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Agricultural technology for development

Report of the Secretary-General

Summary

Agricultural technologies are vital to sustainable rural development, both to increase crop and livestock productivity and to strengthen resilience of agricultural systems. Traditional emphasis on yield maximization has been tempered in recent years by growing recognition of the need to ensure the long-run sustainability of yield improvements and to preserve vital rural ecosystems and their functions. The recent food crisis and slow progress towards the achievement of the Millennium Development Goal of eradicating hunger have highlighted the wide disparities in technologies used and productivity achieved in different agricultural systems. While input and resource-intensive agriculture is the norm in many developed and middle-income developing countries, many developing countries continue to rely on low-input, low-productivity agriculture. Even as the former group of countries need to shift towards less intensive and more environmentally sound methods, farmers in many developing countries would benefit from greater input use. Yet, in principle, they should also benefit from the latest scientific knowledge and field testing of sustainable methods able to achieve high and stable yields and resilience in the face of climate change. To do so, however, will require a combination of measures, including scaled-up research on adapted technologies for local agroecological conditions, strengthened and reoriented extension services, greater investments in farmers' education and training and closer interaction between research and farming communities.

The decision of the Commission on Sustainable Development at its seventeenth session provides a useful strategic framework for addressing agricultural technology challenges in a comprehensive way.

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Contents

I. Overview

1. The present report has been prepared in response to General Assembly resolution 62/190, entitled "Agricultural technology for development", in which the Assembly requested the Secretary-General to submit to the Assembly at its sixty-fourth session a report on agricultural technologies and conditions for their effective deployment, assessing their contribution to development.

2. The purpose of the report is to assess the recent evidence on how agricultural technology development and deployment can best achieve the objectives of boosting productivity and promoting growth and food security, especially in low-productivity agricultural systems, and ensuring resilience and long-run sustainability of agricultural production. This is a well trodden theme, and has been the subject of several United Nations studies and reports over the years. The intent of the present report is not to revisit old ground, but rather to examine the old question in the light of several new challenges that confront agriculture today. These include: (a) the 2008 food crisis (exacerbated by a spate of shocks that hit the world economy); (b) the continuing low rate of agricultural productivity growth in Africa (which faces particular challenges, due in part to the diversity of agroecological conditions, crops and agricultural systems); (c) the potential impact of climate change; (d) the question of risk management with regard to some of the promising technologies (of which the most frequently mentioned are genetically modified organisms and biofuels); (e) the slower moving ecological crisis and, in particular, the ecological unsustainability of high-input modern agriculture; (f) the question of intellectual property and its relationship to agricultural technology; and (g) the difficulties of reaching key groups, especially small farmers and women farmers. On a number of these challenges, national and global policymakers have introduced a variety of response measures at least since 1992. The objective of the report is to provide policy guidance to decision makers on an integrated approach as to what works and why, what may be needed to scale up successful experiences and adapt them to local realities, especially in challenging production environments, and what additional actions may be called for.

3. The report benefited from inputs received from the Food and Agriculture Organization of the United Nations, the International Fund for Agricultural Development, the United Nations Environment Programme and from the analysis and conclusions presented in the International Assessment of Agricultural Knowledge, Science and Technology for Development. It also draws upon the relevant outcomes of the seventeenth session of the United Nations Commission on Sustainable Development[1] that pertain to the effective deployment and scaling-up of technologies for agriculture and rural development.

II. Review of agricultural productivity and sustainability challenges

4. Although agricultural technology has often been thought of as a combination of seeds, inputs and practices that increase the yield potential of crops and livestock, and bridge the gap between the potential yield and actual yield on the farm, in recent years the concept has been expanded to incorporate sustainability concerns, risk management, and indigenous knowledge and practice. In particular, there is increasing emphasis on soil husbandry practices and water conservation methods.

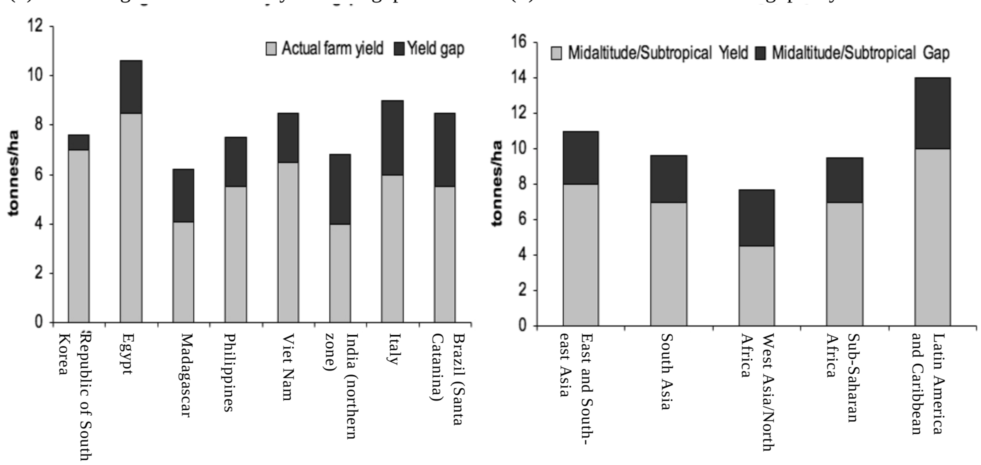
[1] *Official Records of the Economic and Social Council, 2009, Supplement No. 9* (E/2009/29).

5. Accordingly, it is useful to think of agricultural technology in systemic terms, as a complex of institutions, knowledge, practices and communities which collaborate to produce results that enhance the current and long-term productivity of natural resources, and thus cater to human development needs. At one end of the spectrum are agricultural research institutions, where the goal is to raise yield levels in experimental farms through improved cultivars, genetic modification, and techniques of land and water management. Next in line are dissemination institutions, especially extension systems that seek to bring the resultant scientific knowledge to farmers and private sector or other input suppliers. Indeed, the great success of the Green Revolution lay in the speed with which the knowledge (and hence the higher yield levels) were disseminated. This continues to be the greatest window of opportunity for enhancing agricultural productivity. Today, while the yields of wheat and maize in the United States of America and Europe are relatively high (about 80 per cent of the potential),[2] they are much lower in developing countries, especially in sub-Saharan Africa, and for orphan crops.[3] Even without a major breakthrough in improved varieties, bringing the yield levels on farms in developing countries closer to genetic potential can bring about 40 to 800 per cent increases in maize yields,[4] 500 to 1,000 per cent in cassava, and 10 to 60 per cent in rice yields[5] (figure 1).[6]

Figure 1

Crop yield and gap for irrigated rice[7] and maize[8]

(a) Irrigated rice actual yield and gap (b) Maize current and gap in yield



[2] Potential farm yields are generally lower than those in a controlled setting in a research station. Actual farm yields are even lower and are dependent on management practices and level and timing of input applications.

