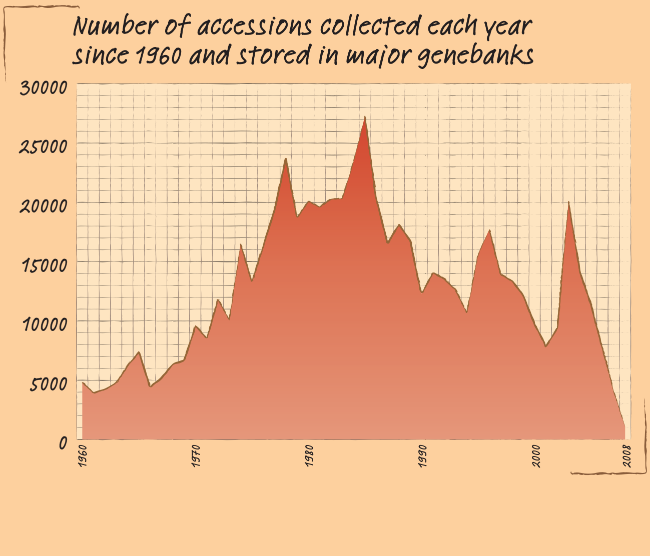
Improving the conservation and use of plant genetic resources

Plant genetic resources – the inter- and intra-specific diversity of crops, varieties and related wild species – are central to agricultural development and improvements in both the quantity and quality of food and other agricultural products. Genes from traditional varieties and crop wild relatives were at the heart of the Green Revolution, providing the semi-dwarfing characters of modern wheat and rice varieties, as well as crop resistance to major insect pests and diseases.

The success of SCPI will depend on the use of PGR in new and better ways. However, the crucial importance of genes from local varieties and crop wild relatives in development of new varieties is matched by rising concern over the loss of diversity worldwide, and the need for its effective conservation. International recognition of PGR is reflected in the conclusions of the World Summit on Food Security[4], held in 2009, the ratification by more than 120 countries of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)[5], and the strategic goals of the Convention on Biological Diversity (CBD)[6].

In mobilizing plant genetic resources for sustainable intensification, the international dimension will play a fundamental role. The international framework for conservation and sustainable use of PGR has been greatly strengthened by the International Treaty, the Global Crop Diversity Trust and the programme of work on agricultural biodiversity of the CBD. A global system that can provide support for SCPI is emerging. Since much of the diversity that will be needed may be conserved in other countries, or in the international genebanks of the CGIAR, national participation in international programmes will be indispensable.

Developing countries need to strengthen their national PGR programmes by enacting legislation to implement fully the provisions of the ITPGRFA. Guidelines on implementation have been prepared[7] and the Treaty Secretariat, Bioversity International and FAO are working on implementation issues in collaboration with some 15 countries. Implementing the revised Global Plan of Action on Plant Genetic Resources for Food and Agriculture and Article 9 of the ITPGRFA on Farmers' Rights will make an important contribution to the creation of the national operating



FAO. 2010. The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture. *Rome.*

framework for implementing sustainable intensification.

In order to adopt sustainable intensification strategies, countries will need to know the extent and distribution of the diversity of crop species and their wild relatives. Technologies for mapping diversity and locating diversity threatened by climate change have improved[8]. A major project supported by the Global Environment Facility in Armenia, Bolivia, Madagascar, Sri Lanka and Uzbekistan has established and tested ways of improving the conservation and use of crop wild relatives. The project developed and implemented area and species conservation management plans, identified climate change management actions to conserve useful diversity, and initiated plant breeding programmes using new materials identified thanks to the conservation and prioritization work[9].

Intensification will require an increased flow into breeding programmes of germplasm and promising varieties. The multilateral system of access and benefit sharing under the ITPGRFA provides the necessary international framework, although – given the increased importance of diversity to SCPI – it may need to be extended to a greater number of crops than those currently covered in Annex 1 of the Treaty. On the technical side, a number of procedures are available to identify useful materials in large collections, such as the Focused Identification of Germplasm Strategy now under development[10].

wild wheat

banana

Moving genetic material will also require improvements in the phytosanitary capacity and practices, as well as the distribution capacities, of genebanks.

