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Ministry of Agriculture, Forestry and Fisheries
National Council for Sustainable Development
Ministry of Environment

Adaptation Technologies Guide – Agriculture

2019

Adaptation Technologies Guide – Agriculture

June 2019

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FOREWORD

Cambodia has been identified as one of the vulnerable countries to climate change; these changes could have a negative impact on agricultural production and the food supply for the Cambodian people, with a projected population growth from the present 16 million to 30 million by 2050.

Floods, droughts and storms occur regularly in many parts of Cambodia. Consequently, climate risk and long-term climate change has been identified as major issues to be addressed for Cambodia's improved environmental management and development. In the long-term, with further increase in average temperatures and evapotranspiration rates and changes in rainfall patterns, these hazards are likely to increase in frequency and intensity. Seasonal rainfall patterns are likely to change significantly.

The Second National Communication Report (2015) found that under future climate predictions (for years 2025 and 2050), most of Cambodia's agriculture areas will be exposed to higher drought risks. The Length of Growing Period for most agriculture areas will be less than the "normal" five months. While it is projected that average rainfall will increase, periods of annual agricultural drought are expected to lengthen significantly, particularly in the Mekong floodplain in Cambodia (with up to a 30% increase in the number of drought days each year in some provinces by 2050).

Climate change will influence agriculture more than other sectors. Floods and droughts result in long-term effects on the agricultural sector and farmers, while poverty limits the ability of an individual farmer or community to cope with floods and droughts, and adapt to long-term changes. The 2011 floods affected 350,000 households (over 1.5 million people) and 52,000 households were evacuated in 18 provinces. In 2009, typhoon Ketsana affected 180,000 people in 14 provinces. The 2012 droughts affected 14,190 hectare of rice fields and destroyed 3,151 hectares in 11 provinces, and as a consequence food shortage were reported in some provinces (NCDM, 2014).

Despite many studies assessing the impacts of climate change on agriculture, there is not much literature documenting climate-resilient agricultural practices in Cambodia. Therefore, the understanding and documentation of the climate-resilient agricultural practices are crucial to farmers in response to climate change.

The Royal Government of Cambodia (RGC) has been focusing on the enhancement of the development of agricultural sector, as addressed in Government Rectangular Strategy. Agriculture sector has played an important role in reducing poverty and has generated employment for rural people and contributed to national development goals and regional market integration. As the agriculture sector is still one of the most important economic sectors in Cambodia, but in the context of climate change, agricultural development needs to consider the use of appropriate technology to adapt to these changes. Overall, the development and mainstreaming of climate-resilient agricultural technologies remains the key factor to ensuring the sustainable growth of the agricultural sector.

TA 8179-CAM Mainstreaming Climate Resilience into Development Planning (MCRDP) project funded by Asian Development Bank (ADB) and coordinated by Ministry of Environment (MOE) had supported the development of an adaptation technology guide for the agricultural sector to provide information on 34 technologies and options for adapting to climate change in the sector. The guide is aimed at helping policy makers, practitioners, agricultural experts and other stakeholders with the knowledge and application of technologies which have been developed specifically for the agricultural sector. NGOs, rural communities and agricultural practitioners can examine and include appropriate options in their portfolios of technologies and options for agricultural development. The guide is expected to stimulate further identification of options for climate change adaptation in the agricultural sector in Cambodia and other countries located in South East Asia.

Technologies that promote agricultural diversity are likely to strengthen agricultural production in the face of uncertain future climate change scenarios. The technologies presented in this guide are those that can help in conservation and restoration of diverse and improved appropriate agricultural production systems, selected after an assessment of current and possible future impacts of climate change in a particular location. Agro-ecology is an approach that encompasses concepts of sustainable production and better biodiversity promotion and therefore provides a useful framework for identifying and selecting appropriate adaptation technologies for the agriculture sector.

Phnom Penh, 19 . June . , 2019

Minister of Agriculture, Forestry and Fisheries

Veng Sakhon

Phnom Penh, 19 . June . , 2019

Chair of National Council for Sustainable Development and Minister of Environment

Say Samal

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Secretary of State of Ministry of Environment
and SPCR Program Coordinator

H.E. Prof. Dr. SABO Ojano

ACRONYMS

AC	Alternating Current
ACIAR	Cambodia Australia Center for International Agricultural Research
AEZ	Agro-ecological Zone
ARCC	Adaptation and Resilience to Climate Change
AWD	Alternate Wetting and Drying
AWG	Adaptation Working Group
CA	Conservation Agriculture
CAM	Climate change adaptation and mitigation methodology
CARDI	Cambodian Agricultural Research and Development Institute
CBA	Community Based Adaptation
CBDRM	Community-based Disaster Risk Management
CBSS	Community-Based Seed System
CCAP	Climate Change Action Plan (by sector)
CCCA	Cambodia Climate Change Alliance
CCCSP	Cambodia Climate Change Strategic Plan
CCD	Climate Change Department
CDI	Cambodian Development Institute
CEA	Cost-Effectiveness Analysis
CEDAC	Center d'Etude et de Development
CFAP	Cambodian Farmer Association Federation of Agricultural Producers
CSA	Climate-smart agriculture
CSB	Community Seed Bank
CWR	Crop Water Requirement
DANIDA	Danish International Development Agency
DAPH	Department of Animal Production and Health
DC	Direct Current
DI	Deficit Irrigation
DMC	Direct Mulch-seeding Cropping
DTW	Development Technology Workshop
EPM	Ecological Pest Management
EPS	Ensemble Prediction System
EWS	Early Warning System
FAO	Food and Agriculture Organisation of the United Nations
FFS	Farmer Field School
FSI	Farmer System Intensification
FUG	Forest User Groups
FWUC	Farmer Water User Committee
GDA	General Directorate of Agriculture

GHG	Greenhouse Gas
GIS	Geographic Information System
IAEA	International Atomic Energy Agency
ICEM	International Center for Environmental Management
INM	Integrated Nutrient Management
IPM	Integrated Pest Management
IRRI	International Rice Research Institute
LMB	Lower Mekong Basin
MAB	Marker-Assisted Backcrossing
MAFF	Ministry of Agriculture, Forestry and Fisheries
MARS	Marker-Assisted Recurrent Selection
MBRLC	Mindanao Baptist Rural Life Center
MCA	Multi-criteria Analysis
MCRDP	Mainstreaming Climate Resilience into Development Planning
MOE	Ministry of Environment
MOWRAM	Ministry of Water Resources and Meteorology
MPWT	Ministry of Public Works and Transport
MRD	Ministry of Rural Development
NAP	National Adaptation Plan
NAPA	National Adaptation Program of Action
NCDM	National Committee for Disaster Management
NGO	Non-Government Organization
NSDP	National Strategic Development Plan
NTFP	Non-Timber Forest Products
OFAT	On-Farm Adapted Trials
PDA	Project Development Assistance
PIP	Public Investment Program
PPCR	Pilot Program for Climate Resilience
PV	Photovoltaic
PVS	Participatory Varietal Selection
RGC	Royal Government of Cambodia
R&R	Research and Development
RRIC	Rubber Research Institute of Cambodia
RUA	Royal University of Agriculture
SALT	Sloping Agricultural Land Technology
SCCSP	Sectoral Climate Change Strategic Plan
SIP	Seasonal Inter-annual Prediction
SPCR	Strategic Program for Climate Resilience
SRI	System of Rice Intensification
TA	Technical Assistance

UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
VA	Vulnerability Assessment
WMO	World Meteorological Organisation
WUA	Water User Association
WUE	Water Use Efficiency
WUG	Water User Group

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A INTRODUCTION TO THE GUIDE

1. INTRODUCTION

The agriculture sector in Cambodia faces the daunting challenge of providing adequate food and other necessities to a growing population, which is projected to increase to 30 million by 2050 from a present population of 16 million. There is relatively limited scope for expansion of arable land, and the emerging threat to agriculture from climate change in the form of unpredictable weather, floods, and other disastrous events makes the task of providing enough food for the country's population even more challenging. Since the agriculture sector is still one of the most important economic sectors in Cambodia – providing employment and the main source of income to the poor – it is not surprising that there is a heightened interested in technologies for adapting agriculture to climate change.

Technologies and practices do exist, or have been developed in different parts of the world, to facilitate adaptation to climate change in the agriculture sector. Measures range from improved weather forecasting systems to water conservation technologies, drip irrigation, sustainable soil management practices, better livestock management, and changes in crop types and planting, among others. Some of these measures may need investment while other practices primarily require improved awareness and capacity.

1.3 OBJECTIVE OF THE GUIDE

This Adaptation Technologies Guide prepared under the TA 8179-CAM Mainstreaming Climate Resilience into Development Planning (MCRDP) project, provides information on 34 technologies and options for adapting to climate change in the agriculture sector. It describes what policy makers, development planners, agriculture experts and other stakeholders in Cambodia should consider while determining a technology development path in agriculture. NGOs, rural communities and agricultural practitioners could examine and include appropriate options in their portfolios of technologies and options for agriculture. The guide expands on the United Nations Environment Programme (UNEP) work on climate change adaptation in agriculture[1], and is expected to stimulate further work on identifying options for climate change adaptation in the agricultural sector in Cambodia and other South East Asian countries, and as such is considered work in progress. The guide is intended to provide a starting point of ideas and technologies for a more comprehensive compendium on adaptation technologies solely focused on the Cambodian situation.

[1] Clements, R., J. Haggar, A. Quezada, and J. Torres. 2011. Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Risø Center, Roskilde.

Presented in this guide is a selection of technologies for climate change adaptation in the agriculture sector. A set of 34 adaptation technologies is showcased. These are based primarily on the principles of agroecology (ecozones), but also include scientific technologies of climate and biological sciences complemented by important sociological and institutional capacity building processes that are required for climate change adaptation. The technologies cover:

- Planning for climate change and variability
- Sustainable water use and management
- Integrated soil management
- Sustainable crop management
- Sustainable farming and livelihood systems
- Capacity building and stakeholder organisations

Technologies that tend to homogenise the natural environment and agricultural production have low possibilities of success in conditions of environmental stress likely induced by climate change. Conversely, technologies that allow for, and promote diversity are more likely to contribute to a strategy that strengthens agricultural production in the face of uncertain future climate change scenarios. The technologies presented in this guide have been selected because they facilitate the conservation and restoration of diverse and increased agricultural productivity. Many of these technologies are not new to agricultural production practices, but they are implemented based on the assessment of current and possible future impacts of climate change in a particular location. Agroecology is an approach that encompasses concepts of sustainable production and biodiversity promotion and therefore provides a useful framework for identifying and selecting appropriate adaptation technologies for the agriculture sector.

