UNITED NATIONS CONFERENCE
ON TRADE AND DEVELOPMENT

UN Commission on Science and Technology for Development

2010–2011 Inter-sessional Panel
Geneva, Switzerland
15–17 December 2010

Issues Paper on

Technology and Innovation for Sustainable Agriculture

ADVANCE UNEDITED DRAFT

NOT TO BE CITED

Prepared by the UNCTAD Secretariat

At its 13th session held in May 2010, the Commission on Science and Technology for Development (CSTD) selected “Technologies to Address Challenges in Agriculture and Water” as its priority theme for the 2010-2011 inter-sessional period. To contribute to a further understanding of the issues and to assist the CSTD in its deliberations at its 14th session, the UNCTAD secretariat will convene a panel meeting in Geneva, from 15 to 17 December 2010.

This paper presents key issues related to the role of science, technology and innovation in addressing challenges in agriculture.

Contents

I. Introduction

Agriculture provides a livelihood for 40% of the global population. Seventy percent of the poor in developing countries live in rural areas and directly or indirectly depend on agriculture for their livelihood. At the same time, agriculture has a major influence on clean water supply, pollination, pest and disease control, and carbon emissions[1]. Improvements in agriculture can significantly impact many aspects of life for many people.

Despite all the attention and effort that have been devoted to alleviating hunger, nearly 1 billion people are undernourished [2]. On average, nearly a thousand children die each hour from malnutrition and hunger-related diseases[3]. The number of undernourished people may increase even further as a result of the global financial crisis, sustained high levels of unemployment, increased food price volatility, shortages, and predictions of further widespread droughts and floods[4].

Hunger is not simply a production problem—enough food is being produced globally to feed everyone in the world. Over the past 50 years, global per capita agricultural production has outpaced population growth—the world produces 17% more calories per capita and on average people have 25% more food than they did in 1960, even with a doubling of the global population, and there is enough to provide everyone in the world with at least 2,720 kcal per day[5]. However, increased food supply does not automatically mean increased food security. The dramatic increase in production over the past few decades, mostly a result of the Green Revolution, has not led to major reductions in hunger and poverty in developing countries[6].

The majority of the chronically hungry in developing countries are smallholder farmers, most of whom reside in Africa and Asia. They manage around 80% of the farmland in Asia and Africa and supply about 80% of the food consumed in the developing world[7]. As shown in Figure 1 and Table 1, the bulk of child malnutrition lies in these two continents, where the

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[1] IAASTD 2009
[2] IFAD 2011
[3] World Food Programme 2010
[4] Vidal 2010
[5] FAO 2002 in World Hunger Education Service 2010 and UNCTAD 2008
[6] UNCTAD 2008
[7] IFAD 2010

average farm size is 1.6 ha, compared to the average farm size of 121 ha in North America. Globally, 95% of farms less than two hectares are in Asia (87%) and Africa (8%)[8].

Figure 1: Proportion of the population unable to acquire sufficient calories to meet their daily caloric requirements, 2003 estimates[9]

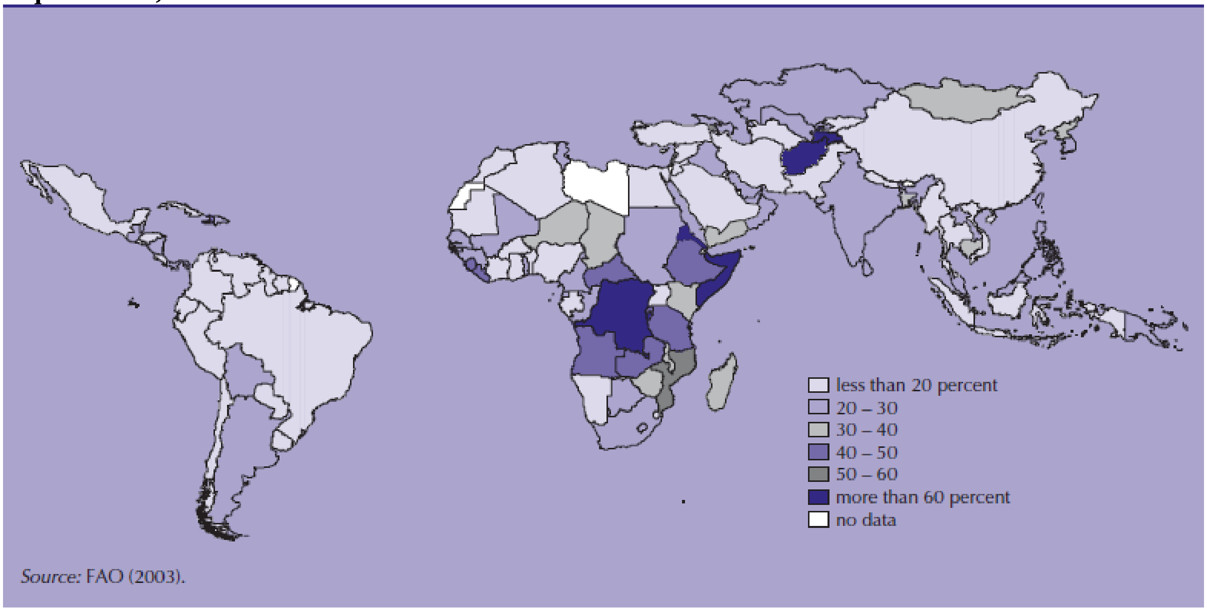

Table 1: Average farm size by region[10]

Region	Average Farm Size (ha)
Africa	1.6
Asia	1.6
Latin America & Caribbean	67.0
Western Europe	27.0
North America	121.0

Challenges particularly facing smallholder farmers are lack of access to knowledge, skills, inputs, credit, markets, and infrastructure. Furthermore, they live and work on marginal lands at increased risk of soil degradation, droughts, floods, storms, pests, and erratic rainfall[11] and the poorest farmers with little safeguards against dramatic climate changes often live in areas prone to natural disasters[12]. Sustainable agriculture—building on the principles of economic, social and environmental sustainability—holds the promise to address many of these challenges faced by resource-poor farmers.

