

*Technology options for feeding 10 billion people*

**Plant breeding and innovative agriculture**

**Summary**



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This document is the Layman's summary of the STOA study 'Technology options for feeding 10 billion people - Plant breeding and innovative agriculture'. The full study with annexes and an Options Brief related to the topic are available on the STOA website.

### **Abstract of the study**

In the frame of the STOA project “Technology options for feeding 10 billion people”, this report analyse how farming management concepts, practices and technologies, including plant breeding, could enable sustainable intensification of crop production, with the aim to increase food production and support food supply. The aim of sustainable intensification is to produce more food from the same area of land while reducing the environmental impacts, under social and economic beneficial conditions.

The study addresses agriculture in developing countries as well as in industrialized countries (Europe), small-scale and large-scale farming, extensive and intensive agricultural production systems, and low and high tech production practices. The main topics are:

- Reducing yield gaps – sustainable intensification and improving crop management;
- Increasing yield potentials – plant breeding;
- Reducing crop losses – improving harvest and postharvest procedures.

For these topics, options for action are identified and discussed.



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## LAYMAN'S SUMMARY

Achieving and securing food security for the growing world population is a major challenge. In the frame of the STOA project “Feeding 10 billion people”, this study analyses possible contributions of

- > farming management concepts, practices and technologies,
- > plant breeding technologies and approaches, and
- > reduction of food losses

to sustainable intensification of crop production. Sustainable intensification means producing more food from the same area of land while reducing the environmental impacts, under social and economic beneficial conditions.

The scope of the study includes agriculture in developing countries as well in industrialized countries (Europe), small-scale and large-scale farming, extensive and intensive agricultural production systems, and low- and high-tech production practices. The assessment reflects the suitability of crop production systems and technologies for different farming systems. Just as worldwide, farming systems in the EU differ strongly, from semi-subsistence farming to specialist and intensive, larger-scale crop farming and to large-scale corporate farming.

## 1. CHALLENGES TO AGRICULTURE

Increasing food crop production is challenged by a number of constrains, including soil fertility, water availability, nutrition supply and incidences of pests, diseases and weeds. These constrains differ greatly between industrialised and developing countries and also between different European regions, for geographic, social and economic reasons.

Soils are an essential and non-renewable resource for crop production. Soil fertility in Europe is threatened in many areas by decrease of soil organic matter, soil erosion (by water or wind), soil compaction and desertification.

Water availability is a precondition for plant growth. Water scarcity, defined in terms of access to water, is a critical constraint to agriculture in many areas of the world. Poor water management can lead to land degradation in irrigated areas through salinisation and waterlogging. In Europe, many countries have experienced drought episodes of various significance, duration and extend in the past decades. A relevant number of river basin area in the EU are under water stress.

Nitrogen, phosphorus and potassium are the major crop nutrient, and are crucial determinants of crop yields. Agricultural productivity growth and higher yields are dependent from inputs such as fertilisers. Input requirements depend largely on the applied agricultural production systems. In the future, developments related to reserves, access, changing geopolitical conditions and/or economic development and energy costs could lead to temporary shortfalls and high prices for mineral fertilisers in some regions of the world.

Competition from pests, diseases and weeds has the potential to significantly reduce crop yields. Therewith, crop protection and resistance breeding play a key role in safeguarding crop productivity. In the EU, fungicides and herbicides are the most sold pesticides, measured in quantity of active ingredient.

Production in many developing countries is constrained by energy inputs. Animals or human labour are often used for soil cultivation. In contrast, intensive crop production in industrialised countries is highly dependent from energy inputs. The need to reduce greenhouse gas emissions means that agriculture will have to become less reliant on non-renewable energy resources derived from fossil fuels.

Depending from agro-ecological conditions, economic and social potentials, and knowledge and skills, these constrains lead to more or less high yield gaps. Yield gap is the difference between yield potential and average farmers' yields which can be measured with different approaches (Figure 1). Many regions worldwide and also in the EU show large yield gaps. Yield gaps can be reduced by improved crop management.

**Figure 1: Conceptual framework for three measures of yield potential and average farmer yields**



Note: Different measures of the yield gap (YG) are indicated at the right side of the figure: YGM - model-based yield gap (yield potential is simulated with a model); YGE - experiment-based yield gap (yield potential is estimated with a field experiment); and YGF - farmer-based yield gap (yield potential is estimated with maximum of farmers' yields).

Source: Lobell, D.B., Cassman, K.G., Field, C.B. (2009): Crop Yield Gaps: Their importance, magnitudes and causes. *Annu. Rev. Environ. Resour.* 34, 179-204 (p. 185)

## 2. IMPROVING CROP MANAGEMENT

A broad spectrum of crop production systems, technologies and practices have the potential to contribute to sustainable intensification. Improved crop production can contribute to three major objectives:

- > Higher production
- > Better input use
- > Increased site specific yield potential

Crop production systems work with principles for agricultural practices as well as soil and ecosystem management, based on a common reasoning. They include every step in cultivation, from soil preparation and sowing to crop harvest. Combinations between different production systems for sustainable intensification are possible and practiced to a varying degree.