1.4 METHODOLOGY

The guide provides a systematic analysis of the most relevant information available on climate change adaptation technologies in the agriculture sector. It has been compiled based on a literature review of key publications, journal articles, and e-platforms, and by drawing on documented experiences sourced from a range of organisations working on projects and programmes concerned with climate change adaptation technologies in the agriculture sector. Its geographic scope focuses on developing countries, like Cambodia, where high levels of rural poverty, agricultural production, climate variability and biological diversity intersect.

In formulating this Guide, the Food and Agriculture Organisation of the United Nations (FAO) approach to addressing climate resilience in agriculture – **climate-smart agriculture** (CSA) – was utilised. FAO's approach is comprehensively presented in the Climate Smart Agriculture Sourcebook (FAO, 2013). The definition of CSA used by FAO is as follows:

> *Agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances the achievement of national food security and development goals.*

Key arguments for CSA are: (a) agriculture and food systems must undergo significant transformations in order to meet the related challenges of food security and climate change; (b) increasing resource efficiency is essential both to increase and ensure food security in the long-term and to contribute to climate change mitigation; (c) building resilience to every type of risk is essential to be prepared for uncertainty and change; (d) efficiency and resilience have to be considered together, at every scale and from environmental, economic and social perspectives; (e) implementing CSA can be a major driver of a Green Economy and a concrete way to operationalize sustainable development; (f) addressing food security and climate change requires concerted and coordinated involvement and action of all stakeholders on a long-term perspective; and (g) CSA is not a new agricultural system, nor a set of practices; rather, it is a new approach, a way to guide the needed changes of agricultural systems, given the necessity to jointly address food security and climate change.

As a cross-reference and a general starting point for readers of this guide, the box below presents contents of the FAO CSA Sourcebook, which contains comprehensive information on a wide range of issues related to climate change adaptation and mitigation.

Contents of FAO's Climate Smart Agriculture Sourcebook

Section A **"The case for climate-smart agriculture"** consists of two modules establishing a conceptual framework and is targeted to a broad audience. Module 1 explains the rationale for CSA and module 2 focuses on the adoption of a landscape approach.

Section B **"Improved technologies and approaches for sustainable Farm Management"** is divided in nine modules. It is targeted primarily to the needs of planners and practitioners and analyses what issues need to be addressed in the different sectors, in terms of water (Module 3), soils (Module 4), energy (Module 5) and genetic resources (Module 6) for upscaling of practices of crop production (Module 7), livestock (Module 8), forestry (Module 9) and fisheries and aquaculture (Module 10) along sustainable and inclusive food value chains (Module 11).

Section C **"Enabling frameworks"** encompasses seven modules targeted at policy makers. It provides guidance on what institutional (Module 12), policy (Module 13) and finance (Module 14) options are available. It also provides information on links with disaster risk reduction (Module 15) and utilization of safety nets (Module 16), and also illustrates the key role of capacity development (Module 17) and assessments and monitoring (Module 18).

Source: FAO 2013.

The CSA approach forms an integral part of MAFF's policy to address climate change, as documented in its Sector Climate Change Strategic Plan (SCCSP). In support of this policy initiative, TA8179-CAM has prepared this Adaptation Guide as an introduction to concepts and adaptation technologies for the agriculture sector in Cambodia. The guide focuses on the adaptation aspects of CSA, and does not cover mitigation or other sub-sectors which fall under MAFF's mandate (livestock, fisheries and forestry), as these are beyond the scope of current ADB TA agreement for MCRDP.

MAFF is working closely with FAO and the International Atomic Energy Agency (IAEA) in a collaborative research and development program focusing on the use of isotopic techniques to help farmers increase yield and revenue, particularly in regard to developing climate smart adaptation technologies. Key areas where progress is being made are more efficient use of inorganic fertilisers, the introduction of alternative crops, and optimising water use. A summary of the work being undertaken and the key adaptation technology outcomes are presented in Annex 3.

Key concepts around climate change adaptation are not universally agreed on. It is therefore important to understand local contexts – especially social and cultural norms – when working with national and subnational stakeholders to make informed decisions about appropriate technology options. Decision making processes should be participative, facilitated, and consensus-building oriented and should be based on the following key guiding principles: (a) increasing awareness and knowledge, (b) strengthening institutions, (c) protecting natural resources, (d) providing financial assistance, and (e) developing context-specific strategies.

To assist with decision-making, the Community Based Adaptation (CBA) framework is proposed for creating inclusive governance. The CBA framework engages a range of stakeholders directly with local or district government and national coordinating bodies, and facilitates participatory planning, monitoring and implementation of adaptation activities. Seven criteria are suggested for the prioritisation of adaptation technologies: (i) the extent to which the technology maintains or strengthens biological diversity and is environmentally sustainable; (ii) the extent to which the technology facilitates access to information systems and awareness of climate change information; (iii) whether the technology supports water, carbon and nutrient cycles and enables stable and/or increased productivity; (iv) income-generating potential, cost-benefit analysis and contribution to improved equity; (v) respect for cultural diversity and facilitation of inter-cultural exchange; (vi) potential for integration into regional and national policies and up scaling; and (vii) the extent to which the technology builds formal and informal institutions and social networks.

It is important to note that research and development processes play a critical role in the emergence, testing and dissemination of new adaptation technologies. This guide however focuses on existing technologies and is non-exhaustive. As such, some adaptation technologies that are important for certain provinces/ecozones and to certain climate change impacts may not be covered here.

1.5 STRUCTURE OF GUIDE

The guide is divided into five parts. Part A has four sections which include this introduction (Section 1) and three other sections as follows; Section 2 outlines an adaptation technology matrix which shows the possible combinations of technologies across a range of agro-ecologies (ecozones) and for a diversity of agriculture policy development strategies; Section 3 provides background on MAFF policies and strategic plans for climate change; and Section 4 briefly outlines approaches to assessing economic and other benefits of the adaptation options. Part B comprises of six sections which outline the 34 adaptation technologies suitable for the agriculture sector in Cambodia and South-East Asia in fact-sheets. These are grouped into six categories or sub-sections: (i) planning for climate variability and change, (ii) sustainable water use and management, (iii) integrated soil management, (iv) sustainable crop management, (v) sustainable farming and livelihood systems, and (vi) capacity building and stakeholder organisation. This is followed with an analysis of the suitability of the various adaptation technologies as they pertain to the four major ecozones (coast, delta, Tonle Sap, and plateau and mountains) present in Cambodia in Part C. General literature cited in the guide is presented in Part D. Finally, Part E – Annexures, consists of four annexes: Annex 1 presents a table of the agriculture adaptation technologies by ecozone; Annex 2 details the matrix of the multi-criteria analysis (MCA) of the 34 adaptation technologies; Annex 3 outlines the collaborative research and development being undertaken by MAFF and FAO/IAEA to develop adaptation technologies; and Annex 4 presents approaches for assessing costs and benefits of adaptation options.

Information provided for each adaptation technology as separate factsheets, is presented as follows: (1) description and application, which describes the measure, purpose/objectives and what the measure seeks to achieve; (2) strengths, which describes the benefits of the approach/method; (3) limitations, which describes the limitations of the measure; (4) assessment of adaptation options contribution to climate resilience, which draws on information from the MCA covering issues such as cost and economic efficiency, labour requirements, flexibility or scalability, ease of use, relevance, equity, institutional feasibility, environmental impact, health and safety, market orientation, likelihood of acceptance, and climate change adaptation impact; and (5) sources for further information on the measure. Further information is also provided on (a) specific location and context, and (b) who is involved/responsible, more particularly, the organisations and communities involved in a particular adaptation technology.

2. ADAPTATION TECHNOLOGY MATRIX

Adaptation technologies, particularly those focused on agriculture, often work best when combined. To help practitioners begin implementing green-based climate smart options in agriculture, we have provided a matrix to illustrate how different technologies may be combined, and how they interact with complementary techniques. The columns represent two aspects: (i) location in respect to ecozone, and (ii) the development policy needs that may be encountered in a rural context. For each, elements of the appropriate agricultural adaptation technology that could add benefit are indicated. All the development needs listed are covered by one or more adaptation intervention.

ADAPTATION INTERVENTION	ECOZONE: Coast	Delta	Tonle Sap	Plateau & Mountain	DEVELOPMENT POLICY: Food Security	Water Resource Development	Value Chain Development	Input Supply	Productivity	Markets & Post Harvest	Biodiversity & Environmental Protection	Agri-business Development	Poverty Reduction
PLANNING FOR CLIMATE CHANGE AND VARIABILITY													
National CC monitoring system	X	X	X	X	X	X			X	X	X	X	X
Seasonal to inter-annual prediction	X	X	X	X	X	X	X	X	X	X	X	X	X
Decentralised community-run EWS	X	X	X	X	X	X				X	X		
Climate insurance	X	X	X	X	X				X			X	X
SUSTAINABLE WATER USE AND MANAGEMENT													
Sprinkler irrigation		X		X		X			X			X	
Drip irrigation	X	X	X	X		X			X			X	
Solar water pump	X	X	X	X		X			X			X	
Windmill water pump	X	X	X	X		X			X			X	
Rainwater harvesting	X	X	X	X	X	X		X	X			X	X
Crop water requirement planning	X	X	X	X		X			X			X	
Deficit irrigation	X	X	X	X		X							
INTEGRATED SOIL MANAGEMENT													
Sloping agriculture land technology	X			X	X			X	X		X	X	
Slow-forming terraces	X			X					X		X		
Conservation tillage	X	X	X	X	X				X		X		
Integrated nutrient management	X	X	X	X	X				X		X	X	
Compost making	X	X	X	X				X	X				
Soil salinity management	X	X	X						X	X	X		
Vetiver and soil stabilisation grasses				X							X		
Live staking				X							X		

