FEEDING A GROWING POPULATION: THE CHALLENGE FOR LAND AND WATER[1]

CONCEPTION DES SYSTEMES D'IRRIGATION AU NIVEAU DU BASSIN POUR UNE PERFORMANCE ROBUSTE

Parviz Koohafkan[2]

ABSTRACT

The world's population continues to rise. Today's population of around 7 billion is expected to increase to about 9 billion by 2050 (UN, 2009). By this time, another one billion tonnes of cereals and 200 million extra tonnes of livestock products will need to be produced every year (Bruinsma, 2009). The imperative for such agricultural growth is strongest in developing countries, where the challenge is not just to produce food but to ensure that families have access to the food. The challenge of providing sufficient food for everyone worldwide has never been greater.

Today almost 1 billion people are undernourished, particularly in Sub-Saharan Africa (239 million) and Asia (578 million).Even if agricultural production doubles in developing countries by 2050, one person in twenty still risks being undernourished – equivalent to 370 million hungry people, most of whom will again be in Africa and Asia. Such growth would imply agriculture remaining an engine of growth, vital to economic development, environmental services and central to rural poverty reduction.

In recent decades, the world's farmers have responded to increased demand with remarkable improvements in productivity and output. Today the developing world is producing more than twice as much food as it did fifty years ago, while the net global cultivated area has only grown by 12%. Over the same period, the world population has more than doubled from 3.3 billion in 1965 to nearly 7 billion in 2011.

The policies, practices and technologies needed to boost production and strengthen food security have long been discussed. Institutional mechanisms, the development of trade and markets and the financial facilities needed to raise productivity in a sustainable way have

1 This paper is based on the FAO report on the State of the World Land and Water Resources for Food and Agriculture, prepared under the supervision of the author

2 Parviz Koohafkan is Director of Land and Water Division, in Natural Resources and Environment Management Department of FAO, Rome

been negotiated at the international level. At national level, measures to raise output and strengthen food security are being put in place, including investment in pro-poor, market-friendly policies, institutions and incentives, as well as the infrastructure and services needed to improve productivity. Yet the challenge still remains.

Key words: *Level basin, Volume balance, Salinity control, Application efficiency, Simulation study.*

RESUME

L'irrigation au niveau du bassin est largement utilisée au sud-ouest des Etats-Unis où l'eau est très chère. Un système d'irrigation bien conçu au niveau du bassin est facile à gérer, et détient un potentiel important d'atteindre une plus grande efficience d'application et de contrôle de la salinité, en particulier quand le terrain est nivelé par laser. Depuis des années, trois critères différents suivants sont évolués pour le projet des systèmes d'irrigation au niveau du bassin : le critère de projet d'équilibre de volume proposé par « Soil Conservation Service (SCS) » de « United States Department of Agriculture (USDA) »; le critère de projet de longueur limitée; et le critère de réalisation-d'avance. Chacun de ces trois méthodes comporte des avantages et des inconvénients. Pour atteindre la haute efficience d'application, outre la meilleure conception, un régime d'irrigation bien défini doit être suivi afin que le déficit d'humidité du sol lors de l'irrigation soit similaire à la profondeur du projet du système d'irrigation.

Sinon, l'efficience d'application réelle sera différente (normalement plus bas) à l'efficience d'application. L'efficience réelle du besoin en peut être significativement différente (sous-irrigation ou sur-irrigation) à l'efficience du besoin en eau du projet. Cependant, si le critère de réalisation-d'avance est utilisé, la différence entre les rendements réels et les efficiences du projet (efficience d'application et efficience du besoin en eau) sera au minimum. De plus, la performance actuelle du système d'irrigation au niveau du bassin utilisant le critère de réalisation-d'avance sera presque similaire à la performance du projet, même s'il y des fluctuations dans le débit d'entrée au niveau du bassin. Ce document présente les résultats d'une étude de simulation menée sur la performance robuste du projet des systèmes d'irrigation au niveau du bassin utilisant le critère de réalisation-d'avance.

Mots clés : *Niveau du bassin, équilibre du volume, contrôle de la salinité, efficience d'application, étude de simulation.*

1. INTRODUCTION: THE CHALLENGE OF LAND AND WATER

The availability of land and water to meet national and global demands for food and agriculture production have been put into sharp focus following the recent rise in commodity price levels (and associated volatility) and increased large-scale land acquisition. The social impacts of rapid food price inflation have proved intolerable. The buffering capacity of global agricultural markets to absorb supply shocks and stabilize agricultural commodity prices is tied to the continued functioning of land and water systems. At the same time, climate change brings additional risks to the harvests for farmers. While warming may expand agriculture in the north hemisphere, it is anticipated that key agricultural systems at many other places will need to cope with new temperature, humidity and water stresses.