### ***Precision agriculture***

Precision agriculture (PA) in a broad sense is information-based management of agricultural production systems. In a more narrow sense, it is the spatially variable management of crop production, on which the assessment is focused. The overall aim is to apply the right treatment in the right place at the right time, by taking into account in-field variations of soil and crop.

Depending upon the temporal relationship between the collection of data, decision-making and management measures, PA approaches can be differentiated in

- > sensor systems also called online-systems,
- > map based systems also called offline systems,
- > hybrid systems which are sensor approaches with mapping overlay.

Various new or advanced technologies are applied such as satellite-supported positioning systems, yield mapping, remote sensing, sensor technologies for data collection, geo-information systems, various rate application techniques and decision support systems. PA applications can be found in all the main work stages of the agricultural production process such as nutrient application, manure placement, weed control, disease management and water management. The manifold PA approaches are in different stages of development, from research and demonstration to commercially availability. Adoption of PA techniques has mainly taken place in highly productive areas of Europe (Denmark, France, Germany, United Kingdom), in the USA and Australia. For the EU, data on the area under PA are not available.

### ***Conservation agriculture***

Conservation agriculture (CA) aims to prevent soil degradation and to preserve and/or enhance soil fertility by strengthening natural biological processes above and below the ground. The three key principles of conservation agriculture are continuous no or minimal mechanical soil disturbance, permanent organic-matter soil cover and diversified crop rotations. Equipment such as for direct seeding is available.

CA cannot be reduced to a simple standard approach. Thus, the interactions between the possible technological components and the location-specific conditions of farming must be adequately taken into account. CA implies changed weed management. Weed control by tillage has to be replaced by use of herbicides and/or soil cover management.

Worldwide, CA is used on about 125 Million ha (around 9% of the arable land), mainly in South and North America and Australia. In Europe, conservation agriculture is not widespread. Different assessments report uptake of no-tillage in the EU-27 on 1.35 - 3.5 million ha (2010), 1.3 - 3.4% of the arable land.

### ***System of rice intensification***

The System of rice intensification (SRI) started as a civil society innovation. It comprises basically a set of modified practices for managing rice plants, and the soil, water and nutrients that support their growth. In the meantime, the approach is also transferred to other crops such as sugarcane and cereals. SRI practices are not used in Europe.

### ***Organic farming***

Organic Farming (OF) relies on ecological processes, biodiversity and cycles adapted to local conditions. Major aims are a more efficient nutrient use and re-use by optimising the scope of nutrient recycling, and the exploitation of agro-ecological mechanisms. Especially readily soluble mineral fertilisers, synthetic pesticides and performance stimulants are renounced. Organic agriculture is defined by international principles and standards, and is a legally defined production method for food.

The yield effects of organic farming in developed and developing countries is quite different. For developing countries, the comparison of organic production to locally prevalent methods under field conditions shows higher yields in organic farming. For developed countries, in average around 20% lower yields for organic production are reported. But yield differences between organic and conventional agriculture are highly dependent from local settings.

Worldwide, around 37 million hectares were organic agricultural land (including in-conversion area) in 2011. Organic farming in Europe has rapidly and continuously developed since the beginning of the 1990s. In the EU-27, more than 9.5 million hectare (5.4% of the agricultural area) were managed organically in 2011.

### ***Agroforestry***

In Agroforestry systems, annual crops and trees are combined deliberately. Agroforestry consists of a set of reasoning and design principles rather than fixed planting schemes. Aims are to explore productively a variety of ecological niches while minimising inter- and intraspecies competition, and to establish and maintain a tight nutrient cycle, including nitrogen fixation by means of leguminous trees. An important result of agroforestry systems is a diversification of agricultural production. There are countless Agroforestry systems that have been developed across the globe. It is estimated that worldwide approximately 375-425 million ha or around 20% of the arable land involves agroforestry.

In Europe, silvoarable systems, the combination of annual crops and shrubs/trees, represent formerly widespread traditional systems in decline. Partly, they have already become extinct or exist only in a threatened state. For the EU, only partial data on the extend of agroforestry are available. Silvoarable agroforestry remains of importance in many regions of the Mediterranean.

### ***Integrated crop-livestock production systems***

These are farming systems in which livestock and crops are produced within a co-ordinated framework. In many mixed systems, the waste products of one component serve as a resource for the other: manure from livestock is used to enhance crop production, whilst fodder crops, crop residues and by-products feed animals.

Integrated crop-livestock systems have been a foundation of agriculture for hundreds of years. Worldwide, around half of total agricultural land is used by mixed farming systems. A mix of crops and livestock helps feed many people in the world, and it supports farmers obtain an income in different agro-ecologies.