ADAPTATION INTERVENTION	ECOZONE				DEVELOPMENT POLICY								
	Coast	Delta	Tonle Sap	Plateau & Mountain	Food Security	Water Resource Development	Value Chain Development	Input Supply	Productivity	Markets & Post Harvest	Biodiversity & Environmental Protection	Agri-business Development	Poverty Reduction
Mulching	X	X	X	X					X		X		
SUSTAINABLE CROP MANAGEMENT													
Crop diversification and new varieties	X	X	X	X	X	X	X	X	X	X	X	X	X
New varieties from biotechnology		X	X		X						X	X	
Ecological/integrated pest management	X	X	X	X	X	X					X		X
Seed and grain storage	X	X	X	X	X		X	X	X				X
System of rice intensification		X	X				X	X					
Alternate wetting and drying rice irrigation	X	X	X	X			X	X					
SUSTAINABLE FARMING AND LIVELIHOOD SYSTEMS													
Integrated rice-fish systems	X	X	X		X	X	X		X				X
Mixed farming systems	X	X	X	X	X	X			X				X
Agroforestry				X					X		X		
CAPACITY BUILDING AND STAKEHOLDER ORGANISATION													
Community based agricultural extension	X	X	X	X	X				X				X
Farmer field schools	X	X	X	X	X								
Forestry user groups				X							X		
Water user associations	X	X	X		X	X							X
Community based seed systems	X	X	X		X		X	X					

3. CLIMATE CHANGE POLICY AND STRATEGIC PLAN

Cambodian agriculture has played an important role in reducing poverty, generating employment for rural people, and contributing to national development goals and regional market integration. However, this sector is sensitive to on-going climatic changes. Background to the impact and vulnerability of agriculture, livestock, fisheries and forestry to climate change, is presented as a situation analysis in the box below:

Situation analyses of agriculture, livestock, fishery and forestry in Cambodia

Agriculture

- The Cambodian floodplain supports a diverse rice-based farming system, where different cropping patterns depend on the duration of inundation.
- A recent economic analysis suggests that with a 1^{o}C rise in temperature, annual mean crop falls by around ten percent.
- Cambodian agriculture is extremely vulnerable to climate change.
- In wetter areas, potential increases in flooding and longer periods of inundation may result in low-lying areas becoming unviable for rice crops; in turn, this may require transformations of production systems, such as shifting rice cropping into the dry season and relying on irrigation.
- Rubber plantations are severely impacted, with production areas in Western Cambodia shifting due to increased rainfall or prolonged droughts.

Livestock

- Small and medium scale commercial operations are most vulnerable and have limited capacity to adapt.
- The increase in commercial units is associated with an increase in the use of higher performance genetics and higher productivity management practices such as heightened stocking rates. High-performance breeds managed in high-density systems will be negatively affected by expected climate changes.
- Threats that were considered include temperature change, precipitation change, change in soil water availability, and changes in frequency and intensity of drought, flooding, and storms. In the livestock theme report these threats were each considered at provincial level where exposure to specific threats varied considerably.

Forestry

- Forest resources have been seriously degraded.
- The RCG has now set a policy target of maintaining 60 percent forest cover.

- Climate change predictions suggest that forests will be affected by changes in temperature, precipitation and shifts in seasons. Such changes directly affect the existence and vitality of species and ecosystems, and will increase the risks associated with pests.
- Under emission scenarios SRESB1 and SRESA2, up to 2050, most lowland forests will be exposed to a longer dry period, particularly forest areas located in the northeast and southwest. More than 4 million ha of lowland forest, which currently has a water deficit period of between four and six months, will become exposed to a water deficit period of between six and eight months or more. However, by 2080 soil water conditions will be similar to current conditions.

Fisheries

- Capture fisheries in the Lower Mekong Basin (LMB) is buffered against climate change by the exception-ally large aquatic ecosystem biodiversity. As a result, some species will likely benefit from the changing conditions, possibly maintaining the overall fisheries productivity, while other less adaptive species will decline. This is likely to lead to an overall loss in biodiversity.
- The Cambodian fisheries sector is vulnerable to climate change. A recent global study of the vulnerability of national economies to the impact of climate change on fisheries ranks Cambodia as 30th most vulnerable in the world.
- Aquaculture is a long-established activity in parts of the LMB, particularly on the Tonle Sap Great Lake and the Mekong Delta. Aquaculture appears to be more vulnerable to climate change scenarios than capture fisheries, although it tends to have a high adaptive capacity.
- The vulnerability assessments confirm the hypothesis that aquaculture will be more vulnerable to climate change scenarios than capture fisheries.

Cross-cutting

- Climate change impact on agriculture does not fall into one single sub-sector as mentioned above. Impact will cut across sectors and influence all five components including water resources.
- Agriculture (on which 71 percent of men and women in Cambodia are dependent) and natural resources management will be central for (medium-term) adaptation and to reduce vulnerability.
- Any declines in natural productivity would have serious food security implications that could not be offset by other forms of food production.
- The continued degradation of forest and land resources makes the largest contributions to GHG emissions in Cambodia, and forest resources are likely to be further degraded by human activities. The impact of climate change may also contribute to changes in forest types in the future.

Source: MAFF (2016) Cambodia's Climate Change Priorities Action Plan for Agriculture, Forestry and Fisheries 2016-2020

3.1 MANDATE, MISSION AND RESPONSIBILITIES

The MAFF has the mandate to manage, develop, and coordinate the agricultural sector in Cambodia, including agriculture, agro-industry, forestry, fisheries, rubber plantations, and livestock sectors. The main roles/responsibilities of MAFF are:

- Develop and establish policies and plans on agricultural development, land use and land reform.
- Coordinate the monitoring and evaluation of policy implementation, agricultural development activities, changes to natural resources in the agriculture sector, and regulate the exploitation of these national resources.
- Assess, develop and use human resources effectively.
- Conduct research into new cropping techniques and provide technical support to farmers for improving their cropping productivities.
- Provide guidance for better use of agricultural land, soil quality improvement, seed selection, fertilizer and pesticides appropriate to local conditions, increasing yield, and adapting to the local environment.
- Collaborate with national and international organization/NGOs for the development of all sectors of MAFF.
- Enhance and encourage investment and export of agricultural products including food. Assist in establishing market and price policy of agricultural products.
- Control food safety of agricultural products from planting to food processing stages.

3.2 LEGISLATION AND POLICIES

The existing legislation and policies of MAFF that involve climate change include: (a) Climate Change Strategic Plan for Agriculture Sector, (b) Law on Management of Agricultural Fertilizer and Pesticide, (c) Law on Fishery, (d) Law on Forestry, (e) Law on Agricultural Community, (e) Sub-decree on Economic Land Concession, (f) Sub-decree on Social Land Concession, and (g) Sub-decree on Management of Forest Concession. However, there is no specific provision or article for climate change in any of these laws and even when it is related to climate change, it is still only broadly outlined.

3.3 STRATEGIES AND PLANS

Facilitated by Cambodia Climate Change Alliance (CCCA)/Climate Change Department (CCD) in MOE, MAFF developed and put in place five-year Sector Climate Change Strategic Plan (SCCSP) and five-year Climate Change Action Plan (CCAP) for the agricultural sector. The SCCSP and CCAP serve as directive tools and guidance for addressing climate change issues and mainstreaming climate change adaptation and resilience in the agricultural sector. CCAP points out priority actions to be done by MAFF within five years (2016-2020). These priority actions include: (a) strengthening capacity and research in climate change and adaptation, (b) building climate resilience capacity, (c) establishing communication, knowledge and information systems on climate change, (d) promoting agricultural systems and practices that are more adaptive to climate change, and (e) promoting and improving groups vulnerable to climate change adaptation and resilience. However, there are still emerging challenges to make these priority actions applicable. The actions require a large amount of finance and they are not clearly matched to sources of financial support. Capacity and availability of technology to coordinate and implement these priority actions remain a big question.

MAFF's SCCSP goals are as follows:

- To ensure food security and the improvement of farmers' livelihoods through an annual 10% increase in crop production in agro-industry.
- To enhance sustainable development of natural rubber by focusing on climate change adaptation and mitigation measures.
- To increase sustainable livestock production (with 3% per annum) and animal health control, and contribute to a 1% reduction of GHG emission from animal production after 2015.
- To enhance sustainable forest management through forestation and reduce emissions from forest degradation and deforestation in order to obtain carbon credit and, enhance forestry communities by ensuring a zero-deforestation balance by 2020.
- Enhance management, conservation and development of fishery resources in a sustainable manner through strengthening capacity, taking appropriate actions and actively dealing with climate change.

The SCCSP objectives for addressing climate change in agriculture are based on reducing the negative effects of climate change. The SCCSP identifies the following five strategic responses:

1. Building institutional capacity to develop new technologies and practices to adapt to climate change, affecting all sub-sectors
2. Promoting the adoption of these techniques by farmers, foresters and fishers
3. Reducing GHG emissions from forest degradation, animals and crops and encouraging sustainable forest management
4. Adaptation of fisheries through research and management of water resources
5. Capacity building in climate change adaptation for MAFF

In response to the impacts of climate change, the Cambodia's Climate Change Priorities Action Plan for Agriculture, Forestry and Fisheries 2016-2020 (CCPAP) sets out a strategy to reach the Cambodia Climate Change Strategic Plan (CCCSP) goals of the MAFF's policy. The expected main outcomes are as follows:

- Agricultural output increased to 36.80 million tons, a national average rice yield of 3,250 kg by 2018 and the value of agricultural exports increased by 30%.
- Beneficiary income in areas vulnerable to climate change increased with 20%, and employment in agri-business and agro-industrial sector increases by 20%. Also, increase area of cash crops resilient to climate change with 20%.
- Map areas of crop land, forest demarcations for agricultural zoning and multi-development areas established
- Promote 10,000 aquaculturists expected to increase yield from 74,000 tons in 2012 to 171,160 tons by 2018 as model farmers for climate resilient aquaculture.
- Provide agricultural extension services aimed at improving resiliency to climate change to at least 5 million farmers.
- Increase livestock production by 3% per year, and decrease livestock losses due to climate change with 5% annually.
- Distribute at least 50 enhanced rubber clones to planters for planting in any Agro-ecological Zone (AEZ) from 2016-2020.
- Establish three fully operational REDD+ projects to obtain carbon credits, and rehabilitate 10,000 ha of forest to enhance carbon stock and biodiversity.

- Protect approximately 0.78 million ha of healthy mangrove forest and 0.068 million ha flooded forest, and identify and protect more than 300 of fish species and their critical habitats.