This paper addresses opportunities and challenges in agricultural innovation with particular attention to technologies and practices relevant to sustainable agriculture for smallholder farmers in developing countries. It highlights the importance of new and traditional

[8] Nagayets 2005 and von Braun 2005
[9] copied from Rosegrant 2006
[10] adapted from Nagayets 2005 and von Braun 2005
[11] UNCTAD 2010
[12] Hoffmann 2010

sustainable production methods and related skills and technologies; an inclusive innovation environment; improved and revitalized agricultural research, education, and extension services; targeted increased investment; financial tools; and policy support[13].

II. Science and technology applications and farming practices

A range of promising, existing science and technology applications and farming practices at all stages of agricultural processes can significantly increase agricultural productivity. New genotypes of crops and advances in breeding, biotechnology, remote sensing, integrated pest and nutrient management, and information and communication technologies (ICTs) can make agriculture more resource-efficient and site-specific[14]. Some of these technologies, applications, and sustainable agriculture practices may be well suited for smallholder farmers. Smallholder farming is generally labor intensive, does not rely heavily on external inputs, and is more dependent on the local environment. Introductions of modern science and technology to smallholder farming should take into account these characteristics and be based on farmer knowledge networks, better infrastructure, and a system approach involving crop rotation and integrated crop and feedstock production.

Adequate water management

Multiple practices and science and technology applications tackle one of the key challenges for agriculture—agricultural water use[15]. Briefly, for relatively large and sophisticated farming systems, new irrigation techniques include automated canal and piped water delivery systems, laser land leveling for surface irrigation applications, automated sprinkle irrigation, microirrigation, and sophisticated control systems[16]. Better design and management of large dams and irrigation systems can maintain aquatic and riparian ecosystems, avoid siltation and salination, and improve equity between upstream and downstream users[17].

Smallholder farmers rarely have the means for permanent or comprehensive irrigation and the bulk of crop production in developing countries is rain fed. In these areas, contour farming, ridging, increased soil organic mater, water harvesting, and no-till farming can increase soil

[13] UNCTAD 2010
[14] IAASTD 2009
[15] We address water including its use in agriculture extensively in a separate, companion issue paper.
[16] UNCTAD 2010
[17] IAASTD 2009

water retention and reduce runoff[18]. No-till farming (also called zero tillage, direct seeding, or conservation agriculture) consists of planting new crops over dead leaves and vegetation left after harvesting prior crops; this technique helps avoid soil loss from erosion. Other suitable irrigation techniques and system components particularly suitable for smallholder farmers include: low-cost drip irrigation for efficient water application, treadle pumps for water lifting, plastic water tanks, and irrigation decision support systems. Additional promising solutions to supply water for all farmers include seawater desalination, moisture sensor-based irrigation systems, recycling and treatment of wastewater, rainwater storage, multiple use water (for rural drinking water and agriculture), and the use of municipal water[19].

Healthy, nutrient-rich soil

In addition to sufficient water, healthy soil and nutrients are important for crops to thrive. One way of providing these nutrients to plants is by applying fertilizer. Inorganic fertilizers are much more costly in Africa so the high cost and an inadequate infrastructure for providing fertilizer in remote areas have limited the use of fertilizer there to date. Inorganic fertilizers make nutrients immediately available to plants, however they are subject to leaching and heavy inorganic fertilizer application can build up toxic concentrations of salts in the soil; these chemicals can also pollute the water system. On the other hand, organic fertilizers must first be broken down by soil microorganisms into simpler, inorganic molecules and ions, so their nutrients are not immediately available to plants, but organic fertilizers do not build up toxic salt concentrations; rather they improve the soil structure and increase its ability to hold water and nutrients[20]. Organic fertilizers also increase the carbon content and absorption of soil which enhances fertility and mitigates climate change[21].

Selecting and culturing the most efficient soil microorganisms and adding them to soils directly or through seeds can help plants absorb nutrients. Bio-fertilizers, which are much cheaper than traditional inorganic fertilizers, are cultured microorganisms packed in carrier materials such as peat or lignite powder for easy application in the field. Some bio-fertilizers or plants have a symbiotic association with other plants and by plowing them into the soil between harvests, crop yields can increase significantly without the need for traditional nitrogen-based fertilizers. Integrated soil fertility management, which combines the use of

[18] *Ibid.*
[19] UNCTAD 2010 and Molden 2009
[20] UNCTAD 2010
[21] Hoffmann 2010

organic and inorganic nutrients with mineral nutrients and focuses on the timing and placement of inputs to maximize nutrient-use efficiency, can improve soil health. Additionally, mixed cropping helps preserve soil utility and certain microbiological techniques can suppress diseases in soils and solubilize phosphorous[22].

Improved plants, livestock, and fish

Science and technology research has not been limited to improving irrigation and soil health; substantial efforts also aim to improve crops themselves. New cultivation techniques and improved varieties of crops, livestock, fish, and trees can be developed through accelerated processes, such as traditional and participatory breeding combined with marker assisted selection, genomics, and transgenic approaches. Several bio-technology developments are promising for agriculture, including smallholder farmers. New Rice for Africa (NERICA) is the result of crossbreeding African and Asian rice to produce progeny with high yields, earlier maturity, hardiness, and resistance to local stress (acid soil and drought resistance). Genetic breeding, the incorporation of resistance genes into high-yielding crop varieties, and other genetic modifications can produce crops with improved crop yields, appearance, taste, nutritional quality, and resistance to drought, insects, disease, and herbicides. Plant tissue culture entails cultivating plant cells, tissues, or organs on specially formulated nutrient media under the right conditions to regenerate an entire plant from a single cell. This represents an important technology for the production of disease-free, high quality planting material and the rapid production of many uniform plants[23].