1.1 Status and trends in the use of land and water resources

Over the last 50 years, land and water management has met rapidly rising demands for food and fibre. In particular, input-intensive, mechanized agriculture and irrigation have contributed to rapid increases in productivity. The world's agricultural production has grown between 2.5 and 3 times over the period while the cultivated area has grown only by 12%. More than 40% of the increase in food production came from irrigated areas, which have doubled. In the same period, the cultivated area of land per person gradually declined to less than 0.25 ha, a clear measure of successful agricultural intensification (Fig. 1). Agriculture currently uses 11% of the world's land surface for crop production, and accounts for 70% of all water withdrawn from aquifers, streams and lakes.

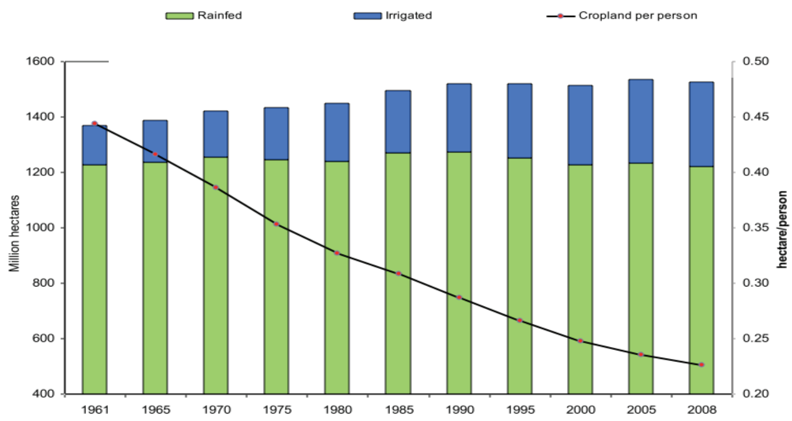

Fig. 1: Evolution of land under irrigated and rainfed cropping (1961-2008)

The distribution of land and water is skewed against those countries which have most need to raise productivity. Cultivated land area per person in low income countries is less than half of that in high income countries (Table 1), and its suitability for agriculture is generally lower (Fig. 2). This is a troubling finding given that the growth of demand for food production, as a function of population and income, is expected to be concentrated in low income countries. The main implication is that a global adjustment of agricultural production will need to be anticipated in order to compensate for these facts of geography.

Table 1: Share of world cultivated land suitable for cropping under appropriate production systems

Regions	Cultivated land (million ha)	Population (million)	Cultivated land per capita, ha	Rainfed crops (%)		
				Prime Land	Good Land	Marginal Land
Low Income Countries	441	2650.604	0.17	28	50	22
Middle Income Countries	735	3223.051	0.23	27	55	18
High Income Countries	380	1031.131	0.37	32	50	19
Total	1556	6904.786	0.23	29	52	19

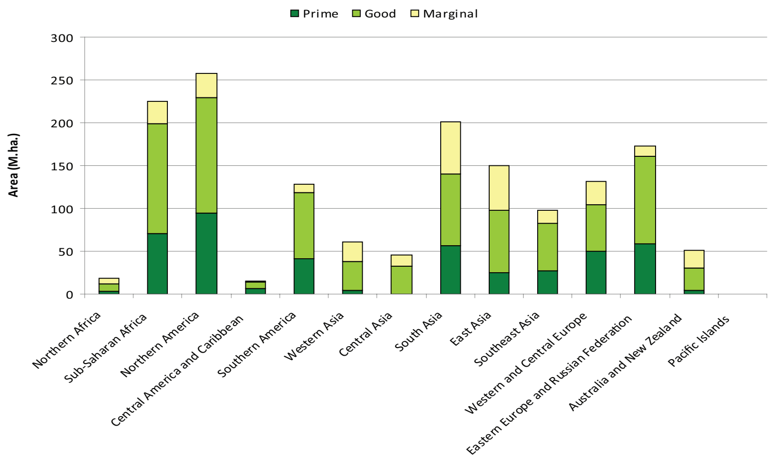

Fig. 2: Total extent of cultivated land by land suitability category for each geographic region

Rainfed agriculture is the world's predominant agricultural production system, but also hosts the majority of the rural poor. The large swathes of temperate cereal production in the northern hemisphere will continue to supply global markets and may even see a northward expansion, nudged by global warming. But in the dry tropics and subtropics, rainfed production is still held hostage by erratic precipitation. Unpredictable soil moisture availability over the course of a growing season reduces nutrient uptake and, consequently, yields. Taken with low soil fertility and carbon content of tropical soils, yields in rainfed systems are little more than half the achievable potential in many low-income countries. While improved land and nutrient management can result in higher yields, these can prove difficult to sustain if the threat of erratic rainfall remains. The rural poor on marginal lands with limited access to improved seed, fertilizer and information remain vulnerable.

The concentration of high-input irrigated agriculture on prime land has relieved pressure on land expansion - to some extent (Fig. 3). The steady trend toward precision agriculture and commercialization of all types of food and industrial crops is clear. Since 1961, while total cultivated land has shown a net increase of 12% to 2009, land under irrigation has more than doubled. While much of the prime agricultural land suitable for irrigation has been developed, the call for on-demand, just-in-time water services is rising and the global area equipped for irrigation continues to expand at a rate of 0.6 % per year. Groundwater use in irrigation is expanding quickly, and almost 40% of the irrigated area is now reliant upon groundwater as either a primary source, or in conjunction with surface water. This pattern of intensification, through a concentration of inputs, has offset expansion of rainfed cultivation for staple cereals and established guaranteed supply chains for a wide range of agricultural products into urban centres.