In the EU, integrated crop-livestock farming decreased over the last decades due to the trend to specialised farming which took place on farm, regional and international level. In the EU-27, around 20 million ha are used by mixed crop-livestock farms, or around 12% of the total agricultural area.

### ***Impacts and relevance of crop production systems***

The assessed crop production systems address the objectives of sustainable intensification in different ways (Table S1). Main impact of precision agriculture as site-specific management within a field is *improved input use efficiency*. Therewith, precision agriculture does not contest per se high external input agriculture and specialisation in crop production, but intends to make these systems more effective and environmental-friendly.

In contrast, the central objective of the other discussed systems is to sustain and improve the *agro-ecological conditions of crop production (site specific yield potentials)*, with maintenance and enhancement of soil fertility in the centre. They imply deeper changes in crop production systems such as diversified crop rotations, plant associations, green manure and permanent organic-matter soil cover, and/or

integration of crop and livestock production. Better input efficiency is in these cases a consequence of the main objective.

**Table 1: Contribution of different crop production systems to main objectives of improved crop production**

| Crop production system            | Higher yields | Better input efficiency | Improved site specific yield potential |
|-----------------------------------|---------------|-------------------------|--|
| Precision agriculture             | (+)           | +                       | (+)                                    |
| Conservation agriculture          | +             | +                       | +                                      |
| System of rice intensification    | +             | +                       | (+)                                    |
| Organic farming                   | +/-           | +                       | +                                      |
| Agroforestry                      | (+)           | +                       | +                                      |
| Integrated crop-livestock systems | (+)           | +                       | +                                      |

**Legend:** +high relevance; (+) restricted relevance, - no relevance

Source: ETAG assessment

Precision agriculture approaches leads in most cases only to restricted *yield increases*. High potentials for increasing yields are reported for conservation agriculture and in developing countries for the system of rice intensification. A mixed picture exists for organic farming, with high yield increases for low external input systems in developing countries and yield reductions in industrialized countries. Mixed systems of agroforestry and integrated crop-livestock farming have also the potential to be more productive.

The crop production systems are not in the same extent suitable for different farming systems. This is the case in a global view as well as for the EU (Table 2). Generally, the overall principles of the crop production systems have to be locally adopted to the agro-ecological and socio-economic conditions of farms.

*Extensive small-scale semi-subsistence farming* in Europe partly uses agroforestry systems and they are often integrated crop-livestock farms. The implementation of conservation agriculture or organic farming is difficult due to their lack of resources. Precision farming is not applicable.

*Extensive farming in less favoured areas* has high potentials to apply conservation agriculture and organic farming due to relative low conversion costs. Traditional agroforestry system survived in a number of less favoured areas so that there are chances for a revival of agroforestry. Beside the important extensive livestock systems based on grazing, integrated crop-livestock farming is also of relevance. The chances to introduce precision agriculture as a high-tech approach are very small.

**Table 2: Current relevance of crop production systems in different farming systems of the EU**

| Crop production system            | Extensive small-scale, semi-subsistence farming | Extensive farming in less favoured areas | Medium intensive, mixed farming systems | Intensive, larger-scale crop farming | Large-scale corporate farming |
|-----------------------------------|---|--|---|--------------------------------------|-------------------------------|
| Precision agriculture             | -   | (+)                                      | (+)                                     | +                                    | +                             |
| Conservation agriculture          | (+)   | +  | (+)                                     | +                                    | +                             |
| Organic farming                   | (+)   | +  | +                                       | (+)                                  | (+)                           |
| Agroforestry                      | +   | +  | (+)                                     | -                                    | -                             |
| Integrated crop-livestock systems | +   | (+)                                      | +                                       | -                                    | (+)                           |

**Legend:** +high relevance; (+) restricted relevance, - no relevance

Source: ETAG assessment

*Mixed farming systems* are per definition integrated crop-livestock farms. Mixed farming is a key element of many organic farms so that the conversion potential is in many cases high. Conservation agriculture and agroforestry can be integrated in mixed farming, restricted by the already existing complexity of the farm operation. The relevance of precision farming is low due to the relative high investment costs and learning requirements.

*Intensive larger-scale crop farming* has a high potential to apply precision agriculture with the aim to enhance input efficiency and to reduce production costs. In this farming system, the maintenance and enhancement of soil fertility is of high importance, for which conservation agriculture is a suitable approach. The competitiveness of organic farming is relatively low and higher conversion rates can only be expected when new marketing channels with attractive price premiums can be opened up. Silvoarable agroforestry has vanished in intensive crop farming due to the impediment of highly mechanised cultivation and unfavourable economic incentives. Barriers for an introduction of modern agroforestry systems are relatively high. Over the last decades, larger-scale crop farms have abandoned livestock production. The potential for a reintegration of crop and livestock production is restricted by the absence of structure and management skills for livestock in specialised crop farms and the large capital requirements for change.