Available, affordable ICTs

The availability of affordable information and communications technologies (ICTs) holds great promise for improving natural resource management, food security, and livelihoods in rural communities. A primary challenge that smallholder farmers face is their isolation from knowledge and information systems, which makes them particularly vulnerable and unprepared to respond to external and internal shocks[24]. Internet access and the spread of mobile phones already facilitate the exchange of scientific, technological, and market information among farmers, scientists, commercial enterprises, extension workers, and others. Integrated advances in nanotechnology, remote sensing, geographic information systems

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[22] UNCATD 2010 and IAASTD 2009
[23] *Ibid.*
[24] UNCTAD 2010

(GIS), global positioning systems (GPS), and other ICT applications could provide opportunities for more resource-efficient and site-specific agriculture[25].

Examples of the myriad applications of ICTs include pest and weed control. Modeling of the dynamics of pest and alien species can reduce the reliance on chemicals. One of the more labor-intensive aspects of agriculture is weed removal. New technologies can assist farmers of all sizes, including smallholder farmers, in applying herbicides efficiently to eliminate weeds. For example, sophisticated GPS can allow farmers to implement specifically designed plans for spraying herbicides and pesticides. Another example is infrared weed detectors that identify specific plants by their unique rates of infrared light reflection and then transmit signals to a pump to spray a preset amount of herbicide onto the weeds, reducing the amount spent on herbicides[26].

Illiteracy poses a major obstacle to the adoption of ICTs and integrated pest management by smallholder farmers so education, extension, and farmer field schools have an important role in helping farmers benefit from these technologies. Another obstacle to ICT adoption is that farmers are usually much more prepared to pay for tangible services such as inputs or veterinary service than information, which was often provided for free in the past[27]. Potential solutions may include public financing or the development of reasonable pricing schemes such as those used for smartphone applications and other mobile value added services.

Post-harvest enhancements

In considering applications of science and technology to agriculture, the post-harvest stage should not be overlooked. By applying post-harvest technologies and innovative management systems, crop losses could be reduced and world food supply increased with minimal additional resources. Maximizing the nutritional impact of available food through improved preparation, processing, preservation, or storage processes may have a greater impact on the wellbeing of the poor than trying to increase yields on tiny plots[28]. For example, millions of poor people in Africa depend on the cultivation of perishable root and tuber crops such as cassava, yams, and cocoyams. Appropriate technologies for processing

[25] IAASTD 2009
[26] UNCTAD 2010 and IAASTD 2009
[27] Christopolos 2010
[28] *Ibid.*

these and other roots, tubers, cereals, and legumes into flours can enhance the shelf life and acceptability to consumers of indigenous foods as well as develop value-added, exportable products. The greatest potential lies in primary processing technologies, such as cleaning, drying, pre-cooling, grading, packaging, and storage[29]. The adoption of post-harvest technologies can significantly improve the livelihoods of women who do the bulk of post-harvest processing and free up time for other activities[30].

Sustainable agriculture systems

Sustainable agriculture adopts inter-related soil, crop, and livestock production practices, while reducing or discontinuing harmful external inputs. As shown in Table 2, sustainable agriculture draws on practices and techniques that integrate and are adapted to local natural processes. Depending on the agro-climatic environment, a mix of different technologies are involved, including integrated nutrient management, no-till farming, agro-forestry, water harvesting, livestock integration, and integrated pest management[31].

Table 2: Examples of prominent sustainable agriculture practices[32]

Category	**Examples of practices**
Soil and water management	▪ Terraces and other physical and biological structures to prevent soil erosion ▪ Contour planting ▪ Hedgerows and living barriers ▪ No-till farming ▪ Mulch, cover crops including biological nitrogen fixing legumes ▪ Water harvesting
Soil fertility management	▪ Manure and compost ▪ Biomass transfer ▪ Agro-forestry ▪ Integrated soil fertility management
Crop establishment	▪ Planting pits ▪ System of rice intensification ▪ Inter-cropping Alley cropping
Weed and pest control	▪ Inter-cropping and rotation ▪ Integrated pest management

[29] UNCATD 2010
[30] Meinzen-Dick et al. 2010
[31] United Nations 2009
[32] Tripp 2006

Organic agriculture, an emerging type of sustainable agriculture system, is defined by FAO/WHO as "holistic production management [whose] primary goal is to optimize the health and productivity of interdependent communities of soil, life, plants, animals, and people." Organic and near-organic agricultural methods and technologies are ideally suited for many poor, marginalized smallholder farmers as they require minimal or no external inputs, use locally and naturally available materials to produce high-quality products, and encourage a whole systemic approach to farming that is more diverse and resistant to stress. For smallholder farmers under marginal conditions that use relatively low amounts of synthetic inputs, yields do not fall and at least remain stable upon conversion to organic agriculture. The better organization and management of organic farmers leads to yield increases right from the outset. Over time, yields increase further as capital assets in systems improve, thus outperforming those in traditional systems and matching those in more conventional, input-intensive systems. Organic farming also leads to increased water retention in soils, improvements in the water table, reduced soil erosion, and improved organic matter in soils, resulting in better carbon sequestration and increased agro-biodiversity. As a result, soils are healthier, better able to hold water, and are more stable, can sustain plant growth better, and have a higher nutrient content, which allows farmers to grow crops for longer periods with higher yields and in marginal conditions. Organic farmers also realize a number of economic benefits. They save from not having to purchase synthetic pesticides and fertilizers, obtain premium prices for certified organic produce, and add value to organic products through processing activities[33].

