

The Environmental, Social and Economic Sustainability of Agriculture in the Dry Areas

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Abstract: This overview addresses the current challenges faced by farmers and pastoralists in the drylands of developing countries who depend on agriculture and livestock for their livelihoods. Many farmers and pastoralists in the drylands are trapped in a perpetual cycle of poverty, poor crop yields, scarcity of natural resources - particularly water, and a lack of supportive policies and institutions. The rapidly increasing population and a markedly higher vulnerability to climate change in other parts of the world will continue to aggravate the challenges faced by local communities. Existing science and technology tools and resources offer the capability to increase sustainable agricultural intensification in the drylands. The impacts resulting from ICARDA's research in partnership with national research and extension systems clearly demonstrate the vital role of science and technology in improving the livelihoods of dryland populations. Further, the need exists to adopt an integrated or "systems" approach to bring together all stakeholders and develop technologies, resource management strategies, and institutional arrangements that are capable of solving the daunting problems confronting dry area production systems.

Key words: Dry lands, developing countries, partnerships, systems approach, environmental sustainability, social sustainability, economic sustainability, ICARDA, food security, water.

The Fragile Agro-ecosystems of Dry Areas: Water Scarcity, Climate Change and Land Degradation

Drylands occupy about 41% of the earth's land area and are home to approximately 2.5 billion people. In the developing world, the drylands are vast, as illustrated in Figure 1. Agro-ecological systems in the dry areas are diverse, dynamic and complex. They can be arid, semi-arid or dry sub-humid. They comprise a mix of pastoral, agro-pastoral, mixed rainfed and irrigated production systems where farmers use land, water, livestock, biodiversity, rangelands, trees and fish to meet their food and livelihood needs. Though natural resources are extremely limited - especially water, drylands contain remarkable biodiversity and are the center of origin for many native and wild crop and pastoral species and a large number of crop landraces and local animal breeds.

Farming remains the backbone for many dryland communities. Drylands are characterized by low, variable, and erratic precipitation, high evaporation, economic and physical water scarcity, groundwater depletion, low soil fertility, high soil salinity, severe land degradation, desertification and loss of

biodiversity. In addition to these burdens, drylands are predicted to be hardest hit by climate change as temperatures rise, and more heat waves and less but more intense rainfall are experienced causing more frequent droughts and an increased risk of severe flooding adversely affecting food production and the four dimensions of food security: availability, access, stability and utilization. In Africa for example, by 2020 yields from rainfed agriculture could be reduced by 50% and scientists predict that 90 to 220 million people will experience increased water stress in 2020 due to climate change (IPCC, 2007). Already the renewable internal freshwater resources per capita in the drylands are below 2000 m³. In some countries, most of them in Sub-Saharan Africa and the Middle East, the per capita share has crossed the water poverty line - below 1000 m³ - and continues to decline further. Figure 2 illustrates this reduction from 1967 to 2011 in Algeria, Egypt, Morocco, Saudi Arabia, Syria and Tunisia.

Already, climate effects are being recorded with serious impacts on agriculture and forcing some of the dryland's poorest and most vulnerable people deeper into poverty. Figure 3 shows expected changes in precipitation, averaged from a large number of general circulation models (GCMs). West Asia and

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North Africa will be severely affected by climate change, with a large part of the region experiencing up to a 30-50% decrease in rainfall (Solh, 2011). In Morocco, rainfall has declined by as much as 40% in the springtime and in Egypt's Sinai Peninsula, rainfall decreased by 20-50% over the past 30 years impacting the livelihoods of the Bedouins who live there. In north-east Syria, the 2006-2011 a prolonged drought caused livestock herds to be depleted by 80-100%, causing thousands of small herders and farmers to migrate to urban areas, swelling the urban slums and potentially contributing to Syria's current social and political unrest (The World Bank, 2012).

Climate change, manifested by long drought periods and intense rainfall events is expected to cause a reduction in rangeland production and loss of vegetative cover. Crop yields will decrease—and in some cases dryland farmers will experience complete crop failure. Dryland farmers and pastoralists are expected to absorb increased risk as they try to establish what crops they can grow under changing climatic conditions and determine new and different sowing and harvesting times, how to deal with new pest and disease risks as well as new invasive plant and animal species. Water availability, already scarce in the drylands, will be further threatened by drought and water loss resulting from torrential rains. The productive capacity of dryland soils are expected to decline as they experience greater rates of erosion, higher decomposition of organic matter because of increasing temperatures and reduced soil moisture and moisture storage capacity and increased salinity affecting soil fertility. As a result of the reduction of plant cover, there will be an increase in carbon emissions (FAO, 2004; Trumper *et al.*, 2008). The impact of climate change in the drylands will also impact livestock productivity by reducing the availability of feed and fodder, increasing heat dissipation and introducing new livestock health problems. Habitat change and loss will reduce the biodiversity of key crop and rangeland species, thereby increasing the vulnerability of dryland pastoral communities (Dougill *et al.*, 2010). Seawater intrusion in coastal areas, because of sea-level rises, will swallow fertile land and result increases in soil salinity, rendering some land unfit for agriculture (Thomas *et al.*, 2007; Millennium Ecosystem Assessment, 2011).

Drylands are also characterized by very serious land degradation, defined by the FAO as a reduction in the capacity of the land to provide ecosystem goods and services and assure its functions over a period of time for its beneficiaries. Globally, land degradation costs are estimated to be US\$40 billion annually (FAO <http://www.fao.org/nr/land/degradation/en/>.) Land degradation is due to water erosion, wind erosion, depletion of soil fertility, deforestation, unsustainable livestock grazing practices and water logging, which are further aggravated by water scarcity, droughts, flooding and unsustainable land management practices. The United Nations Convention to Combat Desertification (UNCCD) estimates that each year, 12 Mha of arable land are lost due to drought and desertification with the potential of displacing 50 million people within the next 10 years if this rate continues unabated. In Yemen, where rural poverty is severe, 50% of the total rural area (about 30 Mha) suffers from desertification caused by water and wind erosion, over-grazing and depletion of tree cover, abandonment of terraces and changes in socio-economic factors and farming practices (ICARDA, 2012). Desertification and land degradation impacts about 68 Mha of fragile lands across Pakistan. In Morocco, an economic analysis of land degradation shows a global cost of lost productivity to be 91 to 178 million USD per annum (WB, no date from ICARDA publication). Recent economic analysis shows that an estimated 20% of all irrigated land globally is salt-affected (62 Mha) with an estimated global economic loss at \$27.3 billion per year (Qadir *et al.*, 2014). For example, in India's Indo-Gangetic Basin, crop yield losses for wheat, rice, sugarcane and cotton grown on salt-affected lands could be 40%, 45%, 48%, and 63%, respectively. This would result in employment losses up to 50-80 man-days per hectare, with an estimate 20-40% increase in human health problems and 15-50% increase in animal health problems (Ibid, 2014).