In the case of *large-scale corporate farming*, economics of scale are favourable for the introduction of precision agriculture. Barriers for implementation can be missing management skills. Conservation agriculture is a relevant approach for maintenance and enhancement of soil fertility. Mindset and lower profitability for diversified crop rotations can be barriers. Large-scale corporate farms have successfully converted to organic farming. Conversion implies a major change in farm organisation and marketing. Agroforestry is at odds with the mechanisation and specialisation. In parts, corporate farms are integrated crop-livestock operations. Integration of livestock production in corporate farms specialised on crop production is restricted due to high investments and missing management skills for livestock.

Important overall trends in the frame of sustainable intensification are:

- > Increasing differentiation of crop management
- > Higher complexity of management concepts
- > Agriculture gets more knowledge-intensive
- > Shift to system approaches
- > Mainstreaming of agro-ecological approaches
- > Combination of bottom-up and top-down approaches

### **3. PLANT BREEDING**

In the past, plant breeding made a major contribution to better food supply by increasing the yield potential of crops. The knowledge about the genetic background of diverse traits for agronomical important crop has increased remarkably. Therewith, a major change in plant breeding technologies and approaches has taken place. Overall, modern breeding technologies open new possibilities to create genetic variation and to improve selection, but conventional breeding technologies will remain important.

Plant breeding is confronted with a multiplicity of sophisticated breeding goals. They can be summarised by three main goals that have to be achieved for crop improvement:

- > Increasing yield potential
- > Safeguarding yield
- > Quality of the product

Every plant breeding approach follows three general steps. These are:

- > Creation of a new initial genetic variation
- > Selection of suitable genotypes for creating new varieties
- > Testing, maintenance and reproduction of a variety

Breeding technologies and approaches address these steps in different ways (Table 3) and they are in different states of research and/or practical application (Table 4).

#### ***Conventional plant breeding***

Conventional plant breeding methodologies depend on the particular crop plant species and its propagation type. The type of propagation determines the different breeding strategies and the resulting major types of varieties:

- > pure-line varieties for self-pollinating species,
- > population varieties for open-pollinating species,
- > clonal varieties for vegetative propagated species and
- > hybrid varieties.

**Table 3: Breeding technologies and their relevance for the three main breeding steps**

| Breeding technology                       | Induction of genetic variation | Selection of favourable genotypes | Testing, maintenance and reproduction |
|---|--------------------------------|-----------------------------------|---------------------------------------|
| <i>Conventional breeding</i>              |                                |                                   |                                       |
| - Breeding line varieties                 | +                              | +                                 | +                                     |
| - Breeding open-pollinated varieties      | +                              | +                                 | +                                     |
| - Breeding clonal varieties               | +                              | +                                 | +                                     |
| - Hybrid breeding                         | +                              | +                                 | +                                     |
| <i>Mutation breeding</i>                  |                                |                                   |                                       |
| - Use of physical mutagens                | +                              | -                                 | -                                     |
| - Use of chemical mutagens                | +                              | -                                 | -                                     |
| <i>Tissue culture methods</i>             |                                |                                   |                                       |
| - Embryo rescue method                    | +                              | -                                 | -                                     |
| - Protoplast fusion                       | +                              | -                                 | -                                     |
| - Double haploids                         | +                              | -                                 | -                                     |
| - Micropropagation                        | (+)                            | -                                 | +                                     |
| <i>Marker-assisted breeding</i>           |                                |                                   |                                       |
| - Molecular markers <sup>a</sup>          | -                              | +                                 | +                                     |
| - QTL mapping                             | -                              | +                                 | -                                     |
| - SMART breeding                          | -                              | +                                 | (+)                                   |
| <i>Breeding with genetic modification</i> |                                |                                   |                                       |
| - Transgene approach                      | +                              | -                                 | -                                     |
| - Cisgene approach                        | +                              | -                                 | -                                     |
| - Novel GM techniques                     | +                              | -                                 | -                                     |
| <i>Organic breeding</i>                   | +                              | +                                 | +                                     |
| <i>Participatory plant breeding</i>       | +                              | +                                 | +                                     |

**Legend:** + high relevance; (+) restricted relevance, - no relevance

Note: <sup>a</sup> Molecular markers are also used to test the genetic purity of a variety

Source: ETAG assessment

They dominate the cultivated areas worldwide. Genetic variation is restricted to traits available by sexual crossing. In the past, the plants from the sexual crossing of two promising parental plants were solely screened by phenotype in testing fields.

*Hybrid varieties* are the first filial generation of a crossing between two genetically diverse parental inbred-lines. They have a distinct superior performance in comparison to their parental lines which is called heterosis effect. This heterosis effect gets lost in the next generation which means that farmers cannot produce own seeds out of hybrid varieties. Remarkable yield increases have been achieved with hybrid breeding. The hybrid breeding technology is not easily transferable to all crop plants as it has originally been developed for open-pollinated crop species.