3.4 INSTITUTIONAL ARRANGEMENTS

The institutional structure of MAFF is arranged into six main groups of departments, are: (a) general secretariat of the ministry, (b) Forest Administration, (c) Fisheries Administration, (d) General Directorate of Agriculture (GDA), and (e) General Directorate of Rubber, and General Directorate of Animal Health and Production. Under direction of MAFF have Royal University of Agriculture, two National Agricultural School and Cambodian Research and Development Institute.

3.5 PROCEDURES FOR CLIMATE CHANGE

To respond to and address climate change adaptation and mitigation in the agricultural sector, the Technical Working Group on Climate Change (TWG-CC) of the Ministry of Agriculture Forestry and Fisheries (MAFF) had been developed in 2012 which has 18 members. The technical working group members are responsible on climate change (TWG-CC) for MAFF from other institution under MAFF. The TWG-CC works on climate change if it is related to MOE and has a broad scope, but if it is related to a sectoral department or administrations, the concerned member of TWG-CC will take the matter and discuss it directly within a sector. There is an Office of EIA within the Department of Planning and Statistic.

Department of Planning and Statistics is responsible for developing planning for MAFF. First, the department provides technical guidance to different departments and administrations under MAFF on how to develop the panning. Second, each department and administration will develop the plans of action for their department and administration. Third, each department and administration will submit their plans to the Department of Planning and Statistics and they will compile it into a plan for MAFF.

In terms of design standards for climate resilience, MAFF does not have a specific design standard or guideline on this specific area yet. It is presently in the process of developing these standards.

3.6 SKILLS AND OTHER CAPACITIES

MAFF has conducted a survey on climate change capacity needs for agriculture and fishery sectors. Climate change is an emerging issue, and climate change capacity at MAFF is limited. Therefore, MAFF has outlined the significant need for TA 8719 CAM to be properly focused on the type of advice, training and other support necessary to MAFF staff, instead of generic support. Further work in close dialogue with MAFF staff and the TWG-CC is needed to determine what guidance is required.

Under MAFF one university, the Royal University of Agriculture (RUA), and two agricultural schools have undertaken courses on climate change. With support from development partner RUA has implementing climate change project by integration climate change into curriculum development for Agricultural Education institution in Cambodia. At the same time, in the process of ASEAN integration, MAFF is thinking of incorporating curriculums that are relevant for Cambodia. Furthermore, UNDP has worked with MAFF/RUA to incorporate climate change into the RUA's courses, but was reluctant to set up a master's degree course on climate change.

MAFF needs to build infrastructure such as warehouses, storage units and drying facilities. More importantly, MAFF needs to first build climate resilient infrastructure at the community level; second, build capacity of MAFF and in particular the three agricultural universities; and third, the ministry needs assistance to build capacity of CARDI in mainstreaming climate resilience.

3.7 MAINSTREAMING CLIMATE CHANGE

MAFF has covered a broad range of topics regarding climate change, but discussions with regards to what areas within a broad CCPAP the TA 8179 should cover, are important. Though the CCPAP proposes 28 projects, it is important to know in which area the ministry needs support. MAFF has confirmed that MAFF/TWG-CC needs support from the TA 8179 in particular on cross-cutting issues.

Climate smart agriculture is essential, and to achieve that, water is key. If irrigation cannot effectively deliver water to farmers, rice yield will be low. Thus, assistance to local communities to manage water is important. The cross-cutting issues for an area in need of external assistance are: (i) building staff capacity; and (2) up-scaling community resilience.

The preparation of priority actions for CCPAP is one of the starting points to mainstream climate change into formal development planning. It is important that these actions are included in the next, or on-going and rolling plans for ministry Public Investment Programs (PIPs). As an emerging issue, MAFF has not allocated sufficient financial resources from national budgets for climate change.

4. ECONOMIC BENEFITS OF ADAPTATION OPTIONS

Current and projected climate change for Cambodia will exhibit impacts on numerous systems and sectors that are essential for human livelihoods. An increasing number of countries, regions and communities are embarking on adaptation activities. This strengthened demand for adaptation efforts necessitates access to a range of robust and transparent assessment approaches to enable decision makers to efficiently allocate scarce resources (UNFCCC, 2011).

For adaptation to be successful, it should ideally be undertaken within a comprehensive and iterative process of social, institutional and organizational learning and change. Assessing the costs and benefits of adaptation options is an important part of this process, assisting adaptation planners and practitioners to identify the most appropriate interventions for reducing vulnerability, enhancing adaptive capacity and building resilience. This section introduces a range of different assessment approaches and methodologies and provides support to help choose between numerous possible options. The section then goes on to assess the benefits of the 34 adaptation technologies presented in Part B of this guide using multi-criteria analysis (MCA) as one of the approaches.

4.1 ADAPTATION PROCESS AND ROLE OF ASSESSING COSTS AND BENEFITS OF ADAPTATION OPTIONS

Before elaborating on the different assessment approaches, this section provides an overview on the overall adaptation process and the role of assessing the costs and benefits of adaptation options. The adaptation process can be divided into four stages: (i) assessment of impacts, vulnerability and risks; (ii) planning for adaptation; (iii) implementation of adaptation measures; and (iv) monitoring and evaluation of adaptation interventions. The findings from stage (iv) feed back into stage (i), ensuring that adaptation action is iterative and dynamic over time.

At the outset of any adaptation initiative it is important for adaptation planners in MAFF and other ministries to assess the implications of climate change for natural systems (e.g. agricultural productivity, water supply) and human society (e.g. human health, economic activity) to determine whether, and the extent to which, climate change will have an impact, pose a risk or even offer beneficial opportunities. Questions to be addressed during the assessment of risks, impacts and vulnerability include:

- What are the current climate-related hazards and risks? How are they predicted to change over time?

- What are the current and future impacts of these climate-related hazards?
- How vulnerable is the natural or human system currently and what are the main determinants?
- What development trends and socio-economic factors will determine future vulnerability and impacts?

Building upon the assessment of risks, impacts and vulnerability during stage (i), adaptation planners can effectively identify adaptation options in areas and sectors that are the most socio-economically important and/or most vulnerable to climate change during stage (ii). Questions to be addressed during the planning stage include:

- What are the existing strategies for managing climate risks and addressing climate-related hazards (for example, water conservation, integrated coastal zone management, or early warning systems for extreme weather events)?
- Are these viable in the future and can these be built upon, for example, by increasing robustness of infrastructure design of roads and buildings through climate-proofing?
- What other adaptation options can be utilised to reduce impacts and improve resilience, for example, different legislative, regulatory, and juridical instruments (e.g. regulations and standards), financial and market instruments (e.g. licences, user fees or labelling) or education and informational instruments (e.g. public awareness campaigns)?
- What are the costs and the benefits of each adaptation option?
- Which suite of options constitutes a comprehensive adaptation strategy that addresses cross-sectoral linkages and establishes priorities within and across sectors?
- Is the adaptation strategy consistent with national, local or sectoral development objectives?
- What aspects of decision making processes pose barriers or present opportunities for integrating climate change risks and adaptation into national, local or sectoral policies and measures?

Assessing the economic, environmental and social costs and benefits of adaptation plays a critical role in informing the second (planning) stage of the adaptation process. Assessment of costs and benefits informs planners about when and where to act and how to prioritize and allocate scarce financial and technological resources. When undertaking such assessments, planners need to consider the main purpose and core objectives of the adaptation options to be assessed. For example, planners must decide if their objective is to: (a) minimize or avoid all or only part of the expected or observed impacts; (b) return levels of human well-being to pre-climate change levels; or (c) maintain current levels of risk or, as a minimum, reduce them cost-effectively within agreed budgets or pre-defined acceptable levels.

In practice, objectives vary between regions, countries and communities, and trade-offs will need to be made between adopting all possible measures, and living with the risks. In addition, adaptation planners need to identify and agree upon a set of criteria that will be used to assess the identified adaptation options against the agreed objectives.

Possible criteria include:

- Efficiency – are the outputs achieved optimal relative to the resources allocated?
- Effectiveness – will the option meet the objectives?
- Equity – will the option benefit vulnerable groups and communities?
- Urgency – how soon does the option need to be implemented?
- Flexibility – is option flexible, and will it allow for adjustments and incremental implementation and reiteration depending on the level and degree of climate change?
- Robustness – is the option robust under a range of future climate projections?
- Practicality – can the option be implemented on relevant timescales?
- Legitimacy – is the option politically, culturally and socially acceptable?
- Synergy/coherence with other strategic objectives – does the option offer co-benefits (for example, improving agricultural land management practices could lead to reduced erosion or siltation and carbon sequestration).

When current and projected impacts, vulnerability, risks and planned adaptation options have been assessed, targeted adaptation actions can be implemented (stage (iii)). The monitoring and evaluation of adaptation actions can be undertaken throughout the adaptation process, in addition to monitoring and evaluation after adaptation actions have been implemented (stage (iv)). Knowledge and information gained from monitoring and evaluation of adaptation actions is fed back into the adaptation process to ensure that future adaptation efforts are successful.

4.2 APPROACHES FOR ASSESSING COSTS AND BENEFITS OF ADAPTATION OPTIONS

When assessing the costs and benefits of adaptation options, adaptation planners can make use of a range of approaches which have proven to be effective decision support tools in broader development and sectoral planning contexts. This guide focuses on the three most commonly used techniques:

- Cost-Benefit Analysis (CBA)
- Cost-Effectiveness Analysis (CEA)
- Multi-Criteria Analysis (MCA)

The strengths and weaknesses of each approach are discussed. In addition, other approaches, including risk assessment, are explained briefly. Before elaborating on these techniques, a brief overview is given on relevant methodological issues. More detail on these three approaches is provided in Part D - Annexures: Annex 3.