Socio-Economic, Political and Institutional Challenges Facing the Drylands

There are formidable socio-economic, security and political constraints in the drylands, which are home to a third of the world's population—many of whom are considered among the world's poorest and who lag far behind others in terms

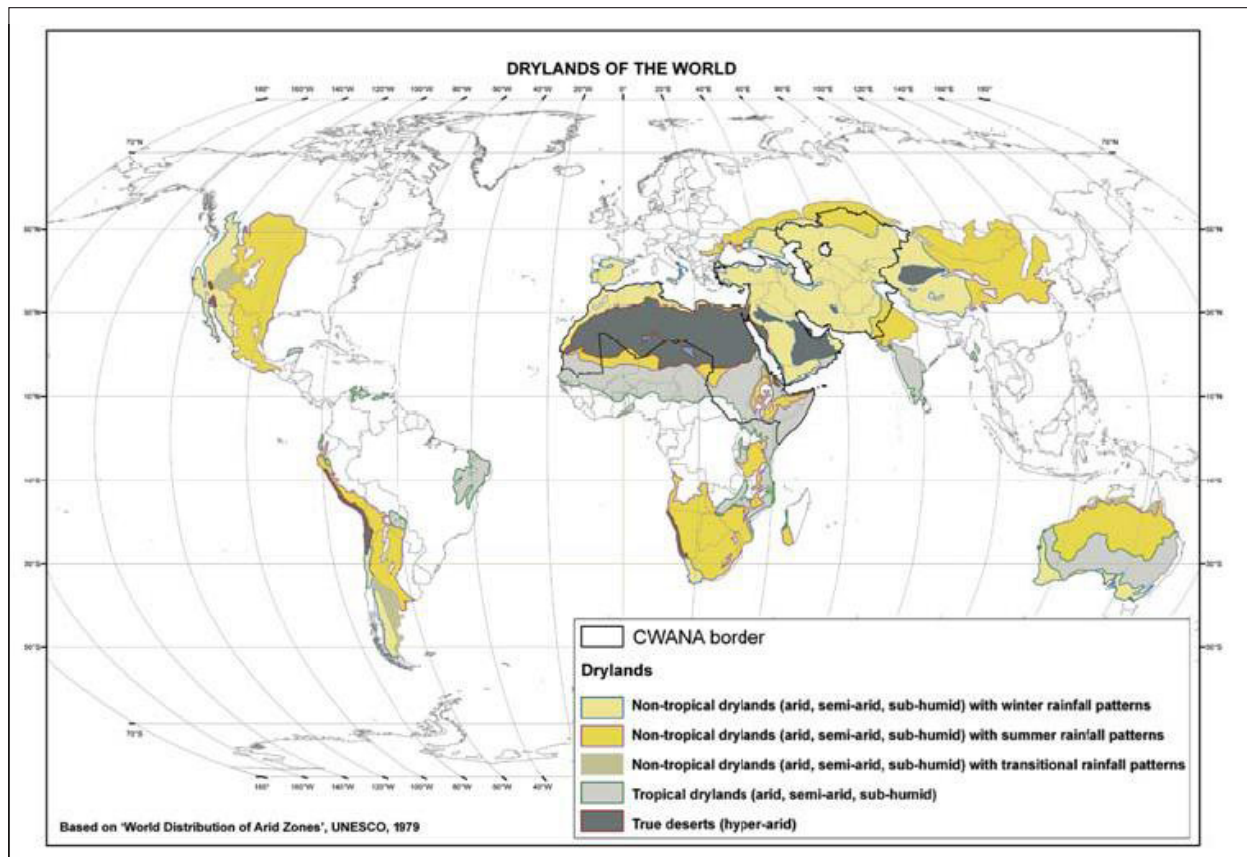


Fig. 1. Map of the drylands.

of well-being and development indicators. For example, Nepal, Senegal, Afghanistan and Burkina Faso have some of the lowest human development indices worldwide (UNDP, 2014). It is estimated that 16% of the dryland's population is marginalized, vulnerable and suffer from chronic and persistent poverty. In the drylands, infant mortality is the highest and GNP per capita is the lowest compared to other regions in the world (UN, nd). About 400 million of the total 2.5 billion people in developing countries who live in the drylands

depend on agriculture and the natural resource base for their livelihoods.

Small-scale farmers and pastoralists in the drylands often lack a political voice and access to finance, markets, production inputs (seeds, fertilizers, water for example), information, and supportive customary and formal institutions and policies and where they are becoming more marginalized in the global food and agricultural economy. Vulnerable groups, particularly women, youth and some ethnic and