*Landraces*, also known as local or traditional varieties, are crop populations produced and maintained by farmers. They are highly unequal and show relatively low yields in comparison to modern varieties under high-input agriculture conditions. But landraces are well adapted to their domestication regions, often with low external input farming in developing countries, and thereby deliver high yield stability. They represent important breeding material for professional breeding programmes.

### ***Mutation breeding***

Mutation breeding aims to create new genetic variation. Plants are chemically or physically treated with mutagens that initiate random mutations throughout the genome and thereby create new genetic variations that can be of interest. Over 2,300 registered plant varieties were created by mutation breeding approaches covering different important crops, such as cereals, fruits, ornamental plants or roots and tubers. Especially countries in Africa and parts of Asia with lower capital and technological options use this technique to a wide extent because it is well established and relatively cheap. Mutation breeding still plays an important role in crop improvement. One very promising new technique is the high-throughput screening for wanted mutations from mutagenesis.

### ***Tissue culture-based methods***

Tissue culture techniques, such as the “embryo rescue method” or “protoplast fusion”, enable crossings of plants that are naturally not combinable. This extends the useable genetic variation. Plants (and thereby their genomes) are combined on the cell level and afterwards artificially grown to fertile plants in special culture media which contains different plant hormones that stimulate plant growth. Many achievements could be made in the past by using these techniques. Recent examples of successful application are new improved rice varieties in West Africa and Asia.

Tissue culture based techniques like “micropropagation” play an important role for the maintenance and reproduction of clonal crops such as potato. Small plant material parts of the variety are cultivated on a special medium, thereby producing a multiplicity of identical clones. The major advantage is that disease-free planting material can be produced.

### ***Breeding with genetic modification***

With genetic engineering, it has become possible to transfer genes from any genome. Since the 1990s, varieties created by genetic modification, so called genetically modified crops (GM crops), have become available. Worldwide, the area cultivated with GM crops has increased continually, to around 170 million ha in 2012. They are used mainly in North and South America, China and India. Currently, two traits (herbicide tolerance, insect resistance) and four major cash crops (cotton, maize, rapeseed, soybean) are dominating the area cultivated with GM crops. GM technology just represents one of different tools to create new initial variation. Conventional breeding methodologies remain indispensable for the further breeding steps.

In the last years, a number of new GM technologies are coming up. The breeding of cisgenic and intragenic crops belongs to these new approaches in development. Both follow the principle that the

gene of interest origins from the same plant species or a closely related species. This means that in principle the gene transfer could also be arranged using classical breeding methods, but that would take much more time. Additionally, other new plant breeding techniques are in the pipeline and may play an important role for plant breeding in the near future. The new plant breeding techniques are “tiptoeing” around transgenic and the GM regulation.

### ***Marker-assisted breeding***

The best individuals of an initial variation must be identified and selected in the second major step of any breeding process. Marker-assisted breeding opens new possibilities to shift from phenotypically screening to more genotype-based methods, such as marker-assisted selection (MAS) and Selection with Markers and Advanced Reproductive Technologies (SMART) breeding. Their principle approach is to analyse the DNA composition of plants and identify individuals with the best genetic characteristics for particular traits. At the moment, *marker-assisted selection* (MAS) is widely applied by major breeding companies for different crop plants. MAS is mainly used for breeding aims like biotic resistances, classification of gene pools, quality assurance in seed production or abiotic stress resistances.

Gene-based selection methods gain more and more importance due to the rapid progress in the gene sequencing and identification sector. Although there are early adopters, *SMART-breeding* is still in the development stage but with remarkable research efforts being made. Gene-based selection methods are assumed to allow a much more precise and effective selection in breeding programs and will increase the accuracy and success of breeding, especially in combination with improved modern phenotyping methods.

### ***Genome sequencing***

The considerable efforts in new plant biotechnology and genetic modification approaches could not have been achieved without the progress in several supporting techniques and research fields. Genome sequencing represents one of the most important and promising ones and makes it nowadays possible to sequence whole plant genomes at relatively low financial costs. Connected with the bioinformatics sector and in cooperation with strongly enhanced phenotyping methods, DNA sequencing enables to explore gene functions and thereby represents a very promising and important field for plant breeding in the near future.

### ***Organic plant breeding and participatory plant breeding***

Breeding for organic farming (organic plant breeding) and participatory plant breeding (PPB) are not specific techniques in itself. They represent principles and/or organisation of breeding that can include different specialised methodologies and procedures. They aim to increase yield potential in low external input agriculture and to provide varieties adapted to specific local cultivation conditions.

*Organic plant breeding* supports the general principles of organic farming. Some of the newer breeding techniques, such as genetic modification or protoplast fusion are strictly prohibited for the production of organic seed. For other modern biotechnologies, it is not quite sure whether they truly fit in the ideals and principles of organic farming. While in the past organic farmers were mainly dependent on conventional breeding and classical bred varieties, the market for organic seeds is now growing due to a consistently growing demand for organic products. Especially for marginal regions, organic seed seem to have advantages towards conventional seeds because of their good adaptation to low-input farming systems.