In too many places, however, achievements in production have been associated with management practices that that have degraded the land and water systems upon which the production depends. Intensive agricultural practice has contributed to loss of biodiversity, biomass, carbon storage and soil nutrients. It has also resulted in salinity build up and surface and groundwater pollution from fertilizer and pesticide use. The cumulative environmental impacts in key land and water systems have reached the point where, in some cases, production and livelihoods are compromised. On a global scale, it is estimated that degraded lands represent approximately 25 % of the total land area (this also includes non cultivated land affected by degradation).

The intensive exploitation of land and water also caused broader ecosystem deterioration, including loss of climatic buffering and carbon storage from forest biomass when cleared, loss of biodiversity, and loss of amenity, tourism and cultural heritage values.

Water availability to agriculture is a growing constraint in areas where a high proportion of renewable water resources are already used, or where transboundary resource management cannot be negotiated. Overall, increasing water scarcity constrains irrigated production, particularly in the most highly stressed countries and areas. In fast growing, low income countries, the demand for useable quality water is outstripping supply. Rising demand from both agriculture and other sectors is leading to environmental stress, socio-economic tension and competition over water. Where rainfall is inadequate and new water development is not feasible, agricultural production is expected to be constrained more by water scarcity than by land availability.

Groundwater abstraction has provided an invaluable source of ready irrigation water but has proved almost impossible to regulate. As a result, locally intensive groundwater withdrawals are exceeding rates of natural replenishment in key cereal producing locations – in high, middle and low income countries. Because of the dependence of many key food production areas on groundwater, declining aquifer levels and continued abstraction of groundwater present a growing risk to local and global food production.

There is a strong linkage between poverty and access to land and water resource. Worldwide, the poorest have the least access to land and water and are locked in a poverty trap. Technologies and farming systems within reach of the poor are typically low management, low input systems that can contribute to land degradation or buffer rainfall variability. Highest trends in land degradation are associated with the poor (Fig. 3).

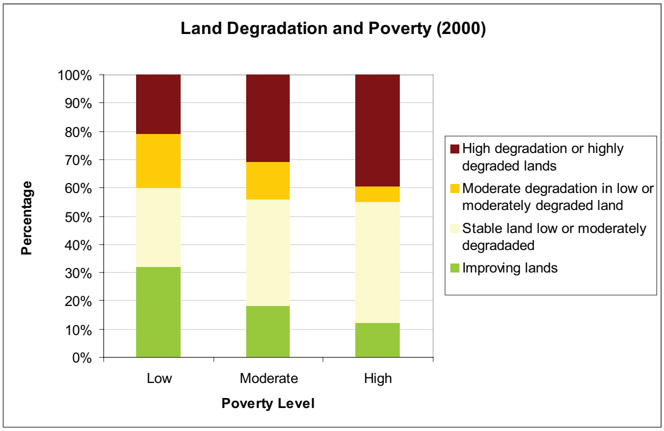

Fig. 3. Relation between land degradation and poverty

1.1.1 Policies, institutions and investments in land and water

The lack of clear and stable land and water rights as well as weak regulatory capacity and enforcement have contributed to competition and conflict over land access and water use.

The systematic inclusion of customary and traditional use rights in national legislation is recognized as a necessary first step in order to protect rural livelihoods and provide incentives for responsible land and water use.

Agricultural development policies have tended to focus on investments in high-potential areas and on irrigation, mechanization and crop specialization (mono-cropping) for marketed commodities and export crops. Their benefits have accrued to farmers with productive land and access to water, machinery and capital, largely bypassing the majority of smallholders who are constrained by generally poor and vulnerable soils under typically low-management, low-input systems. Such policies often prioritized short-term economic gains ignoring long-term resource degradation and impacts on ecosystem services. Rural livelihoods and cultures have also been impacted as these new agricultural systems have been adopted

Land and water use in agriculture is caught in a policy trap. On one hand agricultural policies have been effective in responding to increasing demand but on the other hand they have resulted in a set unintended consequences, including over-application of fertilizer and pesticides and depleted groundwater storage. Equally, water policies have driven expansion of water supply and storage, but in some water-short areas, this has created excess demand and constructed scarcity. Low tariffs for irrigation water service have also encouraged its inefficient use.

In many river basins, the rate of socio-economic change and the accumulation of environmental problems have outpaced institutional responses. Environmental policy has had some influence in high-income countries, but has had far less effect so far on the development agenda of poorer countries.