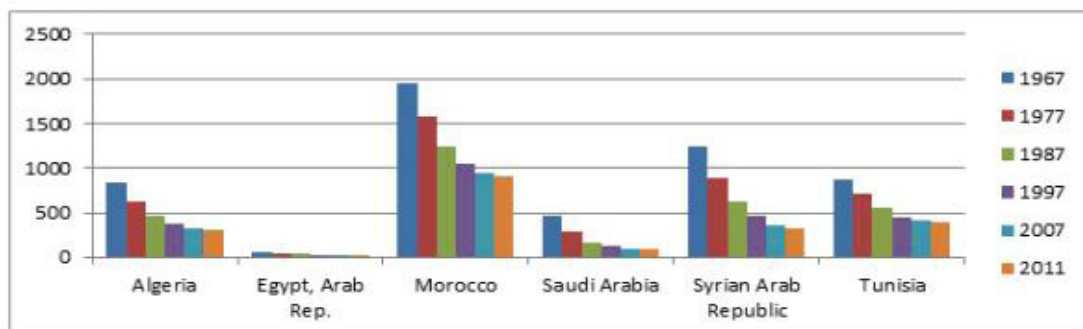
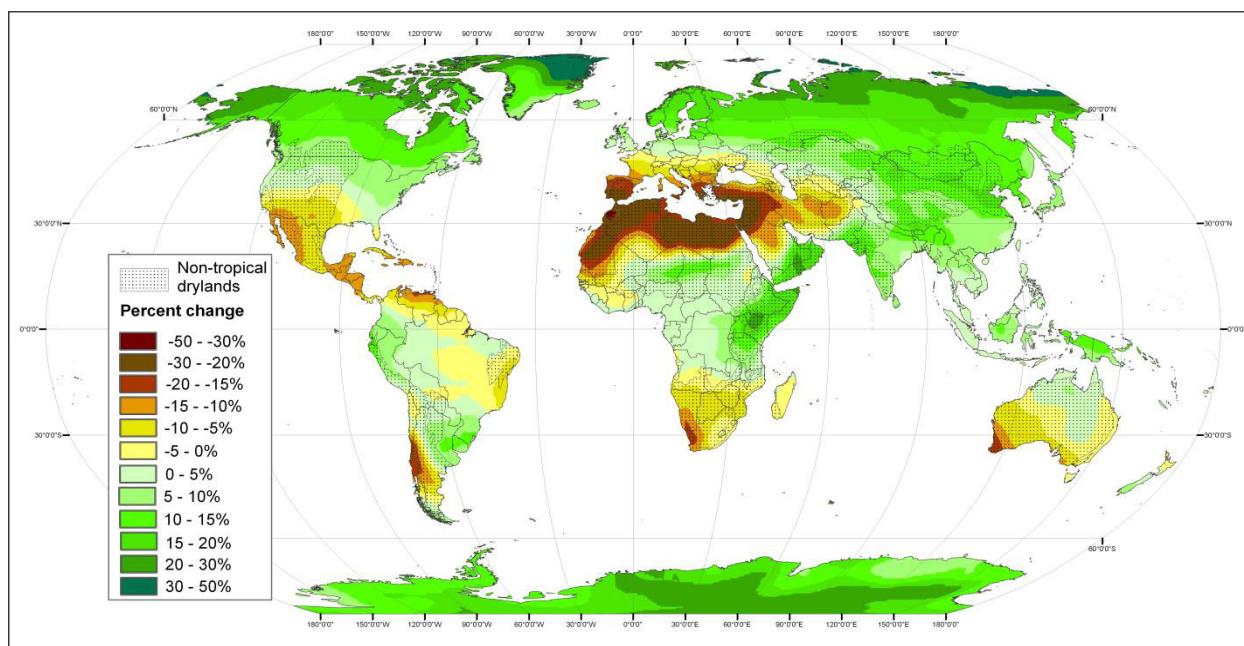


Fig. 2. Renewable Internal Freshwater Resources Per Capita, Select Countries (cubic meters).



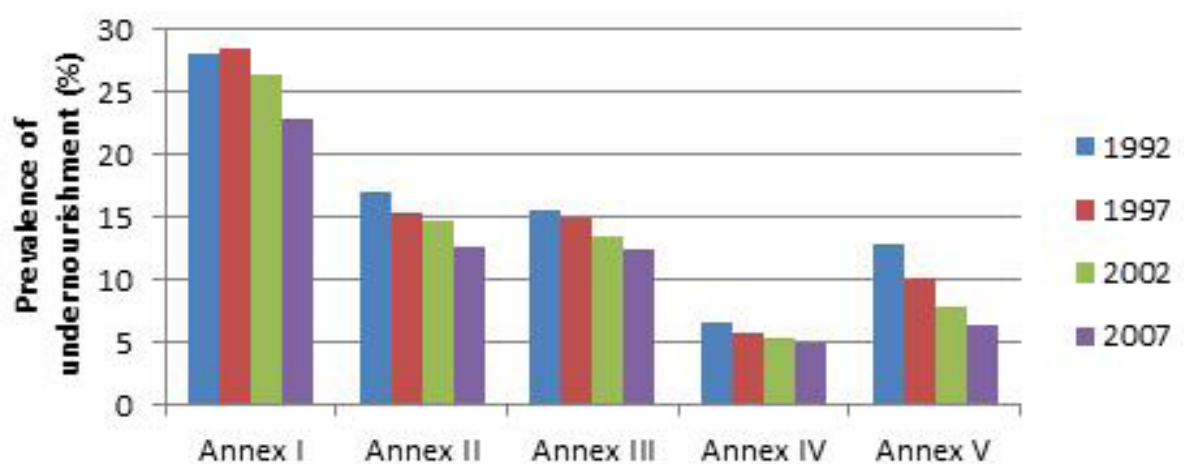
*Scenario A1b, average of 21 GCMs (compiled by GIS Unit ICARDA, based on partial maps in Christensen *et al.*, 2007)
Source: ICARDA, based on Fourth Assessment Report of the Intergovernmental Panel on Climate Change http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml

Fig. 3. Relative change of mean annual precipitation 1980/1999 to 2080/2099*.

religious minorities are discriminated against and are often disenfranchised, which limits their capacity to voice their needs, take active part in development processes and share the benefits of development interventions. Women in particular carry heavy burdens in the dry areas, even though they play active roles as food producers, traders, processors, laborers and entrepreneurs. Women also hold the prime

responsibility for the nutrition, hygiene and wellbeing of their families, but they still face many more obstacles than men in accessing resources and sharing benefits.

FAO defines food security in a country as a situation where “all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets



Annex 1. Africa; Annex II: Asia; Annex III: Latin America and the Caribbean; Annex IV: Northern Mediterranean and Annex V: Central and Eastern Europe Source: UNCCD; Data: WorldDataBank (<<http://data.worldbank.org/>>), accessed August 2011 from <http://www.unccd.int/en/programmes/Thematic-Priorities/Food-Sec/Pages/default.aspx>

Fig. 4. Prevalence of undernourished population by UNCCD annex.

Table 1. Population growth, unemployment, youth unemployment and gender inequality in select dryland countries

Country	Average annual population growth rate (%) 2010-2015	Unemployment (% , ages 15 and older)	Youth unemployment (% , ages 15-24)	Gender inequality index
Sudan	2.1	19.8	22.9	0.628
Ethiopia	2.7	17.5	--	0.547
Yemen	2.3	16.2	33.7	0.733
Tajikistan	2.4	11.5	16.7	0.383
Senegal	2.9	10.4	--	0.537
Mali	3.0	7.3	--	0.673
Pakistan	1.7	5.5	7.7	0.563
Jordan	3.5	12.2	29.3	0.488
Turkey	1.2	8.1	17.5	0.360

Adapted from UNDP Human Development Report, 2014.

their dietary needs and food preferences for an active and healthy life.” For many people in the drylands, such conditions are not available. According to data currently available by UNCCD, countries included in their regional implementation annexes (Africa, Asia, Latin America and the Caribbean, Northern Mediterranean and Central and eastern Europe) accounted for more than 93% of the world’s undernourished people with Africa and Asia showing the highest prevalence rates of under-nutrition. In the Arab countries, where there is some of the driest agriculture in the world and under-nutrition is on the rise, cereal imports to feed rapidly growing populations are increasing exponentially, even in countries that were not long ago self-sufficient in cereal production. The cost of food imports in Arab Countries is estimated to reach \$115 billion by 2020, exposing the region to global food price fluctuations. In 2010, net import of cereals was 65.8 million tons with these imports expecting to continue to rise quickly, costing the governments millions of dollars (Sadik, 2014). To reduce the burden on government spending, policy-makers are now gradually aiming at self-sufficiency through a combination of domestic and regional production, taking into consideration the scarcity of water, the state of the natural resource base and the potential impacts on climate change.