III. Agricultural innovation

We have briefly summarized a number of existing science and technology applications and farming practices that can have a significant impact on agriculture, including for smallholder farmers. In order to have maximum impact and to meet the challenges of tomorrow, we need to continually evaluate and improve how we enable innovation and introduce new science and technology applications and farming practices in the field.

The technology transfer approach to date has been the most widely used institutional model for introducing science-driven technology in the public sector, including in agriculture. Under this more linear approach, a knowledge producer such as an R&D center develops a

[33] UNCTAD 2008

new technology, for example, a different type of fertilizer, which extension agents and others introduce to farmers who then put it into practice. This model has increased productivity and scale when applied to properly managed technologies relevant to target farmers and under the necessary conditions such as access to markets and properly functioning services[34]. A prime example of successful technology transfer is Fundación Chile's introduction of large-scale salmon production in Chile[35].

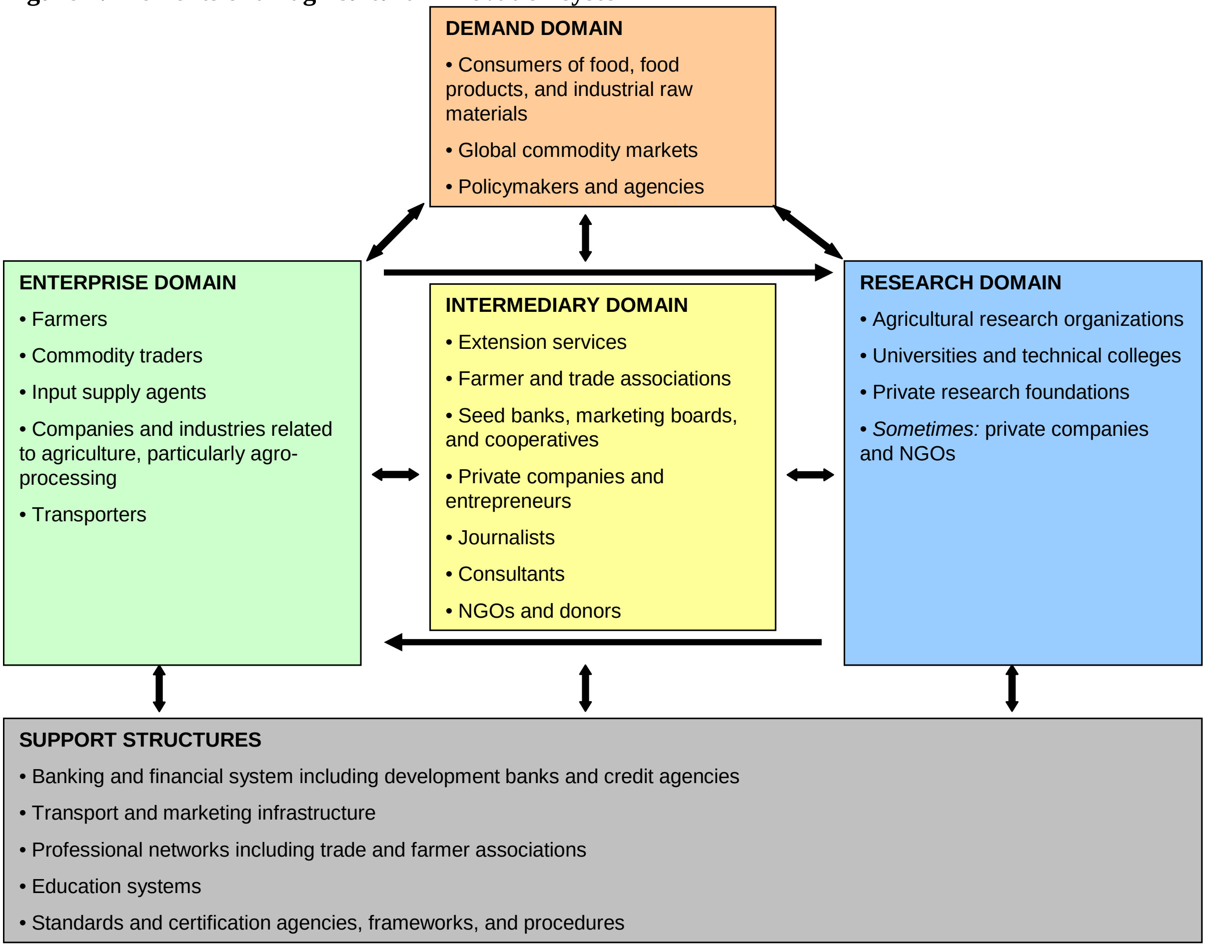
However, to be more effective in promoting sustainability and development, innovation and technology development and diffusion approaches should involve a shared understanding of principles and coordination of practices across multiple levels[36]. Innovation is rarely triggered by agricultural research and instead is often a response of entrepreneurs to new and changing market opportunities[37]. Indeed, a wide range of actors or agents beyond the public sector, including farmer organizations and commercial enterprises, should be involved in developing new ideas for smallholder farmers[38]. As diagrammed in the agricultural innovation system model shown in Figure 2, examples of the many individuals that should be involved and collaboratively linked to form agriculture innovation systems can be categorized among five areas: demand domain, enterprise domain (users of codified knowledge and producers of mainly tacit knowledge), research domain (producers of codified knowledge), intermediary domain, and support structures[39].

Although farmers are considered as primarily knowledge users, often they also are knowledge producers and especially in organic agriculture systems they exchange knowledge as information brokers. Similarly other actors like consumers and engineers can perform a variety of roles to spark innovation.