4.3 OVERVIEW OF METHODOLOGICAL ISSUES

Adaptation costs are defined as “the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs,” and defines benefits as “the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures”. To arrive at an estimate of the benefits of adaptation options relative to a baseline scenario, the projected climate change impacts and the costs of the different options must be examined. Adaptation measures will usually not completely negate the negative impacts of climate change, so the cost of residual damage that remains after implementation of the adaptation option must also be considered. After comparing the options, those with the highest estimated net benefits are selected for implementation. The literature on the costs and benefits of adaptation options raises several methodological issues, which can be grouped under the broad themes of uncertainty, valuation and equity, a brief description of which is presented in the box below:

Brief description of broad themes – uncertainty, valuation and equity

Uncertainty

Uncertainty surrounding future climate change impacts and future socio-economic development constrains the identification of optimal adaptation options. Even under a specific scenario of future emissions, the range of possible impacts is large. It is important to note though that uncertainties will decline over time as more climatic and socio-economic data becomes available. Adaptation measures should therefore be designed in a flexible manner so that adaptation options can be adjusted or reversed as new information becomes available. This is particularly important for adaptation options that have long-term implications, or for measures that will have a long-life span, such as infrastructure.

Valuation

Assessing the costs and benefits of adaptation options can be undertaken narrowly through ***financial assessments*** or more comprehensively through ***economic assessments***. Financial assessments are usually undertaken within the budgetary framework of the adaptation option under consideration and consider financial costs and benefits only. In contrast, economic assessments consider the wider costs and benefits to the national economy. In addition, social and environmental costs and benefits may also be assessed (e.g. impacts on availability of jobs, institutional capacity or ecosystem services). When assessing the costs and benefits of adaptation options, it is important to not only consider market costs and benefits, i.e. costs and benefits that can be easily quantified in monetary terms because they can be traded in markets (e.g. agriculture, fisheries and forestry), but also non-market costs and benefits, i.e. those costs and benefits that are difficult to quantify in monetary terms because they are not traded on markets (e.g. human health and ecosystem services). Other aspects to be considered are the importance of a baseline, the question of discount rates and time-horizon for the evaluation. Refer to Annex 3 for more detail on these important aspects.

Equity

Climate change impacts disproportionately affect vulnerable populations, many of whom are poor. It is therefore important for adaptation planners not only to consider net benefits but also to consider the distribution of the costs and benefits of adaptation options. The distributional aspect of net benefits can be addressed in a number of ways. One is to give weights to different costs and benefits according to who receives the benefits and who bears the cost, for example doubling the benefits for poor people, and halving that for the rich. The difficulty with applying weights is that, in practice, there is a subjective aspect to choosing where the thresholds should lie and what the weighting coefficients should be. An alternative and more popular approach is to present the distributional impacts of adaptation options alongside the aggregate costs and benefits and let the decision be taken by the policymakers.

Source: UNFCCC (2011)

4.4 CHOOSING AN APPROACH TO ASSESS THE COSTS AND BENEFITS OF ADAPTATION OPTIONS

Once adaptation planners have identified possible adaptation options, have agreed upon decision criteria, and have considered the different methodological aspects, they can then choose between a number of approaches to assess the costs and benefits of each option. A comparison of the assessment approaches is presented in the table below with more detail provided in Annex 3.

Approach	Description/ outputs	Strengths/ weaknesses	Criteria for choosing options
Cost-benefit analysis	CBA assesses benefits and costs of adaptation options in monetary terms. Outputs include net present values, internal rates of return or cost-benefit ratios. Most appropriate when looking at actions that have monetary benefits to people, or that affect market activity. Can be used to assess non-marketed economic benefits such as environmental impacts.	**Strengths:** CBA can provide concrete quantitative justification for adaptation options rather than just relative information. It allows for a comparison between different aspects using a common metric (e.g. USD). **Weaknesses:** CBA focuses on efficiency, when other criteria may be important (e.g. uncertainty or equity). It has difficulties with non-monetised costs and benefits and may need a subjective input into the choice of discount rate.	Benefits exceed costs (if only one action is being considered). Ratio of total benefits to total cost greater than 1 or highest in a list of actions ranked by benefit-cost ratio (when several actions are being compared). The rate of return on investment in the action exceeds the cost of borrowing the capital, or average market interest rates.
Cost-effectiveness analysis	CEA identifies the least-cost option of reaching an identified target/risk reduction level or the most effective option within available resources. Can be used to assess issues for which benefits can be quantified but expressing them in monetary terms is not appropriate or	**Strengths:** CEA can assess options, using units other than monetary units, thus it is good for effects that are difficult to value. It can be applied within the context of routine risks (e.g. health effects) as well as major climate risks. **Weaknesses:** CEA is unable to offer an absolute analysis or common metrics. It	Choose the action that achieves the most of the desired outcome per dollar of cost.

Approach	Description/ outputs	Strengths/ weaknesses	Criteria for choosing options
	possible.	deals insufficiently with uncertainty or equity. The selection of thresholds or target risk levels is not always easy or objective.	
Multi-criteria analysis	MCA assesses adaptation options against a number of criteria, which can be weighted, to arrive at an overall score. Can be used for any issue for which stakeholders can identify issues and qualitatively score the performance of the proposed action with respect to that issue.	**Strengths:** MCA can consider monetised and non-monetised costs and benefits together. It also allows for considering a wide range of criteria including equity. **Weaknesses:** Scoring and ranking of options in MCA is subjective and not easily comparable.	Sum or average the scores of each action along each criterion; select the action(s) with the highest scores.
Risk assessment	Risk assessment analyses current and future risks and identifies options to address the greatest threats.	**Strengths:** Risk assessments can address issues surrounding uncertainty and allow for mainstreaming of adaptation. **Weaknesses:** Risk assessments require sufficient data and valid assumptions about the likelihood of various events occurring.	Selection of option with least risk usually using a scoring system

Source: Adapted from UNFCCC (2011).

4.5 MULTI-CRITERIA ANALYSIS OF AGRICULTURE ADAPTATION TECHNOLOGIES

The ranking of the climate change adaptation best practices, as presented in Part B of this guide (consisting of seven technology categories and 34 adaptation interventions) included the following selection criteria: cost, economic efficiency, labour investment, flexibility/scalability, reliance on technical support, relevance, equity, institutional feasibility, environmental impact and health and safety, market orientation, likelihood of community acceptance, and impact on climate change adaptation. The methodology used here has been adapted from SNV (2013) Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia.

Criteria were weighted by percentage (with a combined weighting of 100 percent) according to their relative importance. Each adaptation technology was then assessed and assigned a score of one to five for each criterion. The vertical sum of these yields a score for each adaptation technology, adjusted to give a maximum score of five. The final priority was determined based on the ranking obtained, so that the adaptation technology with the highest score has the highest potential for climate change adaptation. The overall ranking score is presented in the table below:

Ranking category	Overall score	Colour code
Very high	>3.5	
High	>3.0 - <3.5	
Medium	>2.5 - <3.0	
Low	<2.5	

A final summary of the MCA ranking and scoring of climate change agriculture adaptation technologies is presented in the table below. For a complete overview of the MCA scoring and ranking of each adaptation option, refer to Annex 2: Tables 1a to 1d.

Ranking	Agriculture adaptation technology	Score	Colour code
1	Drip irrigation	3.93	
2	Crop diversification & rotations	3.92	
3	New varieties	3.90	
4	Seed and grain storage	3.76	
5	Sprinkler irrigation	3.73	

Ranking	Agriculture adaptation technology	Score	Colour code
6	Decentralized community EWS	3.64	
7	Canal & pumping intervention	3.62	
8	Mixed farming systems	3.58	
9	Seasonal to inter-annual prediction	3.57	
10	Forestry user groups	3.56	
11	Ecological/integrated pest management	3.48	
12	Integrated nutrient management	3.43	
13	Climate insurance	3.39	
14	Crop water requirement planning	3.36	
15	Community based agricultural extension	3.33	
16	Mulching	3.31	
17	National CC monitoring system	3.22	
18	Integrated rice-fish systems	3.22	
19	Community based seed systems	3.28	
20	Water user associations	3.14	
21	System of rice intensification	3.07	
22	Alternative wetting and drying rice irrigation	3.07	
23	Rainwater harvesting	3.01	
24	Deficit irrigation	2.97	
25	Conservation tillage	2.94	
26	Farmers field schools	2.88	
27	Solar water pump	2.84	
28	Agroforestry	2.82	
29	Sloping agriculture land technology	2.70	
30	Slow forming terraces	2.70	
31	Soil salinity management	2.57	
32	Vetiver and soil stabilisation grasses	2.53	
33	Live staking	2.53	
34	Windmill water pump	2.34	

Source: MCRDP team (2016).

For a detailed explanation on the MCA scores for the various adaptation options, reference should be made to each factsheet in Part B of this guide under sub-section “Assessment of Adaptation Option”.

It is important to note that while this guide has assessed each adaptation option in isolation, the highest impact in climate change adaptation would come from designing projects that allow farmers to mix and combine different strategies and available technology, depending on their location and situation, and even stage of season. For instance, farmers with access to water sources from restored canals can maximise their resilience to climate change by also having access to knowledge on how to manage crops in different environmental conditions; farmers using the System of Rice Intensification (SRI) to grow rice, can increase resilience by having access to sources of water during the dry season, through a pond, a water pump or a drip irrigation system to be able to grow vegetables which would allow them to diversify their sources of income; shifting from one rice crop to two, spreads risk of losing the main crop to drought or flood; incorporating more cash crops, as the returns per unit area and time are greater. For this to happen, close collaboration between projects is required so that knowledge can be shared and implementation coordinated.

B ADAPTATION TECHNOLOGIES

5. PLANNING FOR CLIMATE CHANGE AND VARIABILITY

A key topic in the fight to ameliorate the damaging impacts of climate change is the ability of the stakeholders involved in the agricultural sector to be able to plan for these events and take necessary action to cope with climate variability. In this section four adaptation interventions are outlined: (a) national climate change monitoring system, (b) seasonal to inter-annual prediction, (c) decentralized community-run early warning systems, and (d) climate insurance.

5.1 NATIONAL CLIMATE CHANGE MONITORING SYSTEM

Application: Large-scale government and provincial planning

Description: To clearly explain the uncertainty involved in estimating future impacts it is critical to provide access to information about expected climate changes. Monitoring climate change, forecasting impacts and using early warning systems to disseminate data to a range of stakeholders from the national to the local level are all vital components to successful long-term adaptation planning and implementation. Information about climate change should also be spread in ways that will reach everyone affected in a format they can understand. Expanding networks of skilled professionals who can undertake local, regional and national research into climate change and its likely future impacts on agriculture is essential.