From this weakened position, dryland populations are particularly vulnerable to global food crises which increases their food and nutritional insecurity and also places heavy burdens on governments as they become increasingly dependent on food imports.

Drylands have some of the fastest growing populations in the world, with burgeoning youth populations. Large population growth is coupled with high rates of unemployment and underemployment, particularly notable for the youth and women. According to the ILO, unemployment among the youth in North Africa and the Middle East (MENA), where drylands dominate the landscape, is 23.6% and 25.1% respectively, compared to a world average of 12.6%. Similar patterns are observed in other dryland countries (Table 1). According to the World Bank, poverty in MENA has not been reduced since 1990 compared to 2005 because of rapid population growth, and 50 million people still survive at under \$2 a day.

These environmental, economic, and social conditions combine to push people, especially the landless, to pursue non-farm or off-farm work in their country or abroad. Many people leave the agricultural sector to seek seasonal or permanent jobs elsewhere, mainly in urban centers. For example, during the period of 25 years, the percentage of Mauritians living in the capital Nouakchott increased from 9 to 41% (UNCCD, 2009). Many rural people also immigrate legally or illegally to other countries. In both cases, migrants face tremendous hardships. They live in poor congested urban areas where their health and social networks are taxed and they earn low daily wages, which often results in tension and conflict with local communities. The youth and male family members, in particular, migrate as an adaptation strategy and leave the women and the elders to take over their work in agriculture. The feminization of agriculture has been noted

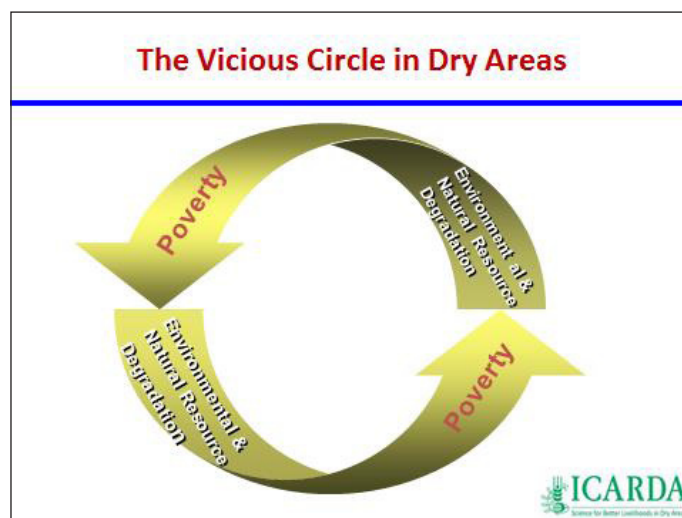


Fig. 5. Environmental, Social and Economic Sustainability of Dryland Farming are interrelated: The Vicious Circle in Dry Areas.

in Syria. However, even though women's labor contributions to agriculture have increased, there has been no rise in their decision-making power and control over income and other resources (Abdelali-Martini and Aw-Hassan, 2014).

In some dryland regions such as Sudan, Syria, Yemen and Nigeria, some analysts have attributed the current conflicts and civil unrest to these countries' deteriorating natural resource base and to climate effects, which have a 'threat multiplier' in situations where multiple stressors already exist. In West Asia, where drylands are predominate and conflict and political instability is intense, the FAO (2014) notes that it is only region in the world which has experienced an increase in undernourishment since the 1990s from 6.3% in 1990-92 to 8.7% in 2012-14. In Yemen, for example, the FAO reports that civil unrest has impacted diet diversity. Inadequate diets increased by 41% between 2009 and 2011 with 4.5 million people considered severely food-insecure and 6 million moderately food-insecure. Additionally, the prevalence of stunted children under five years of age remains critical with 46.6% of the children in Yemen stunted or chronically malnourished and about 5 million people depending on food assistance.

At the global and national levels, drylands have been mostly neglected. Investment strategies tend to favor high potential or densely populated areas, despite the evidence that some of the highest returns to investments can be

captured in less favored lands. Without the conducive policies, institutions and incentives, research for development initiatives are unlikely to succeed. In Vietnam, for example, strong pro-smallholder development policies and institutions transformed the country from a poor underdeveloped and food insecure one to a country that is now exporting food and classified as lower middle-income.

The interrelated environmental, social and economic challenges have created a vicious cycle where environmental and natural resource degradation is increasing poverty, which is in turn is worsening the environmental and natural resource degradation. Breaking this cycle of poverty requires empowering the people of the drylands to take charge of their development agenda and creating robust institutions, fair and equitable policies, larger investments by both the private and public sector, strong political commitment and more research, science, technology and innovation to address the complex factors affecting dryland farming and the evolving needs of the people who depend on them.

Supporting Environmental, Social and Economic Sustainability in the Drylands

While the environmental, climatic, social, economic and political conditions facing farmers and pastoralists in the drylands are daunting, it is important to stress that many agro-ecological systems remain productive and sustainable because of the extraordinary

capacity and resilience of the people to cope with changing conditions. Dryland farmers and pastoralists are traditionally resilient and innovative and are extremely effective change agents who rely on their vast traditional knowledge and expertise, as well as their adaptive capacity and hard work to manage various hardships under changing conditions.

To capture the dynamic potential endowed in the people of the drylands, and address the multiple and complex challenges they face, new integrated approaches, including research for development impacts are needed. Experience has shown that the most successful endeavors involve consultations and meaningful participation and bring together local communities and all other stakeholders, to develop resource management strategies and policies, technological, economic and social innovations as well as dynamic institutional arrangements that build resilience into dryland systems. Efforts need to focus on environmental sustainability, but that is not enough. Environmental sustainability needs to be coupled with social, economic and institutional support using an integrated approach.