[3] This is important for the food security of the poor, but receives little attention from the private sector.

[4] Pingali, P. (ed.). (2001), International Maize and Wheat Improvement Centre (Centro internacional de Mejoramiento de Maíz y Trigo), 1999-2000 World maize facts and trends. Meeting world maize needs: technological opportunities and priorities for the public sector. Mexico, D.F.: CIMMYT.

[5] Food and Agriculture Organization of the United Nations (FAO) (2004a), “Rice and narrowing the yield gap”.

[6] InterAcademy Council (2004), “Realizing the promise and potential of African agriculture”.

[7] FAO (2004a).

[8] Pingali, P., Pandey, S. (2000), “Meeting world maize needs”.

6. In the past, the predominant share of agricultural research was in the public sector, but the picture has changed quite substantially. In areas where there is a closer relationship between research output and profitability (especially where research results are embodied in tangible products, such as seeds, fertilizers, pesticides and other inputs), private sector enterprises have taken on the bulk of research and dissemination. The optimal role of the public sector may include the direct promotion of research in strategic and neglected areas, including where outputs are less tangible in nature, where the benefits are less likely to be commercializable (e.g., longer-term benefits, collective, rather than individual benefits, and ecological objectives), and where the cost-benefit ratio is adverse (e.g., orphan crops, research on local conditions and indigenous knowledge). The public sector may also need to be more actively involved in the regulation of the private sector enterprises, including private sector research and extension services, in order to ensure that these comply with overall societal goals.

7. Another important form of dissemination is through agricultural education institutions, which train new corps of scientists and extension agents. These need to be complemented by other institutions, including those that supply inputs, credit and insurance.

8. The last two institutions are particularly important where risk factors dominate decision-making, for example in marginal and fragile environments, which are extensive in Africa and among rural poor communities. In Africa, input costs are three times the world market prices, yields are highly variable because of rainfall dependence, and crop insurance is usually not available. There, farming communities look for yield stability, especially in bad years, to maintain a minimal level of household food security. Instead of a high input agricultural model, they prefer complex and diversified crop and livestock systems which minimize risk. This inhibits the use of potentially higher-yielding cultivars and farming practices that may not be as resilient. Local livestock breeds generally have low genetic yield potential, due to the absence of historical selection. Importation of high-yielding breeds, however, often requires more nutritional inputs than are typically available in local production systems and requires a ready market and processing capacity for perishable meat and milk products. Similarly, imported germplasm can be ill-adapted to the local environment, requiring more inputs for disease control. All these require investment in risk-management techniques and associated financial instruments.

9. A number of crops and livestock species with large yield gaps, such as maize, cassava and small ruminants, play a significant role in the livelihood of the rural poor in developing countries. Maize, for example, is Africa's most important food crop and is increasingly important to meet Africa's growing urban demand for convenient food products.[9] Traditional maize production, however, is inherently risky, as it does not tolerate drought and erratic rainfall. Cassava is Africa's second most important food staple in terms of per capita calories consumed and also an important source of animal feed. Yet, cassava yield gap has not narrowed in the last decade. Moreover, various diseases and pests cause considerable depression in actual yields.[10]

[9] Ibid.
[10] Ibid.

10. Besides the favourability of agroecological and agronomic conditions, productivity is also related to management methods, technologies and knowledge available to farmers. Even in most favourable areas where farmers typically have access to modern farming inputs, yields could remain low because of lack of soil, water, and crop management knowledge. Not only do farmers need to know how much fertilizer to apply and be able to afford it; they must also know when and how to apply it, taking into account rainfall, solar radiation, etc. For livestock, farmers may lack the knowledge and experience to balance rations properly, detect estrus or control diseases that are often associated with higher-producing animals.

11. Even where such information is available, farmer adoption has been limited because, in addition to the lack of support institutions, security of tenure in land and water, and access to markets, highly location-specific knowledge is needed about crop-soil-nutrient-water management and animal husbandry, which requires a significant amount of time for experimentation. On-farm yields are also limited by availability of labour and finance, lack of institutional support, cultural preferences, gender differences in technology use and information access. The marginal benefits of conducting research on orphan crops, such as sorghum, millet, cassava, yams and legumes, and on small ruminants and buffaloes, are thus very large, because management studies have been limited and fewer genotype improvements have been made.

12. In recent years, a number of international assessments and forums have highlighted the importance of agriculture for economic development, food security, livelihoods and ecosystem services. Agriculture has functions beyond the production of commodities (food, feed, fibres, biofuels, medicinal products and ornaments), which include non-commodity outputs such as improvement of livelihood, enhancement of environmental services, conservation of natural resources and maintenance of social and cultural traditions. Increasing productivity and resilience in agriculture through effective technologies and environmentally benign production practices is seen as key to achieving the Millennium Development Goals, as well as adaptation to climate change.

13. Agricultural productivity growth in Africa, for instance, is vital in attaining food security because agriculture represents 70 per cent of full-time employment, 33 per cent of gross domestic product and 40 per cent of exports earnings.[11] Agricultural productivity growth is therefore an engine of economic growth. In addition, more than three quarters of the poor and hungry in sub-Saharan Africa reside in rural areas and depend on agriculture for their livelihood.

14. Smallholders dominate the agricultural sector in developing countries and have shown a capability of adopting new technology options where the right incentives and market opportunities exist. In addition to supporting institutions, developing markets for traditional crop and livestock products could have more immediate impact on farmers' income than additional research and development on improved varieties and breeds. Response to incentives and market opportunities varies with socio-economic status and cultural values. Incentives must be adapted to these situations by putting local farming communities at the centre of productivity improvement programmes.

[11] International Food Policy Research Institute, (2002), "Ending hunger in Africa: only the small farmer can do it".

15. Boosting agriculture can set in motion a virtuous cycle of dynamic growth. International Food Policy Research Institute has estimated that, for every dollar of additional income created in the agricultural sector, the economy as a whole will grow by about 2.5 dollars. Due to the multipliers between agriculture and the non-farm sector, the urban poor benefit along with the rural poor from broad-based agricultural productivity growth. Each 10 per cent increase in smallholder agricultural productivity in Africa can thus move almost 7 million people above the dollar-a-day poverty line.[12] Past efforts have focused on increasing yields in favourable agroecological conditions, but increasingly, efforts will have to focus on degraded land and resource-poor small-scale farmers that are tilling marginal and more vulnerable lands.