Effective collaboration between land and water institutions has lagged behind patterns of use and consumption. Although land and water function as an integrated system, many institutions deal with them separately. While the legal decoupling of land and water is deliberate to avoid resource grabbing, the growing intensity of river basin development and the degree of inter-dependence and competition over land and water resources require more adaptable and collaborative institutions that can respond effectively to natural resource scarcity and changing market opportunities. Even institutions that are dedicated to integrated regional or basin management deal primarily with either land or water resources and their respective multiple uses, rather than with land and water jointly. National and local institutions regulating land and water use in many countries have come under growing pressure to arbitrate between different uses as competition for land and water has increased. The absence or weakness of trans-boundary cooperation frameworks (both within federated states and between riparian countries) have led to sub-optimal investment and tensions between upstream and downstream users.

Levels of public and private investment in basic agricultural infrastructure and institutions have declined over the past two decades. This has had two broad effects. First the performance of agricultural hardware, from rural roads, irrigation schemes, storage and marketing chains has become unresponsive to changing markets and inefficient in delivering high quality produce. Second, environmental regulation of agricultural practice has resulted in rapid degradation of the natural resource base. Renewed but smarter investment in modern agriculture is now seen as a vital component of global recovery to give more overall stability in food supply. The growing inter-dependence and competition over land and water resources in intensively used river basins indicates that this stability will not be achieved without more effective natural resource allocation and environmental regulation. Existing land and water systems that are threatened by depletion and degradation of natural resource endowments will be a priority target – there is no room to replicate these productive river basins. For these reasons, marginal adjustment of the 'business as usual' model will not be enough.

Large-scale land acquisitions are on the increase in parts of Africa, Asia and Latin America where land and water resources appear abundant and available. Concerns about food and energy security are key drivers, but other factors such as business opportunities, demand for agricultural commodities for industry and recipient country are also at play. Although large-scale land acquisitions remain a small proportion of suitable land in any one country, contrary to widespread perceptions there is very little 'empty' land as most remaining suitable land is already used or claimed, often by local people. While they offer opportunities for development, there is a risk that the rural poor could be evicted or lose access to land, water and other related resources. Many countries do not have sufficient mechanisms to protect local rights and take account of local interests, livelihoods and welfare. A lack of transparency and of checks and balances in contract negotiations could promote deals that do not maximize the public interest. Insecure local land rights, inaccessible registration procedures, vaguely defined productive use requirements, legislative gaps and other factors too often undermine the position of local people.

1.1.2 Perspectives for land and water use towards 2050

By 2050, rising population and incomes are expected to result in a 70 percent increase in global demand for agricultural production. From a 2009 baseline this will need to be a 100% in low and middle income countries. This implies a global annual growth rate of 1 percent and up to 2 percent in low and middle income countries. Increased production is projected to come primarily from intensification on existing cultivated land. Expansion will still be possible in Sub-Saharan Africa and Latin America. In the longer run, climate change is expected to increase to potential for expansion in some temperate areas.

Both irrigated and rainfed agriculture will respond to rising demand. A doubling of current production could be derived from already developed land and water resources. Some further land and water resources could be diverted to crop production, but in most cases they already serve important environmental and economic functions. Possible conversion to crop production would require prior evaluation of the trade-off between production benefits and loss of their current ecological and socio-economic services.

About two-thirds of increased output is likely to be from intensification on irrigated land through improved water services, water-use efficiency improvements, yield growth and higher cropping intensities. Both irrigated area and agricultural water use are expected to expand rather slowly: land under irrigation will increase from 301 million ha in 2009 to 318 million ha in 2050, an increase of six percent. However, any expansion will require trade-offs, particularly over inter-sectoral water allocation and environmental impacts. Considerable growth of supplemental and pressurized irrigation is likely on private farms.

On the basis of existing trends in agricultural water use efficiency and yield gains, it is projected that agricultural withdrawals will need to increase to more than 2900 km3/yr by 2030 and almost 3000 km3/yr by 2050. This indicates a net increase of 10% between now and 2050. Growth in water withdrawals for municipal and industrial use is anticipated to be much higher and it is expected that water allocations currently enjoyed by agriculture will progressively shift towards these higher value uses.

As land and water resources scarcity becomes apparent, competition between municipal and industrial demands will intensify and intra-sectoral competition will become pervasive within agriculture – between livestock, staples and non-food crops, including liquid biofuels. Municipal and industrial water demands will be growing much faster than those of agriculture and can be expected to crowd out allocations to agriculture. Meanwhile, the levels of soil management and precision application of water will need to rise to meet agricultural productivity increases. This will involve intra-sectoral competition for scarce land and water and the ultimate source of naturally available freshwater, groundwater, will be hit hard.

Climate change is expected to alter the patterns of temperature, precipitations and river flows upon which agricultural systems depend. While some agricultural systems in higher latitudes may gain net benefits from temperature increases as more land becomes suitable for crop cultivation, lower latitudes are expected to take the brunt of the negative impacts. Global warming is expected to increase the frequency and intensity of droughts and flooding in subtropical areas. Deltas and coastal areas are expected to be impacted negatively by sea level rise. Mountain or highland systems and irrigated systems that rely on summer snowmelt are also expected to experience long-term changes in base flows. Adaptation and mitigation strategies should focus on increasing resilience of farming systems to reduce current and likely risks such as droughts, excessive rainfall and other extreme events. These strategies should also mitigate the negative impacts of climate change on agricultural production.