A climate change monitoring system integrates satellite observations, ground-based data and forecast models to monitor and forecast changes in the weather and climate. A historical record of spot measurements is built up over time, which provides the data to enable statistical analysis and the identification of mean values, trends and variations. The better the information available, the more climates can be understood and the more accurately future conditions can be assessed, at the local, regional, national and global level. This has become particularly important in the context of climate change, as climate variability increases and historical patterns shift.

National meteorological centers and other specialised bodies usually carry out systematic observation of the climate system. They take measurements and make observations at standard pre-set times and places, monitoring atmosphere, ocean and terrestrial systems.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) low relative cost to farmers; (b) low labour requirement; (c) high potential for scalability; (d) high degree of equity among communities; (e) being institutionally feasible; and (f) low negative impact on environment, health and safety. It is considered to only have a moderate impact on climate change adaptation because of its institutional focus and costs related to implementing this technology on a country-wide basis. Overall, the option is considered to have a high relative score within the MCA.

Strengths

There are many advantages of having a comprehensive and reliable national climate monitoring system. On a national level, accurate weather forecasting is invaluable for many sectors, particularly agriculture. In developing countries, where the main economic activity of the majority of the population is linked to agriculture, predictions about what environmental conditions can be expected during the year can have a huge impact on people's livelihoods and the national food supply. Decisions about what crops to plant, when to plant and when to harvest are crucial and the more accurately weather can be forecasted is a key tool in facilitating these important decisions.

Limitations

Since national monitoring systems all form part of a global network, it is vital that there is as much consistency as possible in the way measurements and observations are made. This includes accuracy, the variables measured and the units they are measured in. The World Meteorological Organisation (WMO) performs a vital role in this respect.

The main disadvantage of a national climate monitoring system is the cost; not just the capital required to purchase, install and/or operate all the necessary equipment, but also the ongoing costs of maintaining the equipment and ensuring accurate collecting of data, building and maintaining databases, making sure that that data is correctly interpreted and, ultimately, ensuring that relevant information is communicated to the appropriate people in a timely fashion. The quality of the information produced by a climate monitoring system is only as good as the quality of the data collected. Inaccurate data resulting from malfunctioning equipment, or gaps in coverage caused by lack of equipment, distort results and can lead to erroneous forecasting.

Sources

Alvarez, G. S. and L. T. Vilca. 2008. Ancestral Bio-Indicators in Andean Highland Regions: Disaster Warning and Resilience Mechanisms, Mountain Forum Bulletin Vol 8 (2) July 2008

Clements, R., J. Haggar, A. Quezada, and J. Torres. 2011. Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Risø Center, Roskilde.

FAO website www.fao.org/nr/climpag

Guralnick, J. 2002. Biological Indicators as Early Warning of ESNO Events. Regional Disaster Information Center (CRID).

Kuika, O., F. Reynèsa, F. Delobelb, and M. Bernardib. 2011. FAO-MOSAICC: The FAO Modelling System for Agricultural Impacts of Climate Change to Support Decision-making in Adaptation, Food and Agriculture Organization of the United Nations, Rome, Italy14-Apr-11, available at:

https://www.gtap.agecon.purdue.edu/resources/download/5306.pdf

Zullo Jr, J., H. Silveira Pinto and D. Assad. 2006. Impact assessment study of climate change on agricultural zoning. Meteorological Applications, Supplement: Weather, Climate and Farmers, Volume 13, Issue S1, pages 69–80, December 2006.

5.2 SEASONAL TO INTER-ANNUAL PREDICATION

Application: Large-scale government and provincial planning

Description: This technology allows for a forecast of Cambodian weather conditions for a period of three to six months in advance. Seasonal forecasts are based on existing climate data; in particular, on sea surface temperatures, which are then used in ocean-atmosphere dynamic models, coupled with the synthesis of physically plausible national and international models. Seasonal forecasts can be developed using mathematical models of the climate system.

According to the WMO definitions, Seasonal to Inter-annual Prediction (SIP) ranges from 30 days up to two years: monthly outlook, three-month outlook (description of averaged weather parameters expressed as a departure from climate values for that 90-day period) and seasonal outlook. Modern and science-based systems facilitate seasonal forecasting. Predicting climate seasonal anomalies requires the use of complex coupled atmosphere-ocean models. It is believed that ocean variability is an important factor influencing climate variations and changes due to the ocean's larger capacity to absorb from and release heat back into the atmosphere. A considerable effort has been made to improve the understanding of the phenomena responsible for seasonal variability and most of the major meteorological institutions around the world have developed Ensemble Prediction Systems (EPS) for operational seasonal forecasting based on coupled atmosphere-ocean general circulation models. Climate change is challenging traditional knowledge about seasonal forecasting and farmers can no longer predict climate using natural indicators.

Strengths

Although knowledge and understanding of the socio-economic circumstances in Cambodian agriculture is important and must be taken into account, it has been demonstrated how knowledge of climatic variability can lead to better decisions in agriculture, regardless of geographical location and socio-economic conditions. Within agricultural systems, this technology can increase preparedness and lead to better social, economic and environmental outcomes. It helps decision making, from tactical crop management options and commodity marketing to policy decisions about future land use. Based on a range of temporal and spatial scales, the types of agricultural decisions that could benefit from targeted climate forecasts are listed below.

Example of decision types	Frequency (years)
Logistics (e.g., scheduling of planting/harvest operations)	Intra-seasonal (<0.2)
Tactical crop management (e.g., fertiliser/pesticide use)	Intra-seasonal (0.2–0.5)
Crop type (e.g., wheat or chickpeas) or herd management	Seasonal (0.5–1.0)
Crop sequence (e.g., long or short fallows) or stocking rates	Inter-annual (0.5–2.0)
Crop rotations (e.g., winter or summer crops)	Annual/bi-annual (1–2)
Crop industry (e.g., grain or cotton; native or improved pastures)	Decadal (~10)
Agriculture industry (e.g., crops or pastures)	Inter-decadal (10–20)
Land use (e.g., agriculture or natural systems)	Multi-decadal (>20)
Land use and adaptation of current systems	Climate change

Limitations

To implement this technology, it is necessary to establish a meteorological service with skilled, trained and experienced personnel. This implies high costs if a country or region is starting from scratch, although these costs could be substantially reduced by using offices in public buildings and by partnering with scientific institutes and Global Producing Centers.

Contribution to climate resilience: The key benefits from this adaptation option are as follows:

- Low relative cost to farmers;
- Low labour requirement;
- High potential for scalability;
- High degree of equity among communities;
- Being institutionally feasible and
- Low negative impact on environment, and health and safety.

It is considered to have a moderately high impact on climate change adaptation because of its institutional focus and costs related to implementing this technology on a country-wide basis. Overall the option is considered to have a very high relative score within the MCA.

Sources

Alexandrov, V. 2006. Using Better Climate Prediction in the Implementation of National Action Programmes (NAPs) – (Eastern) Europe, Environmental Science and Engineering, pp 537-551.

Arribas, A., M. Glover, A. Maidens, K. A. Peterson, M. Gordon and C. MacLachlan. 2009. Towards a new generation of seasonal forecasting systems. Física de la Tierra, 21, 219-224, UK.

Meinke, H. and R. C. Stone. 2005. Seasonal and Inter-Annual Climate Forecasting: The New Tool for Increasing Preparedness to Climate Variability and Change in Agricultural Planning and Operations. Climatic Change (2005) 70: 221–253, Springer.

WMO (World Meteorological Organisation). 2010. www.wmo.int

5.3 DECENTRALISED COMMUNITY-RUN EARLY WARNING SYSTEM

Application: Medium and small scale – community based

Description: An Early Warning System (EWS) is a set of coordinated procedures through which information on foreseeable hazards is collected and processed to warn of the possible occurrence of a natural phenomenon that could cause disasters. These systems are acquiring more importance in view of increased climate variability and the ability to implement them has become fundamental for improving capacity to adapt to climate change. There are two types of EWS:

- **Centralised systems** implemented by national government bodies that are responsible for implementing hazard warning and response activities often using quite complex systems.
- **Decentralised community systems,** usually operated by a network of volunteers employing simple equipment to monitor meteorological conditions and operate radio communication networks.

Operators of decentralized community meteorological stations report the information to a local forecasting center where the data is analyzed and then communicated back to the community network. The demand for community-led systems is increasing due to lower operational costs and the need for local forecasting and monitoring of climate variability and potential disasters.

The following are the main implementation stages of a decentralized community system:

- Establishing an organising committee (leaders of the community and civil society, NGOs, representatives of local authorities and the private sector);
- Creating and analysing information: building and installing measuring instruments, carrying out forecasts;
- Producing a participatory emergency and contingency plan; and
- Implementing a communication system: early warnings, dissemination of prevention, mitigation and adaptation measures.

Increased frequency and intensity of extreme weather events, prolonged drought and processes of desertification, longer periods of heavy rainfall and increased risk of flooding are just some of the impacts of climate change affecting the world's poorest populations. EWS technology designed as a climate change adaptation strategy must therefore be capable of forecasting a number of climatic events that correspond to different time scales:

- Three to four months of advance warning of a drought;
- Two to three weeks of advance warning of freezing weather conditions and monsoons; and
- A few hours of advance warning of torrential rain, hail and floods.

This technology contributes to the climate change adaptation and risk reduction process by improving the capacity of communities to forecast, prepare for and respond to extreme weather events and thereby minimize damage to infrastructure and social and economic impacts, such as loss of livelihoods. The technology is reliant on working closely with MOWRAM, with the latter providing the necessary meteorological data management.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) fairly low relative cost to farmers, (b) low labour requirement, (c) high potential for scalability, (d) high relevance at community level, (e) high degree of equity among communities, (f) being institutionally feasible, and (g) low negative impact on environment, health and safety. It is considered to have a moderately high impact on climate change adaptation because of its community based institutional focus. Overall the option is considered to have a very high relative score within the MCA.

Strengths: Development benefits and other co-benefits provided by this technology include:

- Introduction of hazard-related and disaster management concepts into community-level planning processes;
- Exchange of information of a social or legal nature, in addition to climatic information, through the established of communication networks;
- Facilitation of decision-making in political organisations; and
- Creation and improvement of a structure that incorporates different stakeholders involved in drawing up specific action plans.