16. The focus on increasing yields and productivity must be balanced with ecological stewardship to avoid past negative environmental consequences. Historically, these consequences were often unforeseen, as they occurred over time and some occurred outside of traditional farm boundaries. Agriculture has been associated with overexploitation of freshwater resources, pollution of water basins, deforestation and destructive land use change, and greenhouse gas emissions.[13]

17. A more sustainable set of agriculture practices and models has emerged over recent years, although many are still in an experimental or early deployment phase. The challenge is to scale up and diffuse these sustainable practices across agroecological zones, in order to provide a credible alternative to the traditional input-intensive model. The key to widespread deployment of the new models is that environmental sustainability and high yields must be shown to be compatible and even mutually reinforcing.

III. Supporting technology development

18. Major assessments all come to the same conclusions, namely: (a) greater investment in agriculture is needed; (b) resource-poor farmers, women and ethnic minorities should be targeted; (c) a fundamental shift in agricultural knowledge, science and technology is needed so that development and sustainability goals can be met successfully (International Assessment of Agricultural Knowledge, Science and Technology for Development, 2009b; High-Level Task Force on Food Security; report of the seventeenth session of the Commission on Sustainable Development). That shift needs to account for the ecosystem services supporting and supported by agriculture, the complexity of agricultural systems and the unforeseen environmental impacts within diverse social and ecological contexts.

19. The factors affecting the productivity, resilience and sustainability of agricultural systems fall into the following broad categories.[14]

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[12] Ibid.

[13] Refer to International Assessment of Agricultural Knowledge, Science and Technology report ("Agriculture at a crossroads: global report, 2009") for details on environmental implications of agricultural practices.

[14] FAO (2004a).

A. Biophysical factors

20. The impact on yields of biophysical variables is more difficult to address than the other factors. Weather and climate variability, soil types, water availability, pest and disease pressure and weed propensity are often taken as a given. The impacts of rainfall variability can be assuaged with irrigation technologies. However, this would require Government investment for building the basic infrastructure as well as, when appropriate, the institutions required to manage water access rights. Soil composition, pest pressure and weed propensity can be changed over time through management programmes, as they depend on tillage, aeration, pest control, crop systems, etc.

B. Technical and management factors

21. The best varieties and breeds often fail to express their potential on farmers' fields because of inadequate investment in the development and dissemination of complementary crop-management technologies. Research on and promotion of improved crop and land-management technologies lags behind that of improved varieties. Even where such information is available, farmer adoption has been limited for reasons seen above. Demonstration and pilot projects involving neighbouring farmers' fields can help to overcome resistance to adopting new agricultural technologies.[15] Other important factors include farmers' schooling, access to credit and contact with extension agents.[16]

22. More research on crop and livestock productivity and limiting factors is needed. An exemplary case of research is that done on cassava yields in Kenya and Uganda. Where it was found that average cassava yields are less than one fifth of the maximum yields recorded in the same region. When the limiting factors were isolated, soil fertility was found to be the key limiting factor, followed by weeds and rainfall, with soil texture and pest and diseases last.[17] This research contradicts accepted beliefs that cassava is tolerant to poor soil conditions and drought. In addition, only 12 per cent of farmers considered weeding to be important, while 68 per cent perceived pest and diseases as very important. Although farmers could potentially double yields with improved genotypes, the wide variation in current field yields in Uganda indicates that, even without fertilizer and improved genotype, yields could be significantly increased. Therefore, with proper studies and innovative extension services, African yields in grain equivalent could increase by 3 to 5 tons/ha in semi-arid regions growing one crop per year, and by 13 to 16 tons/ha in humid regions with two to three crops annually.[18]

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[15] World Bank Institute (2008), "Improving rice productivity and achieving water savings. Achieving more with less: SRI — a new way of rice cultivation".

[16] Abdulai, A., Huffman, W. E. (2005), The Diffusion of New Agricultural Technologies: The Case of Crossbred-Cow Technology in Tanzania, *American Journal of Agricultural Economics*, 87:3, 645-659.

[17] Fermont, A. M., et al. (2009), Closing the cassava yield gap: an analysis from smallholder farms in East Africa. *Field Crops Research*, 112, pp. 24-36.

[18] International Assessment of Agricultural Knowledge, Science and Technology (2009).

C. Socio-economic factors

23. Weed management and integrated soil fertility management practices, many of which are labour-intensive, can also be an important yield-limiting factor, as indicated in the cassava production case. Although uncontrolled weed growth may reduce yields by 50 to 65 per cent, farmers weeded much less than the optimal three weed operations per growing cycle. Less well-endowed households have a harder time increasing yields because they are constrained in all factors of production. Moreover, in a multistress environment, removing one source of stress will increase production less than in an environment facing only one or two sources of stress.

24. Simple practices, such as increasing plant density, would reduce weeds and thus labour demand. Combining organic and inorganic fertilizers, targeted microdosage of fertilizers, inter-cropping dual-purpose legumes, and reducing nutrient removals by providing alternative sources of fuels so that the stems and crop residues can be left in the field, can go a long way to reduce the need for purchased inputs. FAO recommends simple farming concepts and tools to reduce labour time required to carry out land preparation, planting and weed control.[19] Some inexpensive tools that can be used to alter conventional methods of land preparation include hand jab direct planters (which directly plant crops into unprepared land) and the magoye ripper (which allows for simultaneous land opening and seed planting in a single pass).[20]

D. Institutional/policy/research factors

25. Research to improve cultivars such as sorghum, millet, cassava and yams, and cattle and goat breeds, and to adapt their management to specific agroclimatic zones, has been underfunded. Such research has been of little interest to private agribusiness, and research funding for public national and international research centres has stagnated in recent years. The share of agriculture in official development assistance has declined sharply over the past two decades, but this trend may be reversing following the 2008 food crisis: in July 2009, the G-8 countries pledged $20 billion for global agricultural development.[21]

26. Yield potential in wheat has continued to increase at the rate of 1 per cent per year over the past three decades since the Green Revolution.[22] The development of super-high-yielding varieties of rice and wheat using conventional breeding techniques is expected to increase yield by 15 to 20 per cent.[23] These improvements have been associated with research centres that have developed plants with durable resistance to a wide spectrum of insects and diseases and which are more tolerant to a variety of physical stresses. These centres were also able to develop cereal grains with enhanced taste and nutritional qualities. However, with the recent exception of

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[19] FAO (2004b), “Saving time and labour”.

[20] FAO (2005), “Labour-saving technologies and practices for households”.

[21] Glickman, D., Bertini, C. (2009), The G-8 announcement on agricultural development: can it save the world from hunger? “Global Agricultural Development”, The Chicago Council on Global Affairs.

[22] Pingali, P., Heisey, W. (1999), Cereal crop productivity in developing countries: past trends and future prospects. Working Paper 99-03, International Maize and Wheat Improvement Centre (Centro internacional de Mejoramiento de Maíz y Trigo).