The environmental sustainability of agriculture in the drylands can be addressed by helping farmers and pastoralists to conserve and sustainably use their land and water. There must be a focus on improving water availability and enhancing water productivity, as well as on building soil fertility, combatting land degradation and conserving biodiversity. However, focusing on environmental sustainability is not enough. These efforts must be coupled with social, economic and institutional support. Without such an integrated approach, the needs of dryland communities will not be fully met.

The social sustainability of agriculture can be addressed by generating employment opportunities for the rural population, increasing the access of resources and opportunities of women, and attracting youth to agriculture by making farming more intellectually challenging and economically rewarding. This requires a very clear understanding of the youth, their aspirations and the incentives they need to be mobilized. Despite many incentives in Nigeria to encourage

youth's involvement in agriculture, their participation in agricultural production and processing has been on a decline. The youth cite poor access to credit, land, inputs, storage facilities, markets, knowledge and insurance as well as poor returns to investments as factors limiting their involvement in agriculture. Many also cited the public's poor perception of farming and their preference to live in urban areas (IFPRI, 2010).

From the economic sustainability perspective, science and development efforts should focus on helping farms in the drylands improve their income by increasing the productivity of their lands and reducing production costs. Producing more high-value, quality products increases the sustainability of farming in the drylands. In many cases, the key factor to the success of the farm is the ability of its members to access micro-credit and have the capability to link directly to the market.

Research That Works for People and Communities in the Drylands

It is clear that traditional agriculture is failing to bring development to the drylands, hence the need to increasing investments in research. The more than 35 years of research for development work at the International Center for Agricultural Research in the Dry Areas (ICARDA) - a global agricultural research center working with countries in the world's dry areas, and leading the CGIAR Drylands System Program - has resulted in a body of experience and knowledge about the complex environmental, economic and social challenges facing the drylands. ICARDA works on a vast number of programs and projects to increase the productivity of both rainfed and irrigated agriculture, to diversify and sustainably intensify crops and livestock production systems by addressing yield gaps and strengthening linkages throughout the market chain. It also conducts strategic socio-economic and policy research to better understand rural poverty, livelihood strategies, and gender dynamics. The outcomes guide more effective and targeted research for development investments. Another major research area is genetic resource conservation and crop improvement to enhance agricultural productivity, production stability and nutritional quality of barley, food and feed legumes, bread and durum wheat.

Table 2. ICARDA genebank holdings (up to 2010)

Crop	Accessions
Barely	24,975
Wheat	34,227
Wild cereals	7,671
Food legumes	33,313
Wild food legumes	857
Forage legumes	28,469
Forage and range spp.	5,744
Total	135,259

ICARDA has successfully combined the following three practices to improve the efficacy of its activities in the drylands:

- Innovative and cutting edge research that generates practical solutions for the farmer in the drylands;
- Integrated and systems approaches to research for development initiatives to address the complexity of the multiple interrelated issues in the drylands; and
- Partnership with the national agricultural research systems (NARS) and other players along the impact pathway, such as development organizations, local communities and policy-makers to increase ability to solve problems and develop better solutions at the local level, with a particular focus on local initiatives.

The Ability of Science and Technology to Improve Dryland Livelihoods

Much of the work that ICARDA scientists produce in collaboration with national agricultural research partners and with farmers is knowledge and technology to help farmers manage the risks they face under dryland conditions by enhancing their productive potential and improving their income through the sustainable intensification and diversification of their production systems. The following examples of ICARDA's recent results and achievements demonstrate innovative technologies that are ripe for use by countries throughout the dry areas.

Improving and stabilizing crop productivity

Germplasm collection and genebank: Crop improvement requires access to a rich pool of diverse crop genetic materials that can be used to unearth desirable traits, which can then be

used to breed improved crops that can counter biotic and abiotic stresses such as climate change, diseases, pests and harsh weather conditions. ICARDA's genebank, established in 1983, has been playing a critical role as a global resource for genetic materials collected during hundreds of collection missions over the past forty years. The genetic materials collected include unique landraces and wild relatives of cereals, legumes and forages from around the world, including regions where some of the earliest known crop domestication practices were recorded. Since crops in these regions have naturally developed desirable genes from thousands of years of survival, adaptation and evolution, they are a treasured resource for international and national breeding programs seeking to develop improved crop varieties. To date, ICARDA's genebank holds over 135,000 accessions, 65% of which are unique landraces and wild relatives of cereals, legumes and forages (Table 2). The genebank is available as a free public good and is used to conserve and share genetic resources with countries and research partners throughout the world. On an average, ICARDA distributes annually about 25,000 accessions a year to collaborators for this purpose.

While past collection efforts were time-consuming and based largely on trial and error, future collections will be guided by gap analysis, using modern Geo-information Systems-based tools and targeting of valuable traits. The Focuses Identification of Germplasm Strategy or FIGs, developed by ICARDA, the Vavilov Institute of Plant Industry, Russia and the Grains Research and Development Corporation, Australia, is a powerful option to conduct rapid mining of genebanks for useful traits and it is fast becoming an essential aid in breeding improved varieties far more efficiently, saving both time

Table 3. Synthetic wheat lines offer substantial yield advantages under drought conditions. Data from Tel Hadya Research Station, 2008, rainfall 211 mm

Line/parent/variety	Yield t ha ⁻¹	% recurrent parent
Cham 6*2/SW2	1.6	147
Cham 6*2/SW2	1.5	138
Cham-6 (backcross parent)	1.1	100
Attila-7 (check variety)	1.3	-

Source: ICARDA.