1.1.3 Land and water systems at risk; what and where

Across the world, a series of agricultural production systems are at risk due to a combination of excessive demographic pressure and unsustainable agricultural practices. Global figures on the rate of use and degradation of land and water resources hide large regional discrepancies in resource availability. Land and water constraints are expected to compromise the ability of key agricultural production systems to meet demand. These physical constraints may be further exacerbated in places by external drivers, including climate change, competition with other sectors and socio-economic changes. These systems at risk warrant attention for remedial action since they cannot be replicated.

In SOLAW, a production system is considered 'at risk' where locally the current availability and access to suitable land and water resources are constrained. In addition, local scarcity of land and water resources may be further constrained by unsustainable agricultural practices, growing socio-economic pressures or climate change. Systems at risk occur within the nine major categories of global agricultural production systems mapped in SOLAW (Table 1). Figure 4 presents the global distribution of the main categories of risks associated with these production systems.

The global overview of systems at risk presented in Table 1 provides insights into the main risk factors and on the geographic locations where remedial interventions (described in subsequent sections of this document) may be targeted. Further development of technical approaches to reliably identify and characterize such systems at different scales (global to sub-national) would broaden the usefulness of such information to a wide range of development partners.

Table 1: Major land and water systems at risk (a broad typology)

GLOBAL PRO-DUCTION SYSTEMS	CASES OR LOCATIONS WHERE LOCAL SYSTEMS ARE AT RISK
RAINFED CROPPING Highlands	Densely populated highlands in poor areas: Himalaya, Andes, Central American highlands, Rift Valley, Ethiopian plateau, Southern Africa (Risks: erosion, land degradation, reduced productivity of soil and water, increased intensity of flood events, accelerated out-migration, high prevalence of poverty and food insecurity)
RAINFED CROPPING Semi-arid tropics	Smallholder farming in Western, Eastern and Southern Africa savannah region and in Southern India; agro-pastoral systems in the Sahel, Horn of Africa and Western India (Risks: desertification, reduction of the production potential, increased crop failures due to climate variability and temperatures, increased conflicts, high prevalence of poverty and food insecurity, out-migration)
RAINFED CROPPING sub-tropical	Densely populated and intensively cultivated areas, concentrated mainly around the Mediterranean basin (Risks: desertification, reduction of the production potential, increased crop failures, high prevalence of poverty and food insecurity, further land fragmentation, accelerated out-migration. Climate change is expected to affect these areas through reduced rainfall and river runoff, and increased occurrence of droughts and floods).
RAINFED CROPPING Temperate	Highly intensive agriculture in Western Europe (Risks: pollution of soils and aquifers leading to de-pollution costs, loss of biodiversity, and degradation of freshwater ecosystems).
	Intensive farming in United States, Eastern China, Turkey, New Zealand, Parts of India, Southern Africa, Brazil (Risks: pollution of soils and aquifers, loss of biodiversity, degradation of freshwater ecosystems, increased crop failure due to increased climate variability in places).
IRRIGATED Rice-based systems	South-eastern and Eastern Asia (Risks:land abandonment, Loss of buffer role of paddy land, increasing cost of land conservation, health hazards due to pollution, loss of cultural values of land).
	Sub-Saharan Africa ,Madagascar, Western Africa, Eastern Africa (Risks: Need for frequent rehabilitations, poor return on investment, stagnating productivity, large-scale land acquisition, land degradation)
IRRIGATED Other crops	RIVER BASINS Large contiguous irrigation systems from rivers in dry areas, including Colorado river, Murray Darling, Krishna, Indo-Gangetic plains, Northern China, Central Asia, Northern Africa and Middle East (Risks: increased water scarcity, loss of biodiversity and environmental services, desertification, expected reduction in water availability and shift in seasonal flows due to climate change in several places).
	AQUIFERS Groundwater dependent irrigation systems in interior arid plains: India, China, central USA, Australia, North Africa, Middle East and others (Risks: loss of buffer role of aquifers, loss of agriculture land, desertification, reduced recharge due to climate change in places).
RANGE-LANDS	Pastoral and grazing lands, including on fragile soils in Western Africa (Sahel), North Africa, parts of Asia (Risks: desertification, out-migration, land abandonment, food insecurity, extreme poverty, intensification of conflicts).
FORESTS	Tropical forest-cropland interface in South-eastern Asia, the Amazon basin, Central Africa, and Himalayan forests (Risks: cropland encroachment, slash and burn, leading to loss of ecosystems services of forests, land degradation).
Other locally important sub-systems	DELTAS AND COASTAL AREAS: Nile delta, Red river delta, Ganges/Brahmaputra, Mekong, etc. and coastal alluvial plains: Arabian peninsula, Eastern China, Bight of Benin, Gulf of Mexico (Risks: loss of agricultural land and groundwater, health-related problems, sea level rise, higher frequency of cyclones (Eastern and South-eastern Asia), increased incidence of floods and low flows).
	SMALL ISLANDS including Caribbean, Pacific islands (Risks: total loss of freshwater aquifers, increased cost of freshwater production, increased climate-change related damages (hurricanes, sea level rise, floods)).
	PERI-URBAN agriculture (Risk: pollution, health-related problems for consumers and producers, competition for land).