[23] FAO (2005).

cassava, progress in orphan crops has been limited. In addition, little research has been conducted on how to intensify, in a sustainable manner, crop-livestock systems that play an important role in smallholder agriculture.

E. Technology transfer factors

27. Lately, high fertilizer prices have reinforced environmental concerns to provide an impetus to the adoption of less fertilizer-dependent technologies to increase productivity, including integrated crop management and genetic improvement. Most hybrid varieties respond well to fertilizers but have similar yields to traditional varieties without fertilizer. Since hybrid seeds are more expensive, it is not always economical to introduce them if fertilizer inputs are not affordable or available. Other technologies, such as the system of rice intensification, that get higher yields with lower water and nutrient inputs through better soil moisture management and planting density, could be an option. Similarly, modern biotechnology tools complement conventional breeding approaches rather than substituting for them.

28. The enormous success of the Green Revolution in enhancing food supplies and food security in the developing world is well known. The development and promotion of modern, high-yielding varieties, was the most important factor contributing to this success, complemented by the expansion of irrigation, mechanization, specialization, and the use of chemical fertilizers and pesticides. Also crucial was a mosaic of institutions and policies, including for extension, research, education, cooperatives and marketing, and input supply. While the Revolution led to dramatic production increases, especially in Asia and Latin America in the 1960s and 1970s, the rate of growth was not sustained. Growth of global cereal yields has declined from an average of 3.3 per cent per year during the 1960s to under 1 per cent per year since 1990.[24] In addition, this capital-intensive and irrigation-dependent package, has had only limited impact in marginal production areas and where irrigation is not available.

29. At its seventeenth session, the Commission on Sustainable Development concluded that a new Sustainable Green Revolution should broaden the focus of agricultural investments from productivity to consider also resilience and long-run sustainability, including the protection of ecosystem functions and mitigation of environmental impacts. Even in Asia where the Green Revolution was most successful, land degradation, expanding deserts, shrinking forests and competition for water has obliged Asia to produce not only efficiently, but also in ways that respect the environment.[25]

30. Agricultural extension services are among the most important rural services in developing countries.[26] Returns to extension in many cases exceed returns to agricultural research. A review of social rates of return to research and extension in 95 developing countries finds a return for extension of 80 per cent (compared to

[24] World Development Indicators (2008), World Bank.

[25] Economic and Social Commission for Asia and the Pacific (2009), "Sustainable Agriculture and Food Security in Asia and the Pacific".

[26] Faye, I., Deininger, K. (2006), "Do new delivery systems improve extension access? Evidence from rural Uganda", American Agricultural Economics Association Annual Meeting.

50 per cent for research).[27] Evidence indicates that agricultural extension is also a pro-poor public investment. For instance, in Ethiopia, a single agricultural extension visit reduced poverty by 9.8 per cent and increased consumption by 7.1 per cent,[28] while extension visits in Uganda reduced poverty, child stunting and underweight children below the age of 5.[29]

31. Extension services have been evolving over time. In the 1990s and 2000s, Governments and development partners have begun reforming traditional extension services to address their major weaknesses.[30] Several African countries are already implementing some form of demand-driven extension models. These reforms aim to provide extension services that are:

- More demand-driven and participatory;
- Pluralistic in the providers of advisory services and in sources of funding;
- Targeted at vulnerable groups and empowering farmers to demand and manage advisory services;
- More focused, with the type of technology provided dependent on demand; but also
- More limited in services coverage.[31]

32. There is no one-size-fits-all extension service model and there is still room for improvement. Participatory approaches have been shown to perform better than top-down approaches. Yet, supply-driven extension services still play an important role.[32] For instance, sustainable land management practices may not be demanded by farmers, due to limited knowledge about their effectiveness.[33] It is important to include this training in extension services as well as post-production services, such as price and marketing information and strategies, which are often still lacking. In addition, extension services could be improved by taking advantage of farmers' indigenous knowledge.

33. Government financial support for extension services is often weak, such that services are largely donor-funded, which jeopardizes their longevity. Investment in agriculture needs to revitalize public extension services to complement non-governmental organizations and private providers' services that tend to operate

[27] Alston, J. M., Pardey, P. G. (2000), Attribution and other problems in assessing the returns to agricultural R&D, *Agricultural Economics*, 25, pp. 141-152.

[28] Dercon, S., et al. (2008), The Impact of Agricultural Extension and Roads on Poverty and Consumption Growth in Fifteen Ethiopian Villages, International Food Policy Research Institute discussion paper 00840.

[29] Nkonya, E., Benin, S., Okecho, G. (2009), "Enhancing the use of improved agricultural technologies", International Food Policy Research Institute (mimeo).

[30] Röling, N. (2006), "Conceptual and methodological development in innovation", Innovation Africa Symposium, Kampala; Rivera, W., Alex, G. (2004). Decentralized Systems: Case studies of international initiatives. Agricultural and Rural Development discussion paper 8 (1), World Bank.

[31] Nkonya, E. (2009), "Current extension service models, what works and what does not work. United Nations expert group meeting on sustainable land management and agricultural practices in Africa", University of Gothenburg.

[32] Rivera, W. (2001), "Agricultural and rural extension worldwide: options for institutional reform in the developing countries", FAO.

[33] Qamar (2006).

in areas with high market access.[34] Coverage has to be expanded in remote areas and among poor farmers, especially women, where most information is needed. Extension services must also take into account socio-economic conditions and focus on locally available resources. Training farmers to use high-input practices in areas where inputs are prohibitively expensive will fail as demonstrated in farmer field schools in Kenya.[35]