The *participatory plant breeding* approach came up in the 1980s and describes the collaboration between plant breeders and farmers in breeding programmes. Intention is that both farmers and breeding experts benefit from cooperation. Farmers know their production systems and the special requirements for plants grown in their area. Plant breeders have the technical and scientific breeding know-how. In highly

developed countries with high-input agriculture systems, participatory plant breeding has no relevance for crop improvement. Great successes in variety creation by PPB have been made in developing countries with marginal production regions. Participatory plant breeding programmes are strongly supported and financed by several international public institutions.

The current seed legislation which only accepts homogeneous seeds in the variety lists is an obstacle for locally adopted heterogeneous seeds. As a solution, the proposal is to create a special category for organic varieties, landraces and traditional seeds in the seed registration regulations.

### ***Seed industry and intellectual property rights***

Crop improvement by plant breeding is undertaken in both the private and the public sector and the seed market is divided into commercial and non-commercial markets. Parallel to the development of modern biotechnology and genetic engineering, international commercial seed market has undergone a concentration process with increasing market shares for a small number of major international corporations.

Since genetic modification of crop plants came up, plant breeding companies are increasingly trying to protect their inventions by claiming patents on plant material and production techniques, leading to disagreements between farmers, companies and public. One of the main issues discussed in this context is that patented varieties cannot be used by other breeders to create new varieties.

**Table 4: Breeding technologies and their relevance current status in research and practical application**

| <b>Breeding technology</b>                       | <b>Basic research</b> | <b>Applied research</b> | <b>Early adopters in practical breeding</b> | <b>Common approach in practical breeding</b> |
|--|-----------------------|-------------------------|---|--|
| <i>Conventional breeding</i>                     |                       |                         |   |  |
| - Breeding line varieties                        | -                     | -                       | -   | +  |
| - Breeding open-pollinated variet.               | -                     | -                       | -   | +  |
| - Breeding clonal varieties                      | -                     | -                       | -   | +  |
| - Hybrid breeding                                | -                     | +                       | -   | +  |
| <i>Mutation breeding</i>                         |                       |                         |   |  |
| - Use of physical mutagens                       | -                     | (+)                     | (+)   | (+)  |
| - Use of chemical mutagens                       | -                     | +                       | -   | +  |
| <i>Tissue culture methods</i>                    |                       |                         |   |  |
| - Embryo rescue method                           | -                     | (+)                     | -   | +  |
| - Protoplast fusion                              | -                     | +                       | +   | (+)  |
| - Double haploids                                | -                     | -                       | -   | +  |
| - Micropropagation                               | -                     | +                       | +   | (+)  |
| <i>Marker-assisted breeding</i>                  |                       |                         |   |  |
| - Molecular markers <sup>1</sup>                 | +                     | +                       | +   | +  |
| - QTL mapping                                    | +                     | +                       | +   | (+)  |
| - SMART breeding <sup>2</sup>                    | +                     | +                       | +   | (+)  |
| <i>Breeding with genetic modification</i>        |                       |                         |   |  |
| - Transgene approach                             | +                     | +                       | +   | (+)  |
| - Cisgene approach                               | +                     | +                       | +   | -  |
| - Novel GM techniques                            | +                     | +                       | (+)   | -  |
| <i>Organic breeding</i>                          | -                     | -                       | +   | (+)  |
| <i>Participatory plant breeding</i> <sup>3</sup> | +                     | +                       | +   | -  |

**Legend:** + high relevance; (+) restricted relevance, - no relevance

Notes: <sup>1</sup> Early molecular markers such as RFLP become less important for both research and practical approaches; new marker systems like SNP markers get more importance for research and practical breeding

<sup>2</sup> SMART breeding as genomic selection based on sequence information about genes of interest

<sup>3</sup> Mainly applied in developing countries with marginal acreage; extent of farmer participation can vary from low to full-involvement

Source: ETAG assessment

## 4. REDUCING CROP LOSSES

In this study, food losses until the farm gate are analysed. This includes handling at harvest and postharvest, storage, transport and distribution by farmers. Harvest and postharvest losses are an important issue on the global level. Their reduction can contribute to the local as well as global food security.

Harvest and postharvest losses can be caused by environmental conditions (e.g., heat, moisture), by the attack of pathogens (e.g., fungi, bacteria, insects) and natural postharvest processes (e.g., transpiration, sprouting, ripening). The risk of losses increases with the degree of perishability, from grain, over roots and tubers, to fresh fruits and vegetables. Postharvest losses are closely linked to pre-harvest and harvest technologies. Biological spoilage has its roots in poor protection against pests during the growing period, inadequate timing of harvest, and rough handling during harvest and transport from the field to the postharvest facilities.