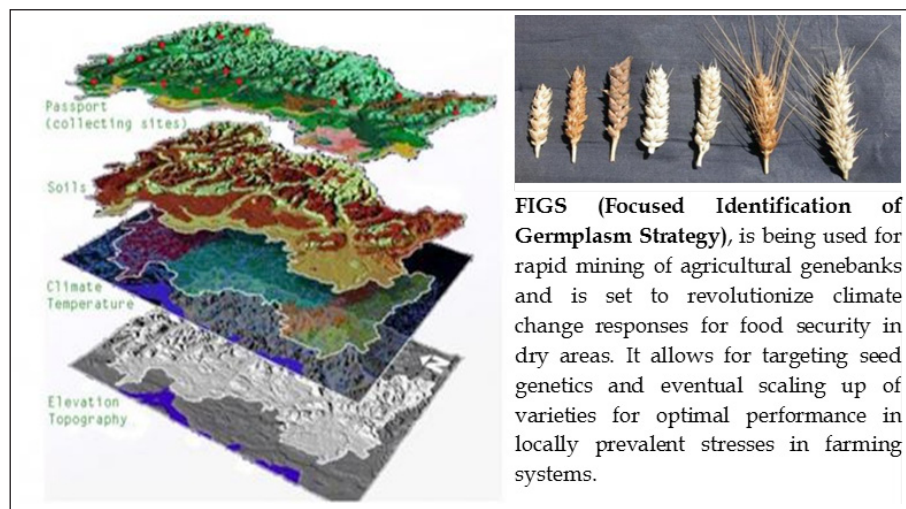


Fig. 6. The Focused Identification of Germplasm Strategy or FIGS Identification of genetic stocks with desirable traits and cross hybridization.

and cost involved with the conventional method of identifying desired genes (Fig. 6). FIGS1 uses a combination of cutting edge mathematics and plant genetics to rapidly identify genetic traits suitable for local farming conditions. As an example of application, synthetic wheat lines were developed based on crosses with wheat's wild relatives, with tolerance to severe drought (Table 3). This approach could hold the key to maintaining yields of the main food staple, despite changes in precipitation and temperature.

Hybridization techniques offer breeders an innovative pathway to develop new varieties

by incorporating desirable attributes of one parent into another. The technique can be leveraged to produce high and stable yields that are also: (1) resistant to major diseases and insects; (2) tolerant to drought, heat and salinity; and (3) contain other useful traits like high micronutrients. This approach is bound to play an increasingly important role in enhancing food security. For example, ICARDA has enjoyed much success in identifying new genetic diversity for wheat through cross hybridization (Fig. 7).

Using wide crosses in the wheat breeding program involving wild relatives (*Triticum*

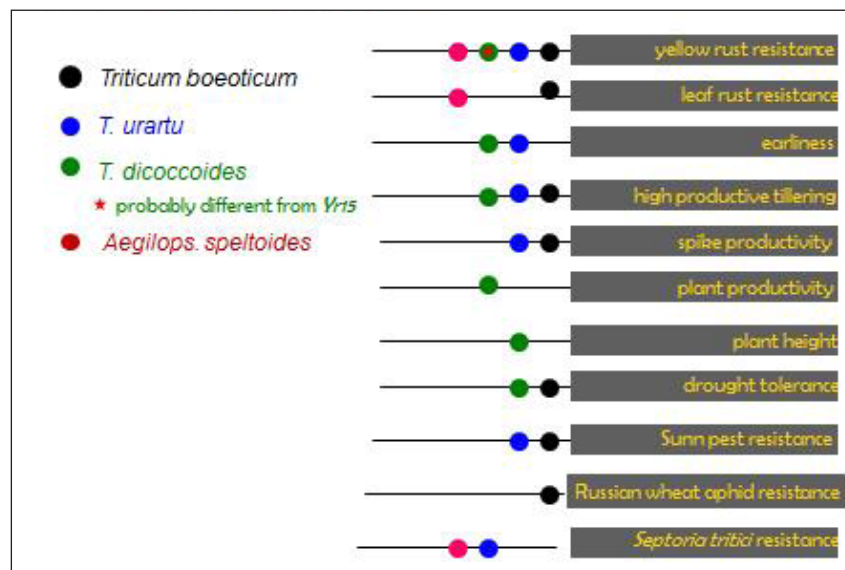


Fig. 7. Desirable traits identified in wheat through crosses with wild relatives.

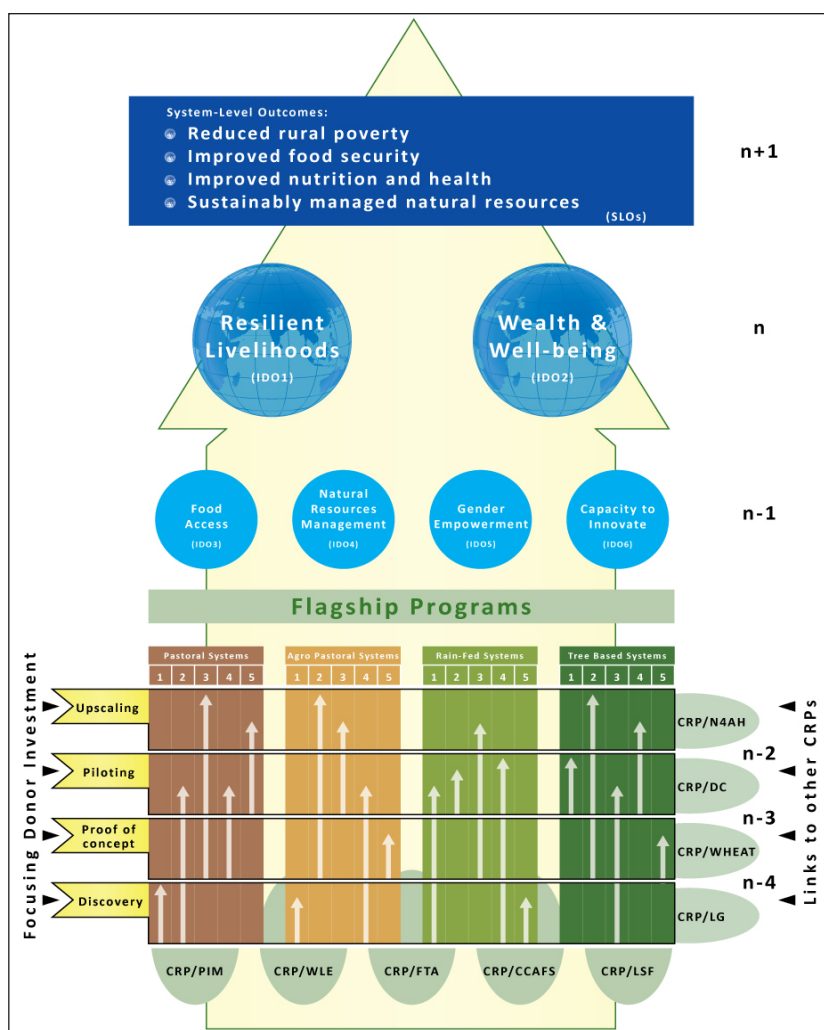


Fig. 8. Conceptualizing the Drylands Systems Approach.

boeoticum, *T. uratu*, *T. dicoccoides* and *Aegilops speltoides*) resulted in identifying desirable traits for high yield potential, such as high productive tillering and productive spikes. These crosses also improved the crop's tolerance to abiotic stresses such as drought, and resistance to biotic stresses such as yellow and leaf rusts, Sunn pest and Russian wheat aphids.