IV. Boosting agriculture sustainably

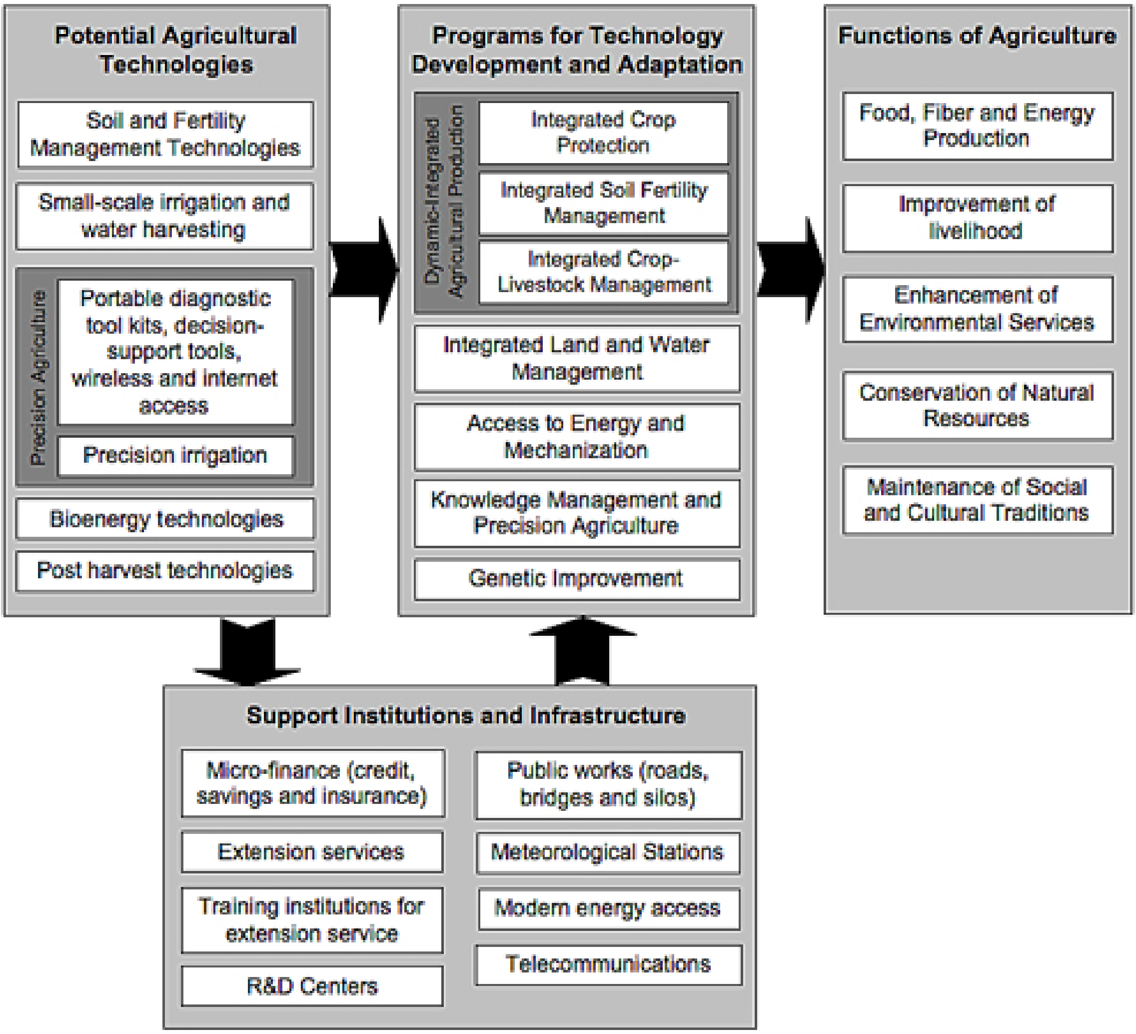
34. While various technologies are available to achieve food security and eradicate poverty, they need to be deployed through a coherent framework, in proper combinations, and with the necessary support from appropriate institutions and infrastructure (figure 2), especially in more complex and diversified smallholder farming systems. Programmes appropriate in the context of developing countries can be grouped as follows:

- Dynamic-integrated agricultural production, which includes integrated crop protection, integrated soil fertility management and integrated crop-livestock management;
- Integrated land and water resource management, with emphasis on community-based land and water management;
- Access to energy and mechanization;
- Knowledge management and precision agriculture; and
- Genetic improvement.

[34] Rutatora, D., Mattee, A. (2001), “Major agricultural extension providers in Tanzania”, *African Study Monograph*, 22, pp. 155-173.

[35] Muli, M. B., et al. (undated), “Enhancing local innovation process”, Kenya Agricultural Research Institute.

Figure 2
Potential technologies and programmes needed to bolster the functions of agriculture



A. Programmes for technology development and adaptation

Dynamic-integrated agricultural production

35. Dynamic-integrated agricultural production involves multiple farming systems (crop and livestock) that interact in space and time. It is dynamic in the sense that it includes an annual strategy of optimizing production, economic and resource conservation goals.[36] Dynamic-integrated agriculture encompasses the principles of integrated crop protection and integrated soil-fertility management.

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[36] Hendrickson, J., et al. (2008), “Principles of integrated agricultural systems: introduction to process and definition”, *Renewable Agriculture and Systems*, 23, pp. 265-271.

36. Integrated crop protection involves a holistic approach to the proper management of pests, weeds and diseases. It views the agroecosystem as an interrelated whole and utilizes a variety of physical, chemical, biological, cultural and genetic approaches to control pests, weeds and diseases with limited disruption to the environment. Integrated pest management is one of the strategies of integrated crop protection, which can include the use of multicropping or polycropping systems with two or more crop or plant species,[37] or using classical biological control by introducing natural enemies against pests and weeds,[38] while avoiding the introduction of invasive alien species. Natural forms of biological control should be exploited first to minimize concerns associated with the environmental and health effects of chemical and physical forms of crop protection.[39] While integrated crop protection has been successfully implemented in a wide range of crop environments in all parts of the world, its adoption remains slow.[40] For example, smallholders in sub-Saharan Africa are still less willing to embrace integrated pest management and there has been limited success with its adoption in staple food crops, even though it is widely advocated as the main crop-protection strategy in the region.

37. Integrated crop and livestock systems, if managed properly, can contribute to a balanced use of natural resources, including water, soils and organic nutrients. From a human nutritional standpoint, even modest increases in consumption of meat and dairy products can deliver significant health benefits by addressing micronutrient malnutrition and improving the nutritional quality of diets that are largely based on cereals and root crops. Research on the promotion and diffusion of improved soil, water and crop-management technologies should be increased. Farm schools could help to bridge the research and field experience to provide location-specific integrated soil fertility and pest management.

38. For farmers that can afford them, molecular biology and biotechnology can support integrated crop protection programmes through improvements to the biological control agents, the affected crops and the target organisms. This also includes genetic pest control based on the sterile insect technique, which is an environment-friendly biotechnology that interferes with the reproduction of the target pests.[41] These technologies depend on gaining greater scientific knowledge on the concerned populations of the species through genetic fingerprinting. This enables direct searches for more effective biological control agents, identification of agent specimens, tracing origins of invasions, and monitoring of the safety and efficacy of integrated crop protection programmes.[42] Thus far, there is limited research on the needs of developing countries with respect to this technology.

39. Integrated soil fertility management is increasingly accepted in developing countries, particularly by smallholders. The objective of integrated soil fertility

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[37] Bale, J. S., et al. (2008), Biological control and sustainable food production. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, pp. 761-776.

[38] Orr, A. (2003), "Integrated pest management for resource-poor African farmers: is the emperor naked?" *World Development*, 31, pp. 831-845.

[39] Rector, B. (2008), "Molecular biology approaches to control intractable weeds: new strategies and complements to existing biological practices", *Plant Science*, 175, pp. 437-448.

[40] Bale et al. (2008).

[41] Dyck, V. A., et al. (eds.) (2005), *Sterile Insect Technique, Principles and Practice in Area-wide Integrated Pest Management*, Netherlands: Springer.