The strength of agricultural innovation systems rests not only on the strength of individual actors in the system, but more importantly, the strength of their interactions, just as the health of the human body requires healthy circulation and communication among each part of the body to function properly. Agricultural innovation systems involve the integration of different sources of knowledge, including local knowledge. For example, a recently study

[34] IAASTD 2009
[35] UNCTAD 2006
[36] IAASTD 2009
[37] Hall 2007
[38] IAASTD 2009
[39] UNCTAD 2010, Albright 2007, and Hall 2006

Figure 2: Elements of an agricultural innovation system[40]



found that women and other marginalized groups often hold local knowledge of low-impact, low-cost methods and coping strategies that can make farming systems more resilient[41]. Conditions that nurture eclectic approaches to innovation must exist and competitors need to work together to continually adapt institutional and policy frameworks for innovation. Coordinated networks relevant to specific challenges, opportunities, or locations are required along with supporting policies. Scientists, policymakers, consumers, and entrepreneurs need to align to mobilize knowledge and continuously innovate[42].

Public policy is essential in creating an enabling environment which encourages technology uptake, innovation, and development[43]. Sectoral mechanisms are critical for coordinating the interaction needed for innovation[44]. One example of how policies can foster innovation is the development of varietal release procedures and criteria to accept and certify farmer-generated

[40] adapted from Hall 2006
[41] Meinzen-Dick et al. 2010
[42] Hall 2007 and Albright 2007
[43] *Ibid.*
[44] Hall 2007

seed in the Netherlands, where potato breeders and commercial organizations cooperate with potato hobby specialists to breed and select potato varieties; farmers are able to negotiate formal contracts that recognize and reward them for their contributions to all potato varieties that are brought to the market[45].

Supporting smallholder farmers in joining sub-regional, regional, or global networks and value chains will help provide them with access to international markets and inputs, finance, and technology. Efforts to support links to value chains can be supported by actively increasing market efficiencies and access, especially to markets for high value-added agricultural exports including processed agricultural exports, putting in place market information systems, and designing and implementing trade facilitation programs. Sub-regional cooperation can address capability and financing shortages as well as scarcity of scientific laboratory equipment. National innovation coalitions and innovation platforms around particular technologies, policies, or processes can be effective vehicles for innovation. There is also room for increased collaboration among international agricultural research centres and national agricultural research systems[46]; the work of the Consultative Group on International Agricultural Research (CGIAR) is a step in this direction[47].

Successful agricultural innovation requires attention to all the components of agricultural innovation systems including research, extension, credit and technical support, healthy markets, functioning infrastructure, and a supportive policy and institutional environment[48]. These areas will now be addressed in more detail.

IV. Key issues

Research institutes and education systems

Despite the important role of research in agricultural knowledge creation and innovation, investment in publicly funded agricultural research and development in many industrialized and developing countries has stalled or declined[49]. Nearly half of global public agricultural R&D spending is concentrated among five countries: the United States, Japan, China, India,

[45] IAASTD 2009
[46] UNCTAD 2010 and Albright 2007
[47] CGIAR 2010
[48] Albright 2007
[49] IAASTD 2009, UNCTAD 2009, and Beintema and Elliott 2009

and Brazil, compared to only 6% among 80 mostly low-income countries with 14% of the world's agricultural land area[50]. The international community has shown decreasing interest in support for African agriculture over the past 30 years. Support for agriculture as a proportion of total international development assistance to African countries has fallen by as much as two thirds from its peak in the early 1980s. Now only 3% of science, technology, and innovation-related aid is destined for agricultural research in the least developed countries and developing countries as a whole invested only 0.6% of their agricultural value added in R&D in 2000, compared to 5% invested by developed countries[51]. This is despite the fact that doubling agricultural research expenditures per hectare in Africa can increase agricultural productivity by about 38%[52]. Persistent problems with research and education include: lack of competence in some scientific fields, movement of capacity to industrialized countries, and lack of incentives to address social needs, especially those related to the poor, which often call for multidisciplinary approaches[53].

Local and national governments and international organizations can facilitate and develop capacity by investing in education and promoting new skills and technologies among farming communities[54]. Resources spent on promoting R&D activities should be linked to local demands for specific products, processes, and services in agriculture. Incentives include restructuring academic systems for researchers and academics to reward applied research and collaborations with agricultural communities and firms, and creating special, competitive R&D grants only for the development of specific local varieties of food grains[55].

A number of academic reforms could bolster agricultural research and make it more relevant to the challenges of smallholder farmers. For example, curricula at all levels could be modified to improve the attractiveness and social relevance of agricultural studies, increasing access to technology education and science-informed farm and agroecosystem management knowledge including organic agriculture to all those working in agriculture, improving collaboration between ministries and universities, developing infrastructure to facilitate ITC use in informal and formal education systems, mobilizing funds to support agricultural education reform, and encouraging university participation in recovering and recognizing

[50] Beintema and Elliott 2009
[51] UNCTAD 2010 and UNCTAD 2009
[52] UNCTAD 2009
[53] IAASTD 2009
[54] *Ibid.*
[55] UNCTAD 2010

traditional and local knowledge[56]. University systems can also expand graduate training to meet a demand for more highly trained researchers in climate change, price volatility in global markets, and water scarcity[57]. Establishing and enforcing codes of conduct for universities and research institutes can reduce conflicts of interest and ensure a focus on sustainability and development in agricultural knowledge, science, and technology[58].

Options for capacity-building in the field include occupational education for farmers, on-line distance learning and education, and competitive grant funding to cover field study in tertiary and post-doctoral training[59]. With improved training in critical thinking and problem solving, extension agents can be better prepared to meet local farmer needs[60]. For example, the conversion to or promotion of organic agriculture requires increased learning, greater cooperative capacity of individuals and groups, and the development of social capital at the local level[61]. Other resources for R&D and capacity-building are research networks, consortia, and decentralized R&D facilities in collaboration with village development centres, NGOs, and farmer organizations[62].