Other recent advances in biotechnology applications are helping to supplement traditional plant breeding methods and improving the effectiveness and efficiency of plant breeding programs. A range of biotechnology tools - genomics, marker-assisted selection (MAS), double haploids, embryo rescue, tissue culture, DNA fingerprinting - are developing improved cultivars or breeding lines which are higher yielding and more resistant

to the pests, diseases and the environmental constraints of the dry areas, namely heat and drought. For example, 600 barley genotypes have been screened, using diagnostic molecular markers, to identify sources of resistance to major barley diseases such as scald, cereal cyst nematode and powdery mildew.

Using both biotechnology and traditional breeding methods, more than 880 crop varieties have been developed from ICARDA germplasm and released to date in partnership with NARS. The new varieties are estimated to generate net benefits worth US \$850 million per year. The new varieties offer a range of valuable traits that are adapted to the environmental conditions in drylands, offering higher and more stable yields, ability to survive harsh conditions, and with climate change adaptation traits such as

tolerance to drought, heat, cold and salinity and resistance/tolerance to biotic stresses such as diseases, insect pests and parasitic weeds.

The Example of Wheat-Legume Cropping Project in North Africa and West Asia: A food security project in North Africa and West Asia supported by EU and IFAD and implemented by ICARDA and its NARS partners brought new wheat and legume varieties which are high-yielding, disease resistant and stress tolerant. These varieties are helping address the gap in food demands of a rapidly growing population. In 2013, around 50 recently released food legume varieties were released through on-farm demonstrations - around 3600 farmers and extension workers were involved. These new varieties were tested in new sustainable management options such as integrated pest management, supplemental irrigation and conservation agriculture. The results were extremely promising: under zero tillage, the improved chickpea varieties in Jordan and Morocco yielded 24% and 25% more than under conventional tillage.

Livestock-based production systems

Small ruminants (sheep and goats) are a key source of livelihood and income in the drylands where rangelands account for the single largest land use. ICARDA's work focuses on integrating crop and livestock production and maximizing crop-livestock synergies to increase the supply of livestock fodder, while maintaining production of food crops. Another key area is conservation, management and genetic utilization of indigenous livestock breeds, which are well adapted to hot, dry conditions.

Research also covers animal nutrition and adding value to livestock products. Fodder production in the region has been significantly improved through the development of improved fodder varieties, introduction of new fodder sources (Atriplex and spineless cactus) into rainfed crop systems, and promotion of low-cost 'feed blocks' made from farm residues and agro-industrial products. The concept of 'strategic feeding' - supplementation at critical periods has been successfully introduced as a solution to the common problem of high feed prices in dry years. In trials, strategic supplementation using balanced but low-cost diets resulted in a net gain of US\$ 18.70 per ewe. In a typical flock

of 50 ewes, farmers using this technology earn an additional US\$ 935. Other related aspects include flock management (practices targeted at market sales), promotion of indigenous fodder species rather than exotics such as alfalfa or Rhodes grass, and rangeland management and rehabilitation through community-led grazing calendars with adequate 'rest' periods for sections of rangeland.

ICARDA also focuses on creating new value chains to diversify and increase incomes for the rural poor, particularly women. One method is the production of dairy and other livestock products for sale. These include yogurt, cheese, mohair, and other indigenous products. Research is complemented by training programs to empower rural women and communities to take advantage of the new technologies. For example, one project, funded by IFAD and implemented by ICARDA scientists, worked with rural women and the local communities of Naryn in Kyrgyzstan to improve incomes through mohair and cashmere processing. Working with 70 women artisans in five pilot villages, the project conducted a value-chain assessment for improving the quality of raw livestock materials to benefit the women who suffer from high levels of poverty and unemployment. Traditional wool products were redesigned to make new products for luxury markets in the West, such as seamless wool slippers, scarves and chair mats. The women found empowerment in the project, earned significantly more income by selling their products and won UNESCO awards in international fairs.

The Systems Approach in the Service of Dryland Farmers

It is clear from past experience that piecemeal, disciplinary research and traditional development efforts are not enough to kick-start agricultural and rural development in rapidly evolving dryland areas at larger scales and deliver new innovations and technologies to farmers. A broader integrated holistic approach is needed. This is why ICARDA has adopted a state-of-the-art 'systems thinking' that takes research-for-development ideas further beyond traditional research approaches. The underlying premise of systems thinking is that successful dryland agricultural systems evolve through an integrated approach that includes the

right mix of innovative partnerships, diverse technologies, and appropriate policies which improve on the effectiveness of project delivery and generates impact at scale.

While the benefits of a systems approach are increasingly acknowledged at the global level, many obstacles remain. One notable hurdle is that project-focused or vertical approaches focusing on a single commodity crop or technology, tend to be favored by many funders, researchers, and development investors.

The systems approach proposes a combination of interventions that can adequately address a country's nutrition and food security needs, and is capable of raising the incomes of small farmers, while ensuring sustainable management of natural resources. These interlocking needs can only be met by approaching the challenges of drylands agricultural systems as a whole - people, crops, livestock, water, land, policy and institutions - instead of targeting narrow objectives such as improving yield per hectare. A systems approach identifies, quantifies, and integrates all of the factors and processes that shape and constrain farming systems. It is a holistic approach to agricultural development which examines every aspect of the climatic, biological, political, social and financial context in which farmers and pastoralists function, identifying an optimum mix of policies, practices, and technologies to ensure sustainable increases in productivity and resilience in smallholder livelihoods.

ICARDA implements a systems approach across all of its research programs to test and deliver validated systems solutions through Dryland Systems, a global research program of CGIAR that it is leading. Dryland Systems engages in integrated agricultural systems research to address key socioeconomic and biophysical constraints that affect food security, equitable and sustainable land and natural resource management and the livelihoods of poor and marginalized dryland communities (Fig. 8). The program uses unique partnership platforms to bind together scientific research results with the skills and capacities of NARS, advanced research institutes (ARIs), non-governmental and civil society organizations, the private sector, and other actors to test

and develop practical innovative solutions for dryland farming communities. To date, the project, which began its full implementation phase in 2013, has developed a clear theory of change and the impact pathways with a strong focus on women and youth. The program is currently testing practices and interventions for improving productivity, building systems stability, diversifying livelihoods for resilience and enhancing value chains in five regions in the world: West African Sahel and Dry Savannas, North Africa and West Asia, East and Southern Africa, the Central Asia and the Caucus and South Asia. The program is working toward delivering integrated solutions targeted to the various 'Agricultural Livelihood Systems' (ALS) prevalent in drylands. The defined ALS units refer to the agricultural context in which farmers work to provide for the sustenance and well-being of their families and include: pastoral systems, agropastoral systems, intensive rainfed systems, irrigated crops systems and tree-based systems. The ALS framework is enabling linking research activities across the program's target regions with similar systems and will facilitate the eventual scaling out of new knowledge, tools, and innovations, thus transforming the potential of dryland areas - the ultimate goal of the initiative.