[42] Rector (2008).

management is to integrate the use of all natural and man-made sources of plant nutrients in order to achieve greater crop productivity in an environmentally sustainable manner. It employs various strategies, including appropriate nutrient application, crop-livestock integration, soil conservation and knowledge transfer of integrated soil fertility management practices to various concerned stakeholders.[43]

40. Applying established nutrient application and soil-conservation technologies is essential in maximizing the plant uptake of nutrients and the prevention of physical loss of soil and nutrients. These include alteration of the field's physical environment, use of biological nitrogen fixation, use of intercropping, and application of manure and mulch.[44] Particularly promising are crops that combine soil nitrogen fixing qualities and human nutritional and/or market values, which are cultivated by poor smallholders and women farmers (e.g., cowpea, promiscuous soybean and dolicos lablab). Dynamic-integrated agricultural production implies taking advantage of the ubiquitous nutrient sources from all agricultural systems, particularly from livestock. Integrated crop-livestock management would facilitate the use of agricultural residuals as feed for animals, while the animal waste products are used to make compost. There are successful cases in Asia and Africa where greater crop productivity was achieved with the use of compost in smallholder farms.[45]

Integrated land and water resource management

41. The core principles of integrated land and water resource management focus on the integration of planning approaches that incorporate both conventional and non-conventional strategies to close the gap between land and water supply and demand. It includes the principles of sustainable development, multi-stakeholder participation and the role of women.[46] The effective implementation of integrated land and water resource management depends on, among others, the nature and intensity of water problems, availability of human resources, characteristics and capacities of institutions, cultural setting and biophysical conditions unique to individual countries.[47]

42. Besides low rainfall, water scarcity in developing countries can result from a shortfall in economic resources and incentives to develop water-related infrastructure. In the case of African smallholders in the semi-arid and arid areas, for example, living at great distances from bodies of water proves to be severely restrictive for agricultural development. Diverting water to these remote areas entails massive engineering projects (i.e., large-scale irrigation systems) that would require enormous amounts of capital.[48] Hence, integrated land and water resource management suggests smaller-scale water infrastructure (e.g., small-scale irrigation

[43] Gruhn, P., et al. (2000), "Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges", Food, Agriculture and the Environment discussion paper 32. International Food Policy Research Institute.

[44] Ibid.

[45] Ching, L. L. (2009), "Is ecological agriculture productive?" Briefing paper 52. Third World Network; also, Sustainable Development Innovation Brief 7, United Nations, Department of Economic and Social Affairs, Division for Sustainable Development.

[46] Global Water Partnership, (2000), "Integrated water resource management".

[47] Funke, N., et al. (2007), "IWRM in developing countries: lessons from the Mhlatuze Catchment in South Africa", *Physics Chemistry Earth*, 32, pp. 1237-1245.

[48] Van Koppen, B. (2003), "Water reform in Sub-Saharan Africa: what is the difference?" *Physics Chemistry Earth*, 28, pp. 1047-1053.

and rainwater harvesting), water conservation, and soil moisture management, as well as community-level water management as economically viable alternatives to addressing water scarcity.[49]

43. Development of rural water resources necessitates the use of low-cost and efficient water technologies that are relatively simple to maintain and that can be constructed and operated at the community-level.[50] An example of a low-cost water harvesting technology is the sand dams that have been extensively tested in several African countries.[51] Low-pressure drip irrigation is another low-cost technology that is currently advocated in developing countries. Such a technology can achieve water savings of more than 50 per cent relative to conventional surface irrigation systems.[52] The Government of Israel, as part of its Techno-agricultural Innovation for Poverty Alleviation programme, is currently working with local institutions and various development organizations to dispatch low-pressure drip irrigation systems in Africa.[53] Of course, increased irrigation efficiency does not alleviate the need to manage the aggregate use of water at the water basin level to ensure sustainability of the resource.

Access to energy and mechanization

44. Mechanization of agriculture holds great potential to increase production. This necessitates a shift from traditional energy (manual labour and use of draft animals) to modern energy. Yet reliance on expensive fossil fuels may be self-defeating in time of rapid increase in world prices. Instead affordable forms of energy such as biomass (including biofuels and biogas from crop residuals and livestock waste), solar, wind and small hydro maybe more sustainable.

45. Renewable energy technologies that have promise in the agricultural sectors of developing countries, particularly in Africa, include small hydro, modern bioenergy and solar dryers. Co-generation using agricultural residuals, such as bagasse, is a well-established technology in Africa.[54] Locally produced biofuels for local energy generation have also shown significant productivity gain.[55]

Knowledge management and precision agriculture

46. Information and communication technologies are now becoming an essential tool for facilitating knowledge management and bolstering agricultural development.[56] The vast distance between many rural communities and centres of

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[49] International Assessment of Agricultural Science and Technology for Development (2009).

[50] Lasage, R., et al. (2008), “Potential for community-based adaptation to droughts: sand dams in Kitui, Kenya”, *Physics Chemistry Earth*, 33, pp. 67-73.

[51] Lasage (2008).

[52] Maisiri, N., et al. (2005), “On-farm evaluation of the effect of low-cost drip irrigation on water and crop productivity compared to conventional surface irrigation system”, *Physics Chemistry Earth*, 30, pp. 783-791.

[53] Israel resolution on agricultural technology for development.

[54] Karekezi, S. (2002), “Renewables in Africa — meeting the energy needs of the poor”, *Energy Policy*, 30, pp. 1059-1069.

[55] Karlsson, G., Banda, K. (2009), “Biofuels for sustainable rural development and empowerment of women”, Case studies from Africa and Asia, *Energia*.

[56] Rao, N. H. (2007), “A framework for implementing information and communication technologies in agricultural development in India”, *Tech Forecasting Social Change*, 74, pp. 491-518.

commerce, finance and governance prohibits an efficient transfer of information. Developing countries lack the transportation infrastructure, financial resources and time needed to make it convenient for rural inhabitants to access information and relevant services. Mobile and wireless technologies have proved to be promising solutions for bolstering administrative efficiency and reducing transaction costs. Information and communication technologies is able to provide farmers with real-time information on the latest market forecasts, weather forecasts, emergency alerts, agricultural technologies, expert consulting, banking transactions, funding opportunities and Government/private notifications.[57]

47. Information and communication technologies is useful in organizing and analysing relevant information on nutrient dynamics and making it available for farmers. Decision support includes computer models and interactive-Internet-based systems, with remote sensing, yield mapping and crop canopy measurements that can be used for more efficient targeted fertilizer applications. For instance, information and communication technologies has made national-level rapid assessments of land fertility, biodiversity[58] and nutrient dynamics[59] relatively easy.