### *Extent of harvest and postharvest losses*

Estimates of harvest and postharvest losses vary significantly. Most estimates relate to specific regions, farming systems and food supply chains often under specific weather circumstances of a particular year. Therewith, data on harvest and postharvest losses can give only an indication of magnitude. For the more perishable food categories, losses can reach around 30% of the production.

There are substantial differences in harvest and post-harvest losses between developed and developing and transitional countries. Particularly post-harvest losses are very low in developed countries. This is an outcome of modern food supply chains which include better post-harvest technologies, storage facilities, marketing organization and infrastructure. However, the temperature and humidity is also an important factor affecting post-harvest losses. These are particularly high for cereals, and root and tuber crops in Sub-Saharan Africa and South and Southeast Asia.

### *Technologies for reducing harvest and postharvest losses*

Mechanical harvest and threshing of *grains* reduces need for labour but also reduces losses. Moisture content of grain is a critical factor of mechanical threshing and storing. A successful storage requires that grain is properly dried and clean of broken and crushed kernels which are more susceptible to mould infestation. The storage must provide firm protection against insects and rodents; the temperature and humidity has to be maintained stable and low. There is a range of safe technologies including small and large sealed plastic bags, small and large metal bins, well protected warehouses, and concrete silos. However, in many regions these technologies are not applied. The reasons are knowledge and costs.

For *roots and tubers*, yam and cassava harvests remain heavily labour intensive, while advanced mechanisation is used for potatoes and sweet potatoes. The technical constraint to the mechanical harvest of yam and cassava rests in size and distribution of tubers and roots in the soil. Whichever method is chosen, skin contusions or bruising should be avoided since they are strongly susceptible to

attacks of pathogens. But roots and tubers have also a self-ability of healing. Regardless of which crop is to be cured, the roots and tubers must be kept at the right temperature to stimulate skin healing. Curing should be carried out as soon as possible after harvest, but in many cases crop is stored or distributed without it in developing countries.

Storage facilities for roots and tubers should assure proper temperature and humidity, but also protection against rodents and insects. Respiration of tubers produces heat which is to be conveyed away by ventilation. To safeguard the effective heat transfer, the crop should be stored in the way that forced air can reach each tuber. The use of sprouting inhibitors is recommended for long term storage. Traditional facilities for potatoes, sweet potatoes and yam (field piles, warehouses, yam barns or underground structures) often give little possibility for controlling temperature and humidity and usually provide poor protection against rodents and pests. Modern warehouses are usually air conditioned, refrigerated and well protected against insects and rodents; however, these are not affordable for small semi-subsistence farmers.

So far the attempts to construct cassava storages have failed due to inability to control effectively temperature, humidity and the development of moulds. Thus the current practice is to chip roots, to dry chips on the sun and then to store them. More research is needed to understand the perishability of cassava.

For *fresh fruits and vegetables*, the current system in developing countries is based on small intermediaries lacking refrigerated storages and transport. High losses are associated with this system, and it can hardly cope with the expansion of the fresh fruit and vegetable markets by increasing urbanisation and middle income classes in many developing countries.

Modern, so called cold chain technologies for fresh fruits and vegetables include:

- > appropriate chemical and biological protection of crops at field/orchard before harvesting,
- > timely harvest, using appropriate harvest methods based on manual picking-up, choosing appropriate and clean containers and the discipline of worker harvesting the crop,
- > cooling down the crop often together with controlling availability of oxygen in order to slow down ripening and other biological processes,
- > appropriate packaging and
- > careful, refrigerated and timely transport.

Failure at the preceding stage will almost inevitably cause losses in the following steps. Thus the process must be controlled from field to shelf. These technologies are largely spread in developed countries.

### ***Mycotoxins***

Mycotoxins are the cause of a range of human and/or animal diseases and occur in a variety of crops (grains, roots and tubers, fruits and vegetables). According to the site and time of infestation, the fungi can be classified as field fungi, storage fungi or advanced deterioration fungi. The spread of mould is associated with wet and warm conditions (weather, storage atmosphere) and availability of oxygen. Lot of crop is wasted each year due to fungal rot and mycotoxins. Protection against fungi and mycotoxins requires an integrated approach from the pre-harvest period until the retail shelf. The proper agronomic practices include crop rotation, removal of crop residuals and chemical or biological protection. The damages of kernels, fruits, leaves and roots should be minimised, broken crop should be excluded from storage, grains must be dried to the proper moisture content, tubers and some fruits should be cured. The surface of any crop should be maintained dry during storage and transport. Low temperatures reduce development of moulds, but some crops might be sensitive to it. If crops tolerate it, modified storage/transport/packaging atmosphere with high concentrations of carbon dioxide and low concentrations of oxygen will effectively stop development of moulds and mycotoxins.

### ***Institutional and socio-economic aspects***

Overall, adequate technologies for reducing harvest and postharvest crop losses are available. But there are number of obstacles to bring them into practice particularly among small poor farmers. These technologies are often not suitable in scale, and they are associated with high investment costs. Most of them require innovations throughout the whole food supply chain. Horizontal and vertical coordination is needed, but there is often no capacity for it.