Extension services

Broadly speaking, extension refers to the various intermediaries that serve at the heart of agricultural innovation systems, connecting the enterprise and research domains as shown in Figure 2. A wide variety of agents such as input vendors, weather broadcasters, or farming lobbyists can serve extension roles, as well as national or regional extension services that deploy extension workers to connect knowledge producers with farmers[63]. Strong extension services are critical catalysts for improving agriculture and various aspects of the agriculture industry make it well suited for extension work: Agricultural research activities are highly applied and oriented towards the utilization of research results to solve farmers' problems[64]. Additionally, the agricultural community is a relatively close-knit group with shared values

[56] IAASTD 2009
[57] Beintema and Elliott 2009
[58] IAASTD 2009
[59] *Ibid.*
[60] Christopolos 2010
[61] UNCTAD 2008
[62] IAASTD 2009
[63] Christopolos 2010
[64] Rogers 1995

and an emotional attachment to the land which facilitates communication among its members[65].

Extension services have experienced a history of significant changes and varying interest and funding. The original national extension services were publicly funded and operated. Over time some countries opted to convert to privately operated extension services and during the last few decades a number of countries abolished their national extension services entirely. In countries that retained extension services, these capacities have often been borrowed for project implementation rather than developed. Recently there has been renewed interest and increasing public investment in extension services in some countries after a long period of steady decline[66].

In order to be successful, extension services require personal contact and adequate resources. Multiple studies have shown that person-to-person contact constitutes the most effective technology transfer mechanism. Personal contact has always been vital to the success of the cooperative extension service in the U.S., where a county agent spends more than half of his or her time in individual contacts, about 40% of time in group demonstrations, and about 6% of time in mass media[67].

Extension services require sufficient resources to enable technology transfer, both for the governments and the farmers. Establishing and maintaining an extensive network of county agents and extension specialists is not cheap and the U.S. cooperative extension service requires significant fiscal commitments from federal, state, and county governments. The access of farmers to financial resources is also important for extension services to ultimately succeed. During the Great Depression, farmers did not adopt some technologies because to do so would have required more funds than what the farmers had or could borrow[68]. Failure to publicly finance extension does not mean extension will not exist, just that it may not contribute to public goals. For example, opium poppy production has spread to a number of areas in Afghanistan where there was no past tradition of opium production. Where there are sufficiently profitable markets, there is demand for extension and services[69].

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[65] McFall & McKelvey 1989
[66] Christopolos 2010
[67] McFall & McKelvey 1989
[68] Rogers 1995 and McFall & McKelvey 1989
[69] Christopolos 2010

Funding or provision of extension services does not have to come solely from the public sector. Some countries have had more success with privately funded or operated extension services than others. In some cases where extension services are privately operated, extension agents have more of an incentive to sell or push certain products or technologies and little or no incentive to share sustainable agricultural practices like rainwater harvesting. However in Malawi, privately provided extension services have been having positive results in the quickly developing smallholder tea industry. Tea estates, which buy the green leaf tea and have a vested interest in ensuring a continual, quality supply, provide tea husbandry extension. The estates provide farmers with advice and fertilizer on credit. Some of the smallholder farmers have become fair-trade certified and they are investing the associated price premium in tea garden improvements and social development services[70].

As with the other components of the agricultural innovation system depicted in Figure 2, information flow among extension services, the enterprise domain (primarily farmers), and the research domain does not necessarily ensure extension success but lack of it will ensure failure[71]. Extension services should ensure that there are effective means of disseminating up-to-date information to extension officers in the field and strong two-way communication between advisors and farmers. Managers of extension services in many countries are centralized, urban-based, and insensitive or out of touch with the realities of field work and under "top-down" planning, farmers and rural communities are excluded from the planning process or the determination of objectives[72]. To succeed as technology brokers, extension agents need their clients' trust to perform their core tasks; mandates to collect taxes or loans or enforce regulations can interfere with this trust[73] and regulatory duties or other non-advisory work takes time away from serving farmers and can make farmer services superficial[74].

The Puno-Cusco area in Peru offers an example of how extension services can be more responsive and organized with more involvement from farmers. There public contests were held in which communities and groups presented competing funding proposals. The winners

[70] *Ibid.*
[71] Schwass 1983
[72] Schwass 1983; Dirimanova and Labar 2010
[73] Christopolos 2010
[74] Schwass 1983

received public funding to contract a technical assistant and were required to invest a matching sum from their own resources to ensure ownership of the activities and to motivate them to maximize the impact of technical assistance. In another example of reversing traditional societal hierarchies and power relations, the local people themselves also selected the technical assistant through a public competition[75].

A one-size fits all approach to extension rarely works. In isolated areas distant from major markets, there may be little market access, so it may be more appropriate for extension to give priority to crops that support subsistence or are intended for local markets[76]. To become more client-oriented and effective, extension services should also be designed with gender issues in mind. In some communities, women do most of the agricultural work and are prohibited from any contact with men outside their immediate family or community, so there is a clear need for female extension field staff[77]. Extension services for women should also be tailored to their needs, preferences, and priorities. In many countries, extension is directed to promote agriculture for cash crops for export or national grain self-sufficiency. However female farmers may have little or no incentive to produce cash crops because they will not control the associated income. Lack of access to and control of land can also cause women to have far less interest than men in investing in expanded or intensive agricultural production. Rather, women often prefer to focus on sources of income they can more easily control, such as subsistence crops, petty trade, or casual labor[78], and because women generally have access to fewer resources, they may be better suited to adopt high-value crops that do not require large initial investments[79].