48. Precision agriculture gathers comprehensive data on spatial and temporal production variability and fine-scale application of soil and livestock factors. Precision agriculture allows for efficient utilization of agricultural inputs, early warning of ill health, and even reduction in pollutant emissions.[60] While high technology precision agriculture is now debuting in large-scale systems in developing countries, its application for smallholders still remains a challenge. Precision agriculture is not only limited to sophisticated technologies, such as global positioning satellites and remote sensing. It includes low-cost and simpler technologies (e.g., portable diagnostic tool kits, such as chlorophyll meter and leaf colour charts), decision support systems and even traditional knowledge.[61] It can also include integrated systems for recording of animal identification, to enhance disease monitoring, genetic selection, production monitoring and product traceability.

49. Improved application of information and communication technology (ICT) for agricultural development requires new strategies and partnerships. Public-private partnerships and ICT have a critical role in enhancing the dissemination of technical information through programmes such as Research for Life (www.research4life.org). Potentially the most significant impact of ICT on agricultural technology generation will be in connecting and engaging communities in participatory agricultural innovation. Improving the understanding and

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[57] Ntaliani, M., Costopoulou, C., Karetsos, S. (2008), “Mobile government: a challenge for agriculture”, *Government Information Quarterly*, 25, pp. 699-716.

[58] Gillison, A. (2009), “Bridging the gap between research and farmers”, Presentation at United Nations expert group meeting on sustainable land management and agricultural practices in Africa, University of Gothenburg.

[59] Goulding, K., et al. (2008), “Optimizing nutrient management for farm systems”, *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, pp. 667-680.

[60] Wathes, C. M., et al. (2008), “Is precision livestock farming an engineer’s daydream or nightmare, an animal’s friend or foe, and a farmer’s panacea or pitfall?” *Computers and Electronics in Agriculture*, 64, pp. 2-10.

[61] Mondal, P., Basu, M. (2009), “Adoption of precision agriculture technologies in India and in some developing countries: scope, present status and strategies”, *Progress in Natural Science*, 19, pp. 659-666.

appropriate application of ICT in agricultural development, regardless of geographic boundaries, necessitates support to local, regional and global communities of practice, such as the e-agriculture community, in order to have the best impact.[62]

Genetic improvement

50. Biotechnology, according to the Convention on Biological Diversity, should ideally include much of the traditional knowledge and technologies for the production, processing and preservation of agricultural products, as well as modern molecular tools. It can have a role to play in bolstering agricultural productivity and fostering rural development and sustainability. A proven and uncontroversial technology with demonstrated capacity to broaden crop adaptability to adverse environments and enhance efficiency of nutrient and water uptake is mutation induction applied to plant breeding. An alternative technology is that of transgenics (genetically modified organisms), which needs to be closely managed to avoid risk of contamination of non-biotech fields.[63] Bioengineering crops have, with a few exceptions, so far focused on developing seeds for plants that are resistant to pests or to specific herbicides and focused on high-valued crops.

51. For livestock, programmes of genetic improvement in local breeds include conventional (record keeping, genetic evaluation, artificial insemination), as well as advanced methods (molecular genetics and genomics), and generally aim to improve productivity while maintaining genetic diversity and adaptability. Thus far, they have been applied to enhance the growth, health and survivability of animals, particularly in terms of resistance to pathogens and diseases.[64] Genomics could lead to great production increases but has been criticized on the basis of risk factors. More generally, the role and value of genetic modification continues to be vigorously debated in both scientific and policy communities. If pursued, such programmes need to be accompanied by appropriate biosafety analysis and screening to ensure that any environmental and human health risks are monitored and minimized. The programmes should also be complemented with programmes on animal identification and recording to establish associations between genotypes and phenotypes in the local environments.

52. Furthermore, genetic improvement must be recognized as only one component of an integrated approach to enhancing productivity of crops and livestock. Less controversial genetic improvement techniques are readily available, such as selection within and between breeds and crossbreeding.[65]

53. Part of the controversy over bioengineering is that patents protecting agricultural biotechnologies are mostly held by a few multinationals and protected under the World Trade Organization (WTO) Trade-Related Aspects of Intellectual Property Rights. The small number of competitors, combined with intellectual

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[62] Maru, A., et al. (2009), “Information and Communication Technologies — Ways to Mobilize and Transform Agricultural Science for Development”, Consultative Group on International Agricultural Research Science Forum.

[63] International Assessment of Agricultural Science and Technology for Development (2009).

[64] Laible, G. (2009), “Enhancing livestock through genetic engineering — recent advances and future prospects”, *Comparative Immunology, Microbiology and Infectious Diseases*, 32, pp. 123-137.

[65] Kosgey, I. S., Okeyo, A. M. (2007), “Genetic improvement of small ruminants in low-input, smallholder production systems: technical and infrastructural issues”, *Small Ruminant Research*, 70, pp. 76-88.

property rights, tends to raise the cost of seeds and relevant technologies, thus potentially limiting smallholders' access.[66] For that reason, the International Seed Treaty has established a Multilateral System of free access and benefit sharing of certain plant genetic resources.[67] Research on orphan crops and crops modified to adapt to climate change should be developed under the Multilateral System to ensure plant breeders and farmers have access to the resulting technologies. Alternatively, intellectual property rights holders could be encouraged to provide developing country users with technologies for a limited period, with the expectation of receiving payment once the technology has been adapted to local requirements.

B. Support institutions and infrastructure

54. Several types of support institutions and infrastructure are necessary for the implementation of technology development and adaptation programmes. Microfinance institutions may offer savings, credit and insurance services that enhance the ability of the rural poor to take on risks. For instance, microinsurance is a means by which to buffer the risks posed by adverse weather conditions that threaten smallholders.[68] Another important institution is the extension service provider, which offers knowledge and information that can improve farmers' income and welfare.[69]

55. Farmers' education is another important factor that needs to be addressed by support institutions. A farmer with four years of elementary education is, on average, 8.7 per cent more productive than a farmer with no education. Thus, the provision of more and better basic education in rural areas is essential. The perceived negative image of agriculture must also be changed to reverse the current declining enrolment in agricultural education.[70] Agricultural education and training have to be brought back to the mainstream education system. Its isolation has led to curricula irrelevance, falling teaching and learning standards, unemployment of graduates, and decreasing investment support.[71]

56. There is a direct link between provision of infrastructure and rural development. The rural poor need access to basic public works, agricultural infrastructure, modern energy, water and telecommunications. These types of

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[66] Lalitha, N. (2004), "Diffusion of agricultural biotechnology and intellectual property rights: emerging issues in India", *Ecological Economics*, 49, pp. 187-198; Walker, S. (2001), "The TRIPS agreement, sustainable development and the public interest: discussion paper", International Union for the Conservation of Nature, Gland.