Limitations

The majority of EWSs were established to prevent or reduce the impacts of climate-related disasters (such as floods and hurricanes). By comparison, the capability of these systems to forecast droughts, extreme colds and Indian summers has been less effective. Droughts are particularly distinguishable from other extreme weather events in that they begin slowly and gradually and are less 'obvious' at the outset. In addition, drought can last extended periods of time and affect extensive areas. Given these complexities, EWS systems should be complemented with historical data on droughts, along with available climatological, hydrological, physical, biological and socioeconomic statistics.

Only by combining this data can the complex cause of droughts be better understood and different scenarios modeled with the aim of developing prognoses (such as the probable start date of the rainy season or possible variations in rainy and dry seasons) to be disseminated via appropriate communication channels.

Sources

IPCC WGII. 2007. Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the IPCC on Climate Change. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds.) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Red Cross. 2010. West and Central Africa: Early Warning/Early Action, Operations Update No.2.

5.4 CROP INSURANCE

Application: Large-scale government and small-scale farmers and farmer groups

Description: Crop losses in years of extreme climatic events can cause extreme hardship on farmers. It can force them into debt, leading them to sell their assets, even their land, and prevent them from being able to invest in the following year's production. These events are considered to be a considerable cause of why resource poor farmers are unable to accumulate sufficient goods and capital to rise out of poverty. It is expected that extreme climatic events, and their impacts on the livelihoods of farmers, are likely to become more frequent with climate change. Almost all farmers have traditional coping mechanisms for surviving periods of drought, such as selling livestock and temporary migration to sell their labour. However, these mechanisms may not be able buffer the impacts of extreme events, or droughts lasting more than one season. Therefore, it is critical to find financial mechanisms, such as climate insurance, to support farmers in years of financial loss due to climatic events. Also, if such losses become more frequent farmers will be less willing to take out credit, and lenders may be less willing to lend (or increase the costs of lending) due to the higher risks involved. If farmers do not have access to credit, then this severely limits their capacity to invest in improving productivity and profitability of the agricultural livelihood.

Climate insurance against crop loss is common in agriculture in developed countries where farmers insure against crop losses due to extreme climatic events such as flooding or drought. Typically, payments are made on the basis of the crop loss from on-farm inspections. However, the on-farm inspections can be expensive and potentially subjective. The table below gives a summary of different kinds of agricultural climate insurance schemes. Index-based climate insurance uses models of how climate extremes affect crop production, to determine certain climate triggers that cause substantial crop loss if surpassed, to support a compensation payment. This has the advantage of being totally objective and not requiring onsite inspection.

Insurance product	Basis	Applicability	Successful examples
Multiple Risk Climate Insurance	Insurance against yield loss below 50-70% of expected yield due to any cause	Example: hail insurance that causes a specific catastrophic loss that can immediately be identified in the field	All continents, especially USA and Canada
Area/Yield Index Insurance	Insured against yield loss below a certain % across a district. Yield changes verified independently on a sample of farms across the district	Suitable for losses from drought, lower costs as not verified on each farm, but assumes same average effect across all farms in a district	Brazil, India, USA
Climate Weighted Index Insurance	Insurance based on certain climatic conditions being met. If met certain loss of production assumed and compensated for	Allows large number of smallholdings to be aggregated in a uniform area. Low cost as no verification, but high cost of development of models, and meteorological monitoring	India, Malawi, Mexico, Canada, USA
Normalised Difference Vegetation Index	Based on satellite monitoring of vegetation development	Mainly applicable to grazing lands	Mexico, Spain, Canada
Livestock Mortality Index	Based on independent estimates of livestock mortality rates	Managed communally or through NGOs	Mongolia
Flood Insurance	Traditionally based on individual verification of areas flooded and damage incurred. Exploring index based systems based on satellite monitoring of area and number of days flooded versus crop losses	Requires prior registration of areas under different land uses by farmers. Risk levels vary considerably over small geographic distances	Index based insurance under investigation in South East Asia

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high potential for scalability, (b) high relevance at community level, (c) high degree of equity among communities, (d) being institutionally feasible, (e) low negative impact on environment, and health and safety, and (f) high likelihood of acceptance. It is considered to have a moderate impact on climate change adaptation because of its community based focus tempered by an as yet unproven working model in Cambodia, and relatively high cost for the farmers. Overall the option is considered to have a high relative score within the MCA.

Strengths

The insurance costs are reduced as no in-situ verifications are made of actual losses. This makes it viable to provide coverage to a large number of small-scale producers for whom it would be unviable to provide standard insurance. The insurance is most easily administered as part of other financial services to farmers, principally credit, and the insurance can be against not being able to pay back the credit in event of losses due to extreme climatic events. This would reduce the risk of farmers losing their land or other assets due to climatic extremes.

Limitations

Index based insurance requires significant capacity for analysis of weather related risk to design the index, good historical weather records, and extensive network of weather stations for monitoring current climate. Another disadvantage is that as payments are connected to the climate surpassing a certain trigger, if crop losses occur without passing this trigger then no payment will be made. Or conversely, if the trigger is passed, payment will be received even if no losses have occurred. This is a cost of not having any in situ inspection. However, it runs the risk of farmers' expectations of compensation not being met, and doubting the value of the insurance.

Sources

Agroasemex. 2006. The Mexican Experience in the Development and Operation of Parametric Insurances Applied to Agriculture, Working Paper, August 2006. Available online at: http://www.agroasemex.gob.mx/media/publicaciones/agricola_in.pdf

Ibarra, H. and O. Mahul. 2004. Self-Insurance funds as agriculture insurance providers: the case of Fondos in Mexico. World Bank mimeo

Mahul, O., and J. R. Skees. 2007. "Managing Agricultural Risk at the Country Level: The Case of Index-based Livestock Insurance in Mongolia." Policy Research Working Paper WPS 4325, the World Bank, Washington, DC

Patt, A., P. Suarez, and U. Hess. 2010. How do small-holder farmers understand insurance, and how much do they want it? Evidence from Africa, Global Environmental Change 20: 153-161

Skees J. 2010. State of Knowledge Report — Data Requirements for the Design of Weather Index Insurance. GlobalAgRisk, Inc. Report to Bill and Melinda Gates Foundation.

6. SUSTAINABLE WATER USE AND MANAGEMENT

Enhancing water availability through adaptation technologies for sustainable water use and management is a key strategy for increasing agricultural productivity and securing food security in Cambodian farming systems. This section deals with a range of adaptation technologies: (a) sprinkler irrigation, (b) drip irrigation, (c) solar water pumps, (d) rainwater harvesting, (e) crop water requirement planning, and (f) deficit irrigation.

6.1 SPRINKLER IRRIGATION

Application: Government extension staff, private sector, small-scale farmers and farmer groups

Description: Systems of pressurized irrigation, sprinkler or drip, can improve water efficiency and contribute substantially to improved food production. Sprinkler irrigation is a type of pressurized irrigation that consists of applying water to the soil surface using mechanical and hydraulic devices that simulate natural rainfall. These devices replenish the water consumed by crops or provide water required for softening the soil to make it workable for agricultural activities. The goal of irrigation is to supply each plant with just the right amount of water it needs. Sprinkler irrigation is a method by which water is distributed from overhead by high-pressure sprinklers, sprays or guns mounted on risers or moving platforms. Today a variety of sprinkler systems ranging from simple hand-moved to large self-propelled systems are used worldwide.

Sprinkler irrigation technology can support farmers to adapt to climate change by making more efficient use of their water supply. This is particularly appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. The sprinkler technology uses less water than irrigation by gravity, and provides a more even application of water to the cultivated plot.

A sprinkler irrigation system typically consists of:

- A pump unit that takes water from the source and provides pressure for delivery into the pipe system. The pump must be set to supply water at an adequate pressure so that the water is applied at rate and volume adequate to the crop and soil types.
- Main pipes and secondary pipes which deliver water from the pump to the laterals. In some case these pipelines are permanently installed on the soil surface or buried below ground. In other cases, they are temporary, and can be moved from field to field. The main pipe materials used include asbestos cement, plastic or aluminium alloy.
- Laterals that deliver water from the pipes to the sprinklers. They can be permanent but more often they are portable and made of aluminium alloy or plastic so that they can be moved easily.
- Sprinklers or water-emitting devices which convert the water jet into droplets. The distribution of sprinklers should be arranged so as to wet the soil surface in the plot as evenly as possible.
- A wide range of sprinkler systems is available for small and large-scale application. Set systems operate with sprinklers in a fixed position. These sprinklers can be moved to water different areas of the field, either by hand or with machinery. Hand-move systems are more labour intensive and may be more suited where labour is available and cheap. On the other hand, mechanically operated systems require a greater capital investment in equipment. Mobile systems minimise labour inputs by operating with motorised laterals or sprinklers, which irrigate and move continuously at the same time.
- Sprinkler irrigation efficiency is highly dependent on climatic conditions. FAO proposed the figures of farm irrigation efficiencies provided in the table below on the basis of climate.

Crop	Water saving (%)	Yield increase (%)
Cabbage	40	3
Cauliflower	35	12
Chillies	33	24
Cotton	36	50
Groundnut	20	40
Maize	41	36
Onion	33	23

Potato	46	4
Wheat	35	24

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) good economic efficiency; (b) relatively low labour requirement; (c) high potential for scalability; (d) high relevance at community level; (e) high degree of equity among communities; (f) low negative impact on environment and health and safety; and (g) potentially highly market oriented. It is considered to have a moderately high impact on climate change adaptation because of its water saving attributes. Overall the option is considered to have a high relative score within the MCA.

Strengths

One of the main advantages of the sprinkler irrigation technology is more efficient use of water for irrigation in agriculture. Sprinkler systems eliminate water conveyance channels, thereby reducing water loss. Water is also distributed more evenly across crops helping to avoid wastage. The sprinkler irrigation system has also been shown to increased crop yields and is suited for most row, field and tree crops that are grown closely together, such as cereals, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices and condiments and for cultivating paddy crop.

Sprinkler irrigation technology is well adapted to a range of topographies and is suitable in all types of soil, except heavy clay. Sprinkler systems can be installed in either permanent or mobile modes. Sprinklers provide a more even application of water to agricultural land, promoting steady crop growth. Likewise, soluble fertilisers can be channeled through the system for easy and even application. The risk of soil erosion can be reduced because the sprinkler system limits soil disturbance, which can occur when using irrigation by gravity. In addition, sprinkler irrigation can provide additional protection for plants against freezing at low temperatures. Secondary benefits from improved crop productivity include income generation, employment opportunities and food security.