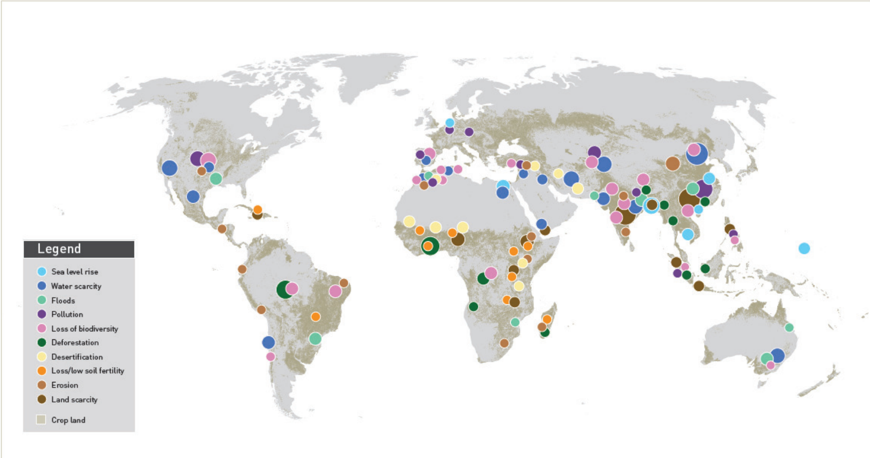

Fig. 4: Global distribution of risks associated with main agricultural production systems

2. LAND AND WATER FOR SUSTAINABLE INTENSIFICATION

More than four-fifths of agricultural production growth to 2050 is expected to come from increased productivity on presently cultivated land. A variety of agronomic and technical approaches are available to achieve higher output, overcome constraints and manage risks. These will need to be accompanied and guided by increasingly effective and collaborative land and water institutions – public and private, formal and informal.

2.1 Land and water productivity gaps: an untapped potential

Land productivity is generally low on rainfed croplands, because of low inherent soil fertility, severe nutrient depletion, poor soil structure and inappropriate soil management practices. This is particularly the case in Sub-Saharan Africa, where yields are often below 1 t/ha. Sustainable land and water management techniques can increase productivity through integrated soil fertility management where rainfall is reliable.

Integrated rainfed production practices, such as conservation agriculture, agroforestry and integrated crop-livestock systems, combine best management practices adaptable to the local ecosystems, cultures and to market demand. Pesticide use and risks can be minimized by integrated pest management (IPM). Integrated soil fertility management, combined with rainwater harvesting and soil and water conservation on slopes could improve rainfed yields. By focusing on nitrogen and carbon cycles, scaling of these practices can also enhance carbon sequestration and mitigate GHG emissions.

These approaches have proven to be successful when they form part of a rural development and livelihoods improvement strategy which includes support services and better market access. Education, incentives and farmer field schools speed the transition to more productive and resilient land-use systems. However, risk and initial low profitability can inhibit the adoption of these techniques. Overall, feasibility and risk assessments are needed to evaluate socio-economic constraints and formulate effective incentive packages for farmers to adopt appropriate management approaches and adapt techniques and practices to their specific farming situation.

Most irrigation systems across the world perform below their capacity and are not adapted to the needs of today's agriculture. The low level of water productivity associated with their management translates into lost opportunities for resource use efficiency and economic returns. Irrigation has had direct benefits in terms of production and incomes, and indirect benefits in terms of reduced incidence of downstream flood damage. However, there have also been associated impacts whose costs may outweigh the benefits of production. They include reduction in environmental flows, changes in downstream access to water, or reduction of the extent of wetlands (which have important ecological functions of biodiversity, nutrient retention and flood control).

To raise land and water productivity on larger irrigation schemes, an integrated modernization package of infrastructure upgrades and management system improvements is required, together with an economic environment providing undistorted incentives, manageable allocation of risk, and market access. There is also scope for improving irrigation efficiency and productivity in small-scale and informal irrigation. This requires mechanisms to ensure the availability of knowledge, technology and investment support, adapted to the local management practices and socio-economic context.

The scope for increase in water supply for irrigation is limited. Additional irrigation water is likely to come from multi-purpose hydropower schemes. Small-scale water storage projects are also expected to boost supply. Although some new groundwater development is anticipated, active management by users can improve water-use efficiency where there is collective interest in maintaining aquifer function and services. A combination of improved irrigation scheme management, investment in modern technology, knowledge development and training can substantially increase water-use efficiency and improve supply to the often poor tail-end users. The highest gains are possible in sub-Saharan Africa and parts of Asia.