The comprehensive characterization and evaluation of genebank collections at national and local levels, with farmers participating in the evaluation of potentially useful material, will make a key contribution to improving the use of PGR. Effective use also requires strong research and pre-breeding programmes. The Global Initiative on Plant Breeding is preparing a manual on pre-breeding to help develop that capacity. Ultimately, however, countries and the private breeding sector will need to support the strengthening of national agricultural research capacity, with the introduction of university courses on conservation and plant breeding for sustainable intensification.

Developing improved and adapted varieties

Sustainable intensification requires crop varieties that are suited to different agronomic practices, to farmers' needs in locally diverse agro-ecosystems and to the effects of climate change. Important traits will include greater tolerance to heat, drought and frost, increased input-use efficiency, and enhanced pest and disease resistance. It will involve the development of a larger number of varieties drawn from a greater diversity of breeding material.

Because new varieties take many years to produce, breeding programmes need to be stable, competently staffed and adequately funded. Both the public sector and private breeding companies will play an important part in developing those varieties, with the public sector often focusing on major staple crops, while the private sector would be concerned more with cash crops. The more open and vigorous the system, the more likely it is that the required new materials will be generated.

An important step forward will be a significant increase in public support to pre-breeding and breeding research. SCPI requires new materials, a redefinition of breeding objectives and practices, and the adoption of population breeding approaches. Properties such as production resilience and stability will need to be inherent, and not dependent on external inputs.

barley

It is unlikely that traditional public or private breeding programmes will be able to provide all the new plant material needed or produce the most appropriate varieties, especially of minor crops which command limited resources. Participatory plant breeding can help fill this gap.

For example, the International Centre for Agricultural Research in the Dry Areas (ICARDA), together with the Syrian Arab Republic and other Middle East and North African countries, has undertaken a programme for participatory breeding of barley which maintains high levels of diversity and produces improved material capable of good yields in conditions of very limited rainfall (less than 300 mm per year). Farmers participate in the selection of parent materials and in on-farm evaluations. In Syria, the procedure has produced significant barley yield improvements and increased the resistance of the barley varieties to drought stress[11].

Policies and regulations are needed to support the production of new varieties and ensure adequate returns to both public and private sector plant breeding. However, they may need to be more open and flexible than current patent-based procedures or arrangements under the International Union for the Protection of New Varieties of Plants (UPOV). The uniformity and stability properties of varieties adapted to SCPI may be different from those currently envisaged under UPOV, and Farmers' Rights, as identified in the ITPGRFA, need to be recognized. Most of all, policies and regulations must support the rapid release of SCPI adapted materials; in many countries far too much time is spent on the approval stage for new varieties.

The institutional framework that supports variety development and release is weak in a number of countries. University and other training programmes will need to be adjusted to furnish a greater number of plant breeders and breeding researchers trained in using crop improvement practices for SCPI. Farmers should be involved more fully both in the identification of breeding objectives and in the selection process. Extension services will need to be strengthened in order to respond to farmers' expressed needs and to provide sound practical guidance on the cultivation of new varieties.

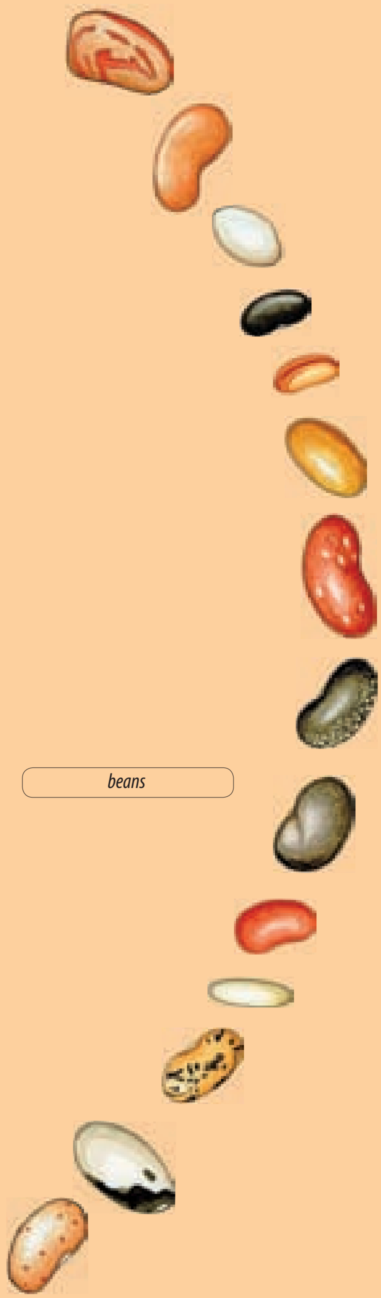
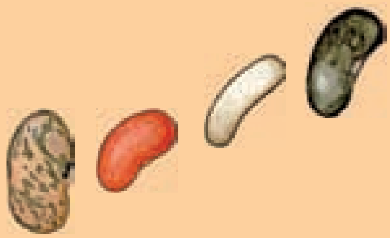
Improving seed production and distribution