Attempts to solve the postharvest problems of small-scale farms include programmes to encourage the delivery of their surplus crop (e.g., cereals, potatoes) as soon as possible into large scale postharvest-storage facilities, usually under conditions regulated by the government. This is generally beneficial, but can have also adverse effects (e.g., improper management of storage).

For poor small-scale farmers and semi subsistence farmers, the most promising way to reduce postharvest losses is improving traditional technologies and enabling participation in modern food supply chains. Technological improvements must be of low cost and tailored to the local climatic, natural and socio-economic environment. In addition, producers must be guided to see a clear direct or indirect advantage, particularly the financial benefit.

Modern and improved technologies require knowledge, skill and in many cases effective extension services. Past experience shows that support systems should not be exclusively technically focused. A set of interventions is needed such as providing effective rules, knowledge transfer support, improved access to credits and direct market intervention providing stabilisation through temporary storage of surpluses. Therewith, government intervention is need.

## **5. POLICIES FOR SUSTAINABLE INTENSIFICATION**

Spread and implementation of existing knowledge, technologies and best practices, and investment in new agricultural innovations and production system approaches are needed to achieve an increased food production in a sustainable way. Sustainable intensification needs political commitment at European and Member State level, supported by informed dialogue with farmers and other stakeholders.

After decades of de-investment in public agricultural research, more public money (EU and Member States) is required. Sustainable intensification will often need specific measures (e.g., public research programmes) to incentivise research that produces public goods and longer-term results.

Crop production systems approaches should be in the centre of research activities. Single technologies and practices promise only restricted advances. Approaches that combine different technologies and practices will produce real progress. A stronger focus should be taken on maintenance and enhancement of soil fertility and exploitation of agro-ecological mechanism to stabilize achieved high yield levels in favourable areas, to realise more of existing yield potentials, and to increase the resilience of farming systems. Long-term agronomic research projects at both farm and research levels throughout the EU are needed because the impacts of greater shifts in crop production (such as with conservation agriculture, organic farming, agroforestry and integrated crop-livestock systems) needs time to manifest.

Increasing input use efficiency is especially needed in intensive production systems to improve their environmental performance and to maintain their production potential. In precision agriculture, scientifically and economically sound decision support systems are a major bottleneck. Therewith, a research focus should be on precise identification of input utilisation factors and yield determining factors, their interaction, and their translation in crop management decision.

Besides commercial plant breeding, progress in plant breeding is dependent from public support for breeding and genomics programmes which emphasise on longer term strategic approaches. Public

breeding research support should include different promising breeding technologies and a broad spectrum of crops. Strengthening of organic breeding and introduction of participatory plant breeding which addresses the needs of European semi-subsistence farmers is proposed. Closer collaboration of plant breeders and farmers could become more important in the future with mainstreaming of agro-ecological approaches and more local differentiation of crop management.

Effective knowledge and technology transfer to the farming communities, using a combination of scientific and practical expertise, is of high importance. Public funded extension services should be revitalised to increase the skills and knowledge base of agricultural producers breadthwise. For up-scaling of advanced crop production systems, new networks among diverse stakeholders are needed to combine top-down and bottom-up knowledge creation and transfer mechanisms, including institutional learning.

In the frame of agri-environmental measures, incentive programmes should be implemented for crop production systems with an agro-environmental focus, because the conversion is often connected with initial investments, costs of learning, risks during adaptation to local conditions, and delayed improved returns. Longer term task is an enabling Common Agricultural Policy (CAP) reform. The direct payments to farmers from the Pillar I of the CAP are neutral in regard to the applied crop production systems. A more enabling surrounding for sustainable intensification would demand a longer-term transformation of the CAP with a phasing out of direct payments, replaced by public payments linked to the provision of societal benefits.

Reduction of harvest and postharvest crop losses, particularly in developing countries and transition countries, demand the establishment of long-term strategies by international bodies, national and regional authorities as well as non-governmental donor organisations. Strategies should be tailored to the nature and causes of losses, to the affected crops and to the beneficiaries and their socio-economic characteristics. Private and public research and development should focus on selection of cultivars resistant or less susceptible to pests, biopesticides (particular against fungal pest producing mycotoxins), and small scale technical equipment.

Reducing crop losses demand the improvement of institutional and socio-economic conditions. This includes infrastructure enhancement, improvement of marketing systems and food supply chains, incentives for the development of rural markets, and exchange of experience among farmers and information flows along food supply chains.

This document summarises the findings and conclusions of STOA study  
“Technology options for feeding 10 billion people - Plant breeding and  
innovative agriculture’.

The STOA studies can be found at:

<http://www.europarl.europa.eu/stoa/cms/studies>

or requested from the STOA Secretariat: [STOA@ep.europa.eu](mailto:STOA@ep.europa.eu)

In addition, a short Options Brief is also accessible through  
the STOA studies website via this QR code:



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