Recycling and re-use of water is another option, but only with effective regulation can water be safely derived from drainage, saline and treated wastewater. On-site and off-site risks from salinization and water-logging require careful drainage planning, investment and management in many irrigation projects. Salt and water balance studies and a regulatory and monitoring system are required.

2.2 National support to sustainable land and water management

The world's farmers will continue to be the prime agents of change and their perspective has to count. Farmers are necessarily engaged in the planning and sustainable management of land and water, but many are forced into unsustainable practices by poverty and lack of aligned incentives; insecure land tenure and water-use rights; lack of adequate local organizations; and inefficient support services including rural credit and finance, markets and access to technology and knowledge. Here, public resources can be allocated more strategically. Together with mechanisms to engage private sector financing, both at the national level and through credit mechanisms at the local level. This should translate into a higher share of public investments in agriculture. Within countries, three principal areas of investment are vital. At the national level, governments will need to invest in public goods such as roads, storage, land and water resource protection works and to facilitate private investment. In addition, investment is needed in the institutions that regulate and promote sustainable land and water management: research and development, incentives and regulatory systems; and land use planning and water management. At basin or irrigation scheme level, an integrated planning approach is needed to drive a sequenced programme of land and water investments. For irrigation schemes, a focus on modernization of both infrastructure and institutional arrangements is needed.

Land and water administration institutions can be strengthened to improve systems for land and water rights where shortcomings inhibit improved productivity. Common-property systems can be adapted to provide secure land tenure by legal recognition and protection or by negotiated and legalized conversion to individual rights. Land markets can be promoted to improve allocation efficiency and equity.

Integrated approaches across coupled land and water systems and multi-level stakeholder participation can greatly enhance water productivity and reduce stress by improving allocation efficiency among sectors and by introducing technologies and a governance structure promoting efficient water use. Examples are participatory collective irrigation or groundwater management. Cooperation in transboundary water management, starting from the technical level, can promote optimal, multi-objective investment and basin-wide benefit-sharing. Future institutional development is likely to increasingly reflect participatory and pluralistic approaches, with growing devolution and accountability at local levels. Participatory planning approaches reflect the need for bottom-up identification of problems and solutions in resource management. Irrigation reforms would build on the movement of governments to decentralize control over irrigation and to seek greater responsibility from irrigating farmers. Basin management approaches reflect best practice in devolving land and water management to the lowest geographic unit and in involving stakeholders in planning and decision making.

In particular, the need to address trade-offs will centre on the level and modalities of intensification, protection and conservation, the balances between commercial farming and staple production and between growth and income distribution, the level of national food security, and the sharing of costs and benefits between urban and rural populations. What is vital is that the analysis should be explicit and decisions taken in the broader public interest. Participatory processes and transparency are thus important.

Improving the application of technology for sustainable land and water management requires the integration of knowledge from research with local diagnosis and adaptation. There is an extensive research basis for most land and water systems, but research and extension need to be equipped to offer adapted technology on demand, for example through outreach programmes such as Farmer Field Schools, in partnership with local farmer groups, NGOs and the private sector – the latter for example on product certification (ecological; fair trade) for value addition or pressurized irrigation technology.

SOLAW has revealed a number of gaps and inconsistencies in existing data bases and information systems. These gaps should be filled by further inventories of land and water resources to help guide choices and implementation. Further research on the main existing farming systems will be essential to determine conservation and intensification strategies.

Methods of assessing and valuing ecosystem services, including land and water audits should be developed to provide the tools that are needed to value development options and help making informed decision. Networks and modern media need to become more effective in exchanging and disseminating knowledge, and for identifying and filling knowledge gaps.

A first step to manage land and water more efficiently is removing distortions that encourage land and water degradation, such as cheap energy prices that drive inefficient, energy-intensive farming or groundwater depletion. An incentive structure including price incentives and regulatory measures can then be designed to promote better practice. Payments for Environmental Services (PES) may rebalance costs incurred by farmers and benefits to other sectors of society.

The recent trend in land acquisition needs to be addressed through appropriate regulations, and well-informed agricultural and food policies that take more account of land availability and access rights. Developing guidelines for land governance, or a code to regulate international investments backed up by capacity building at all levels, would be useful to improve decision-making and negotiations.

2.3 Requirements for international cooperation and investment

There is an urgent need for better and more effective integration of international initiatives dealing with land and water management. International cooperation on sustainable land and water management has become a high priority in many institutions because of concerns about food security, poverty reduction, environmental protection and climate change. Several international agreements contain principles of conservation of natural resources, including land and water, but these have rarely been translated into substantive action on the ground or national codes of conduct or practice, and a consolidated agreement and framework for action on sustainable land and water management is not yet in place.

Several organizations and programmes, including the Global Environment Facility (GEF) have been raising awareness and prompting action on sustainable land and water management, and some have strengthened institutions and governance. However, different organizations often work in the same field with limited resources, which reduces focus and impact, and approaches remain largely sectoral rather than integrated.

A number of recent initiatives and partnerships from civil society and the private sector such as fair-trade, environmental certification or organic labelling may also have positive effects on sustainable land and water management. They should be promoted and guided through better knowledge and monitoring mechanisms.