A key issue when planning SCPI programmes is to determine the status of the national seed system and its capacity to improve the provision of high quality seed of adapted varieties to farmers. An initial step should be the development, in consultation with all key stakeholders, of an appropriate seed policy and regulations for variety release.

The policy should provide a framework for better coordination of the public and private sectors, as well as an action plan for development of a seed industry that is capable of meeting farmers' needs for high quality seed. In many developing countries, the policy will also need to recognize farmer-saved seed as a major source of propagation material. Since local seed enterprises will play an important role in SCPI, creating an enabling environment for them is essential. The action plan should identify gaps and weaknesses in the sector and the main measures that are needed to resolve them.

An improved framework may also be needed for seed production and movement. Because regulations and legislation should favour the rapid deployment of new planting material, and the transfer of new varieties from one area to another, harmonization of legislation among countries is important. For example, 12 member countries of the Economic Community of West African States have adopted harmonized seed laws. The maintenance and use of a larger number of varieties may strain seed quality management systems; therefore, the development of a quality-declared seed system will help ensure that, in the process of adapting seed practices to sustainable intensification, quality does not suffer.

One likely consequence of sustainable intensification will be the increased importance of local seed producers and local markets in supplying farmers. The role of markets in maintaining diversity is increasingly recognized[12]. Markets can be supported through initiatives such as local diversity fairs, local seed banks and community biodiversity registers, which encourage the maintenance and distribution of local materials and favour improvements in their quality[8].

beans

The way forward

Actions in the technical, policy and institutional arenas can help ensure that plant genetic resources and seed delivery systems function effectively to support sustainable crop production intensification. Although they will involve diverse institutions and take place at various scales, the required actions will have their greatest impact if they are coordinated. Recommended measures include:

- *Strengthening linkages between the conservation of PGR and the use of diversity in plant breeding*, particularly through improved characterization and evaluation of traits relevant to SCPI in a wider range of crops, increased support for pre-breeding and population improvement, and much closer collaboration among institutions concerned with conservation and breeding.
- *Increasing the participation of farmers in conservation, crop improvement and seed supply* in order to support work on a wider diversity of materials, to ensure that new varieties are appropriate to farmer practices and experiences, and to strengthen on-farm conservation of PGR and farmer seed supply systems.
- *Improving policies and legislation for variety development and release, and seed supply*, including national implementation of the provisions of the ITPGRFA, enactment of flexible variety release legislation, and the development or revision of seed policies and seed legislation.
- *Strengthening capacity* by creating a new generation of skilled practitioners to support enhanced breeding, work with farmers and explore the ways in which crops and varieties contribute to successful intensification.
- *Revitalizing the public sector and expanding its role* in developing new crop varieties, by creating an enabling environment for seed sector development and ensuring that farmers have the knowledge needed to deploy new materials.
- *Supporting the emergence of local, private sector seed enterprises* through an integrated approach involving producer organizations, linkages to markets and value addition.
- *Coordinating linkages with other essential components of SCPI*, such as appropriate agronomic practices, soil and water management, integrated pest management, credit and marketing.

Many of those actions are already being taken in various countries and by various institutions. The challenge is to share experiences, build on the best practices that have been identified and tested, and focus on ways to adapt them to meet the specific objectives and practices of SCPI. That will ensure that the diversity required for sustainable intensification, and already available in genebanks and farmers' fields, is mobilized efficiently, effectively and in a timely manner.