[67] FAO (2001). Report of the Thirty-First Session, appendix D: International Treaty on Plant Genetic Resources for Food and Agriculture, 2 to 13 November 2001, C/2001/REP.

[68] Zeller, M., Sharma, M. (2000), "Many borrow, more save, and all insure: implications for food and micro-finance policy", *Food Policy*, 25, pp. 143-167; Bryla, E., Syroka, J. (2007), "Developing index-based insurance for agriculture in developing countries", Innovation Briefs, Issue 2, United Nations, Department of Economic and Social Affairs, Division for Sustainable Development.

[69] Anderson, J., Feder, F. (2003), "Rural extension services", World Bank policy research working paper No. 2976.

[70] Pratley, J. E., Leigh, R. (2008), "Agriculture in decline at Australian Universities", Fourteenth Australian Society of Agronomy Conference, Adelaide.

[71] Gasperini, L. (2000), "From agricultural education to education for rural development and food security: all for education and food for all".

infrastructure are able to lower costs by reducing post-harvest losses and allowing farmers to have a more efficient means of delivering crops and acquiring products and services over long distances.[72]

C. Local adaptation and community involvement

57. Technology adaptation programmes would be more likely to achieve their objectives if new technologies were grounded in local context and stakeholders' priorities. Local communities have indigenous knowledge that can facilitate technology adaptation, and hence should be given the opportunity to participate in the planning and management of programmes and the assessment of the local applicability of agricultural technologies. In addition, farmer organizations and cooperatives assist farmers to do more with limited resources, obtain lower input and higher output prices, pool outputs to reduce transportation costs, and even develop local processing capacity.

58. Local adaptation will increasingly have to consider the impact of climate change on agriculture. Climate change projections are characterized by pronounced variability and uncertainty.[73] Even as there is a drive for greater predictability of climate models, response strategies need to account for uncertainties when building resilience in agricultural systems.[74] Besides research into adapted crop varieties, adaptive approaches also need to be integrated into management practices.

V. Summary of recommendations

59. **The development and deployment of technologies, which is critical for realizing the goals of agricultural development, food security, poverty eradication, ecological sustainability, and climate resilience, requires a strategic framework of action, which a number of policy processes have begun to sketch but this is an evolving agenda. The latest and most refined version is set out in the decision agreed at the seventeenth session of the Commission on Sustainable Development, which shapes the policy recommendations which follow.**

60. **The approach combines complementary actions at national level and supportive actions at international level.**

National Actions

61. **Agricultural technology and broader development should be incorporated into national sustainable development strategies. Besides the core strategy for a green revolution, the decision calls for related strategies to protect scarce natural resources, including an integrated strategy for sustainable management of land and water resources, strategies for addressing drought and**

[72] Hemson, D., et al. (2004), "Rural development: the provision of basic infrastructure services", Integrated Rural and Regional Development, Human Sciences Research Council.

[73] Giorgi, F. (2005), "Interdecadal variability of regional climate change: implications for the development of regional climate change scenarios", *Meteorology Atmospheric Physics*, 89, pp. 1-15.

[74] Howden, S. M., et al. (2007), "Adapting agriculture to climate change", *Proceedings of the National Academy of Sciences*, 104, pp. 19691-19696.

desertification and for adapting to climate change, and improved monitoring as basis for measures to reverse land degradation.

62. **Sustainable green revolution: The Commission on Sustainable Development, at its seventeenth session, calls for a green revolution that revitalizes agricultural sectors in developing countries by enhancing agricultural production, productivity, and sustainability through the use of science-based approaches and local indigenous knowledge in a manner that protects and conserves natural resources, limits the use of scarce inputs and pollutants, and enhances the quality of natural resources. Key elements of the strategy are:**

(a) **Increased investment in agriculture, agricultural research and development and critical rural infrastructure;**

(b) **Building the knowledge and information base for effective technology development and deployment, including through effective use of information and communications technologies;**

(c) **Investment in extension services that effectively place scientific knowledge in the hands of farmers and communities, as well as in farmers' education and training to be able to make effective use of that knowledge in combination with traditional knowledge;**

(d) **Promoting use of efficient and cost-effective technologies for the implementation of sustainable land management;**

(e) **Support for national and international market integration, particularly for small farmers and local entrepreneurs;**

(f) **Investment in improved post-harvest technologies and infrastructures to reduce wastage along the food chain, including for improving food handling, testing, processing, storage and transport;**

(g) **Special programme for Africa: the green revolution in the 1960s and 1970s largely bypassed Africa. The Commission, at its seventeenth session, seeks to ensure that this time the continent would benefit from the latest scientific research and that these benefits would not come at the cost of ecological services, cultural arrangements, and indigenous knowledge, and that African agriculture has the capacity to cope with and adapt to climate change.**

63. **Addressing climate change: The Commission, at its seventeenth session, calls for mobilization of funding for research and development of drought-tolerant seed varieties, the promotion of technical solutions and practices in combination with traditional knowledge for drought forecasting, impact assessment, and early warning systems. It also asks for investment in agriculture as a way of addressing climate change.**

64. **Social strategy for sustainable rural development, including:**

(a) **Enhanced support for small farmers, providing incentives to resource poor farmers for acquiring suitable technologies and adopting sustainable practices;**

(b) **Land tenure protection as well as secure access to water, especially for poor and vulnerable groups;**

(c) **Empowerment of rural women, who play a critical role in agricultural production and ensuring household food security, including through land tenure protection. Extension services should be better targeted at smallholders, especially women farmers, and more women need to be trained as extension agents;**

(d) **Social capital and scaling up of best practice: The Commission on Sustainable Development, at its seventeenth session, recognizes the fact that a number of "best practices" have failed to be deployed at significant scale. These include, for example, measures for soil and water conservation, efficient irrigation and water harvesting and storage, integrated water and land resources management, decreasing post-harvest losses, integrated pest management, and benefiting from market opportunities.**

65. **International cooperation will be essential to implement these national actions. The Commission on Sustainable Development, at its seventeenth session, highlighted the importance of mobilizing additional financial resources for agricultural official development assistance and, in particular, to support a green revolution in Africa. Smallholders everywhere also need to have greater protection from both price shocks and weather shocks, including those which may arise from climate change. International support for research and development on orphan crops, improved local livestock breeds and climate-adapted varieties and methods will be critical if African countries and other poor and vulnerable countries are to be able to enhance food security. Greater technology cooperation in the agricultural domain, North-South, South-South and triangular, could help to accelerate technology transfer and deployment where urgently needed. Technologies for effective water conservation and management and efficient irrigation constitute an important example of where there has been some progress, but more technology cooperation is needed broadly in the area of sustainable agriculture and natural resource management. International cooperation is also needed to work towards a consensus on sustainable biofuels.**