Financing agriculture and agricultural innovation

Since the global food crisis of 1974, the role of economic access in food security has gained increasing prominence; any approach to improve food security must go beyond farming practices to include rural development and expansion of economic opportunities through income generation infrastructures and marketing. Key economic factors for achieving food security include access to credit and markets, infrastructure, and land ownership. Relatively recent factors include the production of biofuels, animal feed, availability and efficient use of

[75] Christopolos 2010
[76] *Ibid.*
[77] Schwass 1983
[78] Christopolos 2010
[79] Meinzen-Dick et al. 2010

irrigation water, methods of using arable land, and technologies to increase productivity and generate income[80].

In addition to being an important factor in food security, sufficient financing is one of the key requirements for agricultural science, technology, and innovation. Insufficient financing hampers new innovation and the inability of farmers to access capital to adopt technology renders it useless. Indeed, many technologies potentially of use in sustainable farming are not adopted because smallholder farmers lack access to the means and supporting services necessary to employ the technologies profitably. Inadequate access to capital is also the most commonly reported obstacle to investment and entrepreneurship in the non-farm rural economy[81].

Increased investments in agricultural knowledge, science, and technology, particularly if complemented by supporting investments in rural development such as infrastructure, telecommunications, and processing facilities, can yield high economic rates of return, reduce poverty, and have positive environmental, social, health, and cultural benefits[82]. Segmenting banking systems can protect extremely vulnerable parts of the economy from external shocks. Specialized banks can be created for sectors like agriculture and small and medium enterprises which may not appear very attractive to private banks. Microfinance initiatives have proven to be a successful institutional innovation in financial services for microentrepreneurs including smallholder farmers in developing countries[83]. Insurance and derivatives can also serve as a means of hedging some of the exposure to price volatility, changing environmental conditions, and other variables.

Merely “helping farmers” may be of limited impact if the required infrastructures are absent or weak or the rest of the market chain in dysfunctional[84]. Improvements in physical infrastructures can help farmers of all sizes. Infrastructure improvements should be based on a comprehensive approach that integrates post-harvest storage and processing considerations to reduce losses and add value to agricultural products. This includes distribution and marketing infrastructures connecting farmers to markets. Physical infrastructures should

[80] UNCTAD 2010
[81] IAASTD 2009 and UNCATD 2010
[82] IAASTD 2009
[83] UNCTAD 2010
[84] Christopolos 2010

support the capacity of developing countries to rehabilitate and develop rural and agricultural infrastructure through investments in marketing processing and storage facilities, irrigation facilities, and relevant modes of transportation[85]. Sometimes the poor are excluded from markets because they do not have the capacity to meet high standards of quality, uniformity, bulk, timeliness, and food safety. Extension can help farmers to understand the entry barriers to different markets and make informed choices about marketing, production, and livelihood strategies[86]. Access to markets is also an essential part of organic farming and often conversion to or support of organic farming is accompanied by improvements in physical infrastructure and market access[87].

Private firms have been major suppliers of inputs and innovations to commercial and subsistence farmers and can make significant contributions toward meeting development and sustainability goals. There are considerable spillovers from private suppliers of technology to farmers and consumers; for example, when private investment is made in agricultural production, public investment for promotion of agricultural marketing infrastructure soon follows[88]. The participation of transnational corporations has also introduced new farming methods, knowledge for enhancing production, soil and water management know-how, and various technologies intrinsic to inputs[89]. Government regulations can optimize private investments in agricultural knowledge, science, and technology, by addressing negative externalities and monopolistic behavior and supporting good environmental practices while at the same time providing incentives for investments that aid the poor[90]. Transnational companies could be required to contribute to infrastructure development when receiving permits for large-scale projects[91]. Private investment into agriculture can also be promoted through public-private partnerships with the international private sector and national agricultural organizations. Investments in outgrower networks that also share knowledge, information systems, and supportive hard and soft infrastructures can make a significant contribution to scaling up sustainable agriculture methods. Agriculture can be made a sectoral priority in other policies that seek to attract international private investment, such as

[85] UNCTAD 2010
[86] Christopolos 2010
[87] UNCTAD 2008
[88] IAASTD 2009 and UNCTAD 2010
[89] UNCTAD 2009
[90] IAASTD 2009
[91] UNCTAD 2009

policies for foreign direct investment, with a special focus and additional incentives for firms to engage in tacit know-how transfer.[92]

Various other means can reduce the risk of financing innovation in agriculture including government-support soft-loans, R&D subsidies, public risk capital funds, and public support for private enterprises through grants, subsidies, and private equity. Seed-financing programs, angel investor networks, enterprise subsidy programs, common placement funds for innovation, and research tax credit programs are also means of financing innovation. Other methods of providing access to credit like "starter packs" of free fertilizer and seeds can facilitate the use of an existing technology by smallholder farmers[93]. In some cases, as in multi-organizational arrangements involving supermarkets or commercial actors in market-oriented value chains, the transaction costs of interaction among innovation partners can be recovered from commercial returns[94].

Innovative procurement and program practices can also reduce the risks faced by smallholder farmers. Examples used by the World Food Programme to reduce risks faced by smallholder farmers include forward contracting and warehouse receipt programs that can serve as collateral for loans and the support of value-added production and local food processing. Another way to support producers is by improving tendering systems so that smallholder farmers are in a better position to compete for locally issued contracts[95]. Additionally, brokered long-term contractual agreements such as market alliances, commodity chains, and public and private outgrower schemes, have been effective in improving the livelihoods of smallholder farmers. These arrangements can promote value-chain activities, generate employment, and allow smallholder farmers to take advantage of opportunities through institutional arrangements that provide market access and credit for inputs and planting materials. To illustrate, in 2002, global pineapple demand shifted from the Cayenne variety that Ghana exported to the extra sweet MD2 variety, causing smallholder farmers to cease production. When BOMARTS Farms Ltd. (with approximately 400 ha of pineapples) was facing contract termination, it set up a commercial tissue culture lab with assistance of the University of Ghana. The government contracted BOMARTS to produce 4.8 million plantlets at cost over a two-year period, which were distributed to farmers on credit and at a

[92] UNCTAD 2010
[93] *Ibid.*
[94] IAASTD 2009
[95] UNCTAD 2010

tenth of the price. The number of smallholder farmers growing MD2 is rapidly increasing; for many of these farmers, pineapples are their main source of income[96].