Global investment in land and water management remains below the levels necessary to address persistent food insecurity and deal with natural resource scarcity. Gross investment requirements between 2007 and 2050 for irrigation development and management are estimated at almost US$1 trillion. Moreover land protection and development, soil conservation and flood control will require around US$160 billion. New financing options include Payments for Environmental Services and the carbon Market. Global-level financing should complement public and private finance at the national level. To effectively attract and absorb these higher levels of investment, nations need to develop favourable policies, institutions and incentives, along with a strong monitoring and evaluation mechanism that addresses the social, economic and environmental dimensions of sustainability.

Financial resources to promote sustainable land and water management will need to be sourced and disbursed through existing funds and/or from private and market sources. A dedicated fund to support sustainable land and water management by smallholders could be set up within the context of global climate change negotiations over carbon sequestration financing, with a focus on the multiple benefits of raising soil carbon storage, reducing losses of soil nutrients and controlling runoff from farmer's fields. Programmes could then provide incentives to promote local level adoption of sustainable land and water management practices, and also to promote global goods such as reforestation and carbon capture, and to reduce negative environmental impacts. Programmes adopting the concept of payments for environmental services (PES) could facilitate adoption of such initiatives by farmers.

Land and water management offers important opportunities for of synergies between climate change adaptation and mitigation. Agriculture and deforestation account for up to a third of total anthropogenic greenhouse gas (GHG) emissions. At the same time, climate change is expected impact patterns of land and water use for agriculture. However, many of the sustainable land and water management practices which are recommended to increase resilience and reduce vulnerability to climate change also contribute to mitigation, largely through carbon sequestration. In addition to its contribution as a carbon sink, increasing the storage of organic matter in the soil provides many further benefits, including reduction of runoff, improvement of soil water storage, and retention of soil nutrients. These benefits can reduce fertilizers requirements and enhancing their uptake. This contribution of improved land and water management to mitigating climate change may mean that developing countries should be able to attract financial support based on the carbon sequestration value of their sustainable land and water management.

3. MEETING THE CHALLENGES - BUSINESS AS USUAL IS NOT ENOUGH

The overriding challenges faced by agriculture are; to produce at least 70 percent more food by 2050; improve food security and livelihoods of the rural poor; maintain the necessary ecosystem services; and reconcile the use of land and water resources among competing uses. All these challenges will need to be addressed together with the anticipated impacts of climate change where they have a net negative impact on agricultural production. These challenges will not be met *unless*:

- Existing agricultural practices can be transformed to reduce pressure on land and water systems.
- Negative impacts of intensive production systems are reduced markedly and increased food production is aligned with poverty alleviation, food and livelihood security diversification and the maintenance of ecosystem services.
- Negative impacts of smallholder agriculture associated with high population density, widespread poverty, and lack of secured access to land and water resources, are reduced.
- Agricultural systems at risk are addressed as a priority and progress in redressing risks is monitored.

- Investment, economic and trade policies favour sustainable agriculture and balanced rural development.
- Sustainable intensification can be implemented through integrated planning and management approaches that can be scaled up from local levels to address systems at risk and mainstream climate change mitigation and adaptation simultaneously.

The principles and practices around which major initiatives for sustainable land and water management can be built are:

- Broad adoption of participatory and pluralistic approaches to land and water management, with growing devolution and local accountability.
- Increasing investment for improvement of essential public good infrastructure related to the whole market chain from production to consumer.
- Appraisal of ecosystem services including land and water audits developed to frame planning and investment decisions.
- A review of the mandates and activities of existing global and regional organizations for land and water should be undertaken to promote collaboration, if not integration.
- International trade agreements that favour a 'green economy' approach and contribute to sustainable agriculture overall.
- Cooperative frameworks and basin-wide management institutions that can work together to optimize economic value and ensure equitable benefit sharing in international river basins.
- A dedicated fund to support sustainable land and water management by smallholders could be set up. Incentive programmes such as Payments for Environmental Services for watershed management and clean water, biodiversity and sustainable production schemes could then promote adoption of sustainable land and water management practices capturing carbon and reducing negative environmental impacts.

4. CONCLUSIONS

The land and water systems, underpinning many key food producing systems worldwide, are being stressed by unprecedented levels of demand. Climate change is expected to exacerbate these stresses in some key productive areas.

There is scope for governments and the private sector including farmers to be much more proactive in enabling and promoting the general adoption of more sustainable land and water management practices. These have the potential to expand production efficiently to address food insecurity while limiting impacts on other ecosystem values. However, this will require profound changes in the way land and water are managed. Global and national policies will need to be aligned and institutions transformed to become genuine collaborators in applying knowledge and in responsible regulation of the use of natural resources. Business as usual, with or without some marginal adjustments, will not be enough.

The status and trends of land and water resources for food and agriculture described in SOLAW provide a basis for designing and prioritizing regional programmes and financing to enhance sustainable management of land and water and address the systems at risk.