CGIAR's global research program on Dryland Systems and its other systems research programs are still in early stages of implementation to allow an assessment on the value of systems approach in achieving wide-scale impacts, but a strong monitoring and evaluation process will help inform us of the challenges we face and the successes we achieve. In the meantime, the program's emphasis on participatory research, knowledge synthesis and dissemination is shedding light on the successes and shortfalls in the implementation of the systems approach thus far.

Innovative and Strengthened Partnerships for Greater Impact

ICARDA's experience over the years has shown that effective partnerships are key for enabling impacts from research for development. Partnering with national research and extension systems has, therefore, been a cornerstone of ICARDA's research-for-development initiatives. Additional partners include international

research centers, advanced research institutions, the Global Forum for Agricultural Research and its sub-regional organizations, development agencies, sub-regional organizations, civil society organizations and the private sector. These instrumental partnerships have provided a voice for drylands populations and facilitated ICARDA's work in shaping agendas that are responsive to farmers' needs.

One such successful partnership is the International Wheat Improvement Network (IWIN), an alliance of NARSs, CIMMYT, ICARDA, and other advanced research institutes. The Network is deploying cutting-edge science alongside practical multi-disciplinary applications to develop germplasm that has made major contributions to farmers' lives since the beginning of the Green Revolution. The continuous supply of improved germplasm for nearly half a century has enabled developing countries to have a sustained increase of wheat production and productivity. Wheat production levels have increased from 235 million tons in 1961 to 691 million tons in 2012 globally (CGIAR, 2013). The success of wheat improvement efforts has been remarkable. Today, more than 70% of all spring wheat cultivars grown in developing countries are CIMMYT- and ICARDA-derived, reaching 90% in South Asia, parts of West Asia and North Africa (Byerlee and Moya, 1993; Lantican *et al.*, 2005). The impact of such initiatives has been witnessed by farmers, governments and policy-makers. From the CIMMYT/ICARDA wheat breeding program, it has been reported that more than 1500 wheat varieties have been released during the period 1966-1990 with an average of 65 varieties released annually. Though estimating the economic impact of the CIMMYT/ICARDA international wheat breeding program is very difficult given the diversity of environments and number of countries and research programs involved, Byerlee and Moya (1993), reported that the adoption of improved varieties of spring bread wheat over 1977-90 resulted in about 15.5 million tons of additional wheat production in 1990, valued at about US\$3 billion.

Another example of a successful partnership is ICARDA's collaborative work with Iraqi partners on the USAID-funded project entitled "Harmonized Support for Agricultural Development in Iraq (HSAD)." The objective

of the project was to assist the Ministry of Agriculture in Iraq to identify and address the constraints to the greater competitiveness of selected agricultural/agribusiness value chains and help small farmers generate higher incomes while promoting sustainable management of natural resources. ICARDA scientists worked closely with partners at the national and local levels in Iraq on a number of project components. The first component was to promote integrated pest management on date palm and strengthen the date palm commodity value chain as well as promote date palm tissue culture. The second component was to promote sustainable natural resource management and increase land and water productivity through conservation agriculture and water harvesting. The third component was to improve wheat seed varieties, upgrade seed infrastructure, equipment and expertise and finally to support policy, extension and conduct capacity building activities for farmers and agency specialists. HSAD received full support from both the Iraqi Ministry of Agriculture and the Ministry of Agriculture and Water Resources of the Iraqi Kurdistan Region as well as other related ministries since the inception of the project and helped to mobilize the relevant departments at provincial, regional and district levels to work in the different activities of HSAD, which included farmers. In addition, HSAD received partnership support from the Consortium of U.S. Universities, IFPRI and other international development experts. The results of the project were formidable and largely attributed to strong partnerships that enhanced its achievements. These included:

- An interactive geo-spatial tool to inform food policy-making, using online resources for climatic, biophysical, demographic, governmental, and socioeconomic data
- Modernized national seed systems and extension services through capacity building for the fast-track release and multiplication of improved seed varieties. This led to production of around 5,678 tons of certified commercial wheat seed from five improved wheat varieties, with another 7500 tons on track for 2014. Ministry staff were trained on seed production and certification, and seed labs were upgraded. Guiding seed policy reforms is further ensuring a robust national seed program.

- A strengthened date palm value chain, reviving the Iraqi date palm heritage. HSAD introduced and trained farmers on Integrated Pest Management techniques to enable organic and high quality dates. Capacity was also built in micro-propagation protocol for tissue culture as per international standards so that farmers may obtain large numbers of seedlings in a short time and boost productivity.
- Promotion of conservation agriculture in partnership with the Australian Center for International Agricultural Research, leveraging the innovated, locally manufactured low-cost zero tillage seeders. Extensive training rapidly increased the adoption of conservation agriculture, with about 10% of cereal production area in Kurdistan region of Iraq is targeted for conversion by 2017 - estimated to increase farmer incomes by ~US \$8.8 million per year.

The Way Forward for the Drylands

Many farmers and pastoralists in the drylands are trapped in a perpetual cycle of poverty, poor crop yields, scarcity of natural resources, and a lack of supportive policies and institutions. The rapidly increasing population and a markedly higher vulnerability to climate change than other parts of the world will continue to aggravate the challenges faced by local communities. As a result, investment in science and technology to support agricultural development in dry areas is critical.

Existing science and technology tools and resources offer the capability to increase sustainable agricultural intensification in the drylands. The impacts resulting from ICARDA's research clearly demonstrate the vital role of science and technology in enhancing food security. ICARDA believes that additional large scale impacts can be achieved by increasing investments in innovative and cutting edge research, by adopting a systems approach to increase the efficiency of delivery of options to farmers and create impact at scale and through innovative and strengthened partnerships.

The gains from investing in the drylands have a spillover effect at the global level. Economic, social and environmental sustainability in the drylands implies less debilitating levels

of migration, increased stability, and more security throughout the globe.

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