Farmer groups, cooperatives, and other partnerships also have an important role in supporting agriculture by providing guarantees with regards to investments, a supply of agricultural inputs and credits, and a platform for education and training. Cooperatives also provide opportunities for marketing agricultural products, particularly in the case of smallholder farmers who in most cases cannot meet quantitative and qualitative thresholds so rely on communal storage and marketing instruments. Cooperatives can be instrumental in linking smallholder farmers into the agrifood chain. These partnerships enable and enhance agricultural entrepreneurship and strengthen rural development[97].

Governance

Governments and policymakers can significantly promote innovation and support the livelihood of smallholder farmers. Policy options to enable developing countries to respond to crises and achieve food security and sovereignty include greater democratic control and public sector involvement in agricultural policy, specifically through empowering farmer organizations, national governments, and regional trading blocs. Other policy options include improving the security of tenure and access to land, germplasm, and other resources; diversification with locally important crop species; access to credit and nutrients; supporting rural livelihoods by transparent price formation and functioning markets with the objectives of improving small farm profitability and helping ensure that farm-gate prices are above marginal costs of local production; and strengthening social safety nets[98]. Sustainable agriculture can also be supported by removing or modifying tax and pricing policies that incentivize overuse of pesticides, fertilizers, water, and fuel or encourage land degradation.

Tenancy rights and access to credit are closely interrelated. Land tenure security encourages farmers to improve land productivity in the medium and long term and farmers are more likely to adopt technology and innovate. With the availability of credit markets, technologies, and farm inputs, improved land tenure security leads to higher investment. Transferability of land rights also plays an important role, as land right transferability can improve a

[96] IAASTD 2009
[97] UNCTAD 2010
[98] IAASTD 2009

landholder's creditworthiness, especially for long-term credit. This enhances the land's collateral value and lenders' expected return. Investment may be encouraged by better land tenure security, easier convertibility of land into liquid assets, and emergence of a credit market[99].

An open approach to innovation should be supported by science, technology, and innovation policies. This involves addressing issues pertaining to intellectual property rights, increasing the intensity of R&D, and actively attracting leading researchers. Intellectual property rights regimes that protect farmers and expand participatory plant breeding and local control over genetic resources and related traditional knowledge can increase equity. Open-source or non-proprietary models can harness the full potential of a combined academic-philanthropic-business approach. For example, grants can be provided for the development of nutritionally enhanced seeds to be made available for royalty-free distribution in areas of need[100]. Policy options to strengthen and improve equality in current rights systems for intellectual property and genetic resources may include a closer connection between protection levels and development goals, explicit policies regarding intellectual property management in public organizations, the preservation, maintenance, promotion, and legal protection of traditional knowledge and community-based innovation, and options for benefit-sharing of genetic resources and derived products as illustrated by the Dutch potato partnership scheme[101].

Policymakers and other leaders can also assist smallholder farmers by tackling the high cost of inputs and increasing farm-gate prices. African farmers pay the highest price for fertilizers in the world. Smallholder farmers, not large farmers, in Africa and elsewhere need subsidies to buy fertilizer and other inputs. Vouchers could be suitable instruments to direct subsidies to smallholder farmers that need them the most. Subsidy costs and results should be published and subsidies should help the development of networks of input dealers rather than undercutting them; fertilizer should be channeled through existing dealers rather than by state agencies. At the same time, subsidies should encourage sustainable behavior. Rather than promoting the overuse of inorganic fertilizer, subsidies towards bio-fertilizer or the adoption of other sustainable technologies and practices is preferable. Other policy options to stabilise and increase farm-gate prices include reducing trade distorting subsidies in developed

[99] UNCTAD 2010
[100] UNCTAD 2010 and IAASTD 2009
[101] IAASTD 2009

countries to establish fair competition in the global market and encouraging foreign direct investment in developing countries, streamlining and improving provision of legitimate anti-dumping measures and providing temporary protection, improving international market access for developing countries, and establishing new contractual arrangements[102].

Suitable action is necessary at the international and national level to enable smallholder farmers to benefit from provisions for special treatment on the grounds of food security, farmer livelihoods, and rural development. Additionally, there is a need to re-examine international trade policies so that they support sustainable agriculture including effective agreements and biosecurity measures involving transboundary water, emerging human and animal diseases, agricultural pests, climate change, environmental pollution, food safety, and occupational health. Developing countries could also benefit from reduced barriers and elimination of escalating tariffs for processed commodities, deeper generalized preferential access to developed country markets for commodities important for rural livelihoods, increased public investment in local value additions, expanded local food production, improved access to credit for smallholder farmers, and strengthened regional markets[103].

Questions for discussion

- What special tariff reductions, rebates, or other policies, preferences, or tools can be implemented at the international level to assist smallholder farmers?
- What new financial incentives and support can be provided to agricultural entrepreneurs and smallholder farmers to adopt sustainable agricultural technologies and farming practices?
- What next steps should be taken and commitments made to revitalize and strengthen extension services?
- How can the cost of organic fertilizer, seeds, and other inputs be reduced for smallholder farmers in developing countries?
- What can be done to promote aid harmonization and alignment with national structures and priorities?
- What are suitable new or existing fora or other means to share ideas and approaches to fostering agricultural innovation and supporting smallholder farmers?

[102] UNCATD 2010, IAASTD 2009, UNCTAD 2009
[103] IAASTD 2009

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