Limitations

The main disadvantages associated with sprinkler systems are related to climatic conditions, water resources and cost. Even moderate winds can seriously reduce the effectiveness of sprinkler systems by altering the distribution pattern of the water droplets. Likewise, when operating under high temperatures, water can evaporate at a fast rate reducing the effectiveness of the irrigation. Although sprinkler irrigation can help farmers to use water resources more efficiently, this technology relies on a clean source of water and therefore may not be suited to areas where rainfall is becoming less predictable. Implementation costs are higher than that of gravity-fed irrigation systems and large labour force is needed to move pipes and sprinklers in a non-permanent system. In some places, such labour may not be available and may also be costly. Mechanized sprinkler irrigation systems have a relatively high energy demand.

Sources

FAO. 1982. Mechanised sprinkler irrigation. FAO Irrigation and Drainage Paper No. 35. Rome.

Kulkarni, S.A., F.B. Reinders and F. Ligetvari. 2006. Global Scenario of Sprinkler in Micro-Irrigated Areas. Sept 10 – 16 2006, PWTC, Kuala Lumpur 7th International Micro Irrigation Congress

Kundu, D. K., H. U. Neue, R. Singh (1998) Comparative Effects of Flooding and Sprinkler Irrigation on Growth and Mineral Composition of Rice in an Alfisol. Proceedings of the National Seminar on Micro-Irrigation Research in India: Status and Perspective for the 21st Century. Bhubaneswar, July 27-28, 1998

Narayanmoorthy, A. (no date) Drip and Sprinkler Irrigation in India: Benefits, Potential and Future Directions. Available: http://www.iwmi.cgiar.org/Publications/Other/PDF/Paper%2015%20of%20NRLP%20 series%201.pdf

Savva, A. P. and K. Frenken. 2002. Irrigation Manual Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation. Volume I Modules 1 – 6. Food and Agriculture Organisation of the United Nations (FAO) Sub-Regional Office for East and Southern Africa (SAFR), Harare.

6.2 DRIP IRRIGATION

Application: Government extension staff, private sector, small-scale farmers and farmer groups

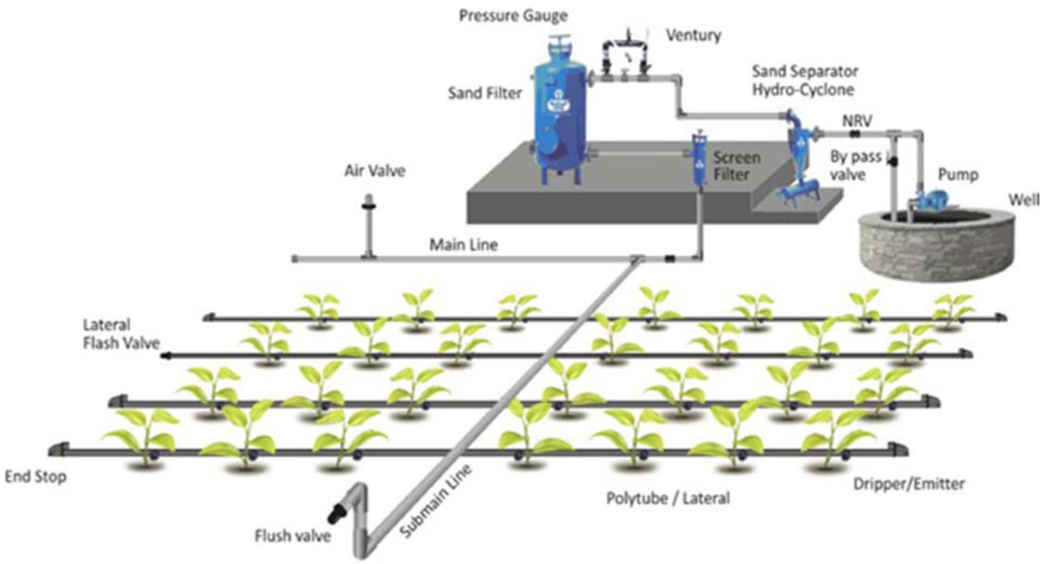
Description: Drip irrigation is based on the constant application of a specific and calculated quantity of water to soil crops. The system uses pipes, valves and small drippers or emitters transporting water from the sources (i.e. wells, tanks and or reservoirs) to the root area and applying it under particular quantity and pressure specifications. The system should maintain adequate levels of soil moisture in the rooting areas, fostering the best use of available nutrients and a suitable environment for healthy plant roots systems. Managing the exact (or almost) moisture requirement for each plant, the system significantly reduces water wastage and promotes efficient use. Compared to surface irrigation, which can provide 60% water-use efficiency and sprinklers systems which can provide 75% efficiency, drip irrigation can provide as much as 90% water-use efficiency. Recently, drip irrigation technology has received particular attention from farmers, as water needs for agricultural uses have increased and available resources have diminished. In particular, drip irrigation has been applied in arid and semi-arid zones as well as in areas with irregular flows of water (or in zones with underground water resources that rely on seasonal patterns such as river-flow or rainfall).

Drip irrigation technology can support farmers to adapt to climate change by providing efficient use of water supply. Particularly in areas subject to climate change impacts such as seasonal droughts, drip irrigation reduces demand for water and reduces water evaporation losses (as evaporation increases at higher temperatures). Scheduled water application will provide the necessary water resources direct to the plant when required. Furthermore, fertilizer application is more efficient since it can be applied directly through the pipes. As is the case with a sprinkler system, drip irrigation is more appropriate where there is (or is expected to be) limited or irregular water supply for agricultural use. However, the drip technology uses even less water than sprinkler irrigation, since water can be applied directly to the crops according to plant requirements. Furthermore, the drip system is not affected by wind or rain (as is the sprinkler technology).

A drip irrigation system typically consists of:

- Pumps or pressurised water systems
- Filtration systems
- Nutrients application system
- Backwash controller
- Pressure control valve (pressure regulator)
- Pipes (including main pipeline and tubes)
- Control valves and safety valves
- Poly fittings and accessories (to make connections)
- Emitters

A wide range of components and system design options is available. Drip tape varies greatly in its specifications, depending on the manufacturer and its use. The wetting pattern of water in the soil from the drip irrigation tape must reach plant roots. Emitter spacing depends on the crop root system and soil properties. Drip irrigation zones can be identified based on factors such as topography, field length, soil texture, optimal tape run length, and filter capacity. Many irrigation system suppliers use computer programmes to analyze these factors and design drip systems. Once the zones are assigned and the drip system is designed, it is possible to schedule irrigations to meet the unique needs of the crop in each zone. Recent automatic systems technology has been particularly useful to help control flows and pressure, and to identify potential leaks thereby reducing labour requirements. System design must take into account the effect of the land topography on water pressure and flow requirements. A plan for water distribution uniformity should be made by carefully considering the tape, irrigation lengths, topography, and the need for periodic flushing of the tape. The design should also include vacuum relief valves into the system.



Drip irrigation system

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) good economic efficiency; (b) relatively low labour requirement; (c) high potential for scalability; (d) high relevance at community level; (e) high degree of equity among communities; (f) low negative impact on environment, and health and safety; and (g) potentially highly market oriented. It is considered to have a moderately high impact on climate change adaptation because of its water saving attributes. Overall the option is considered to have a high relative score within the MCA.

Strengths

Drip irrigation can help use water efficiently and hence ameliorate the effects of climate change. A well-designed drip irrigation system reduces water run-off through deep percolation or evaporation to almost zero. If water consumption is reduced, production costs are lowered. Also, conditions may be less favourable for the onset of diseases including fungus. Irrigation scheduling can be managed precisely to meet crop demands, holding the promise of increased yield and quality.

Agricultural chemicals can be applied more efficiently and precisely with drip irrigation. Since only the crop root zone is irrigated, nitrogen that is already in the soil is less subject to leaching losses. In the case of insecticides, fewer products might be needed. Fertiliser costs and nitrate losses can be reduced. Nutrient applications can be better timed to meet plants' needs.

The drip system technology is adaptable to terrains where other systems cannot work well due to climatic or soil conditions. Drip irrigation technology can be adapted to lands with different topographies and crops growing in a wide range of soil characteristics (including salty soils). It has been particularly efficient in sandy areas with permanent crops such as tree crops (fruit and coffee) and vegetables. A drip irrigation system can be automated to reduce the requirement for labour. Advice on drip system design and management can in Cambodia be provided by the private sector, and international NGOs iDE and SNV.

Limitations

The initial cost of drip irrigation systems can be higher than other systems. Final costs will depend on terrain characteristics, soil structure, crops and water source. Higher costs are generally associated with the costs of pumps, pipes, tubes, emitters and installation. Unexpected rainfall can affect drip systems either by flooding emitters, moving pipes, or affecting the flow of soil salt-content. Rodents or other animals also expose drip systems to damage. It can be difficult to combine drip irrigation with mechanised production as tractors and other farm machinery can damage pipes, tubes or emitters.

Sources

Farm Manager Agriver SAC. 2011. Drip irrigation system results Report Jan. 2011

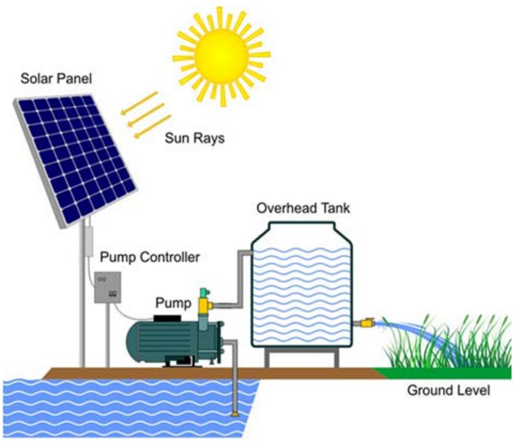
Tanji, K.K. and N. C Kielen. 2002. FAO Irrigation and Drainage Paper 61: Agricultural Drainage Water Management in Arid and Semi-Arid Areas. FAO, Rome.

6.3 SOLAR WATER PUMP

Application: Government extension staff, private sector, small-scale farmers and farmer groups

Description: A solar-powered pump is a pump running on electricity generated by photovoltaic (PV) panels or the radiated thermal energy available from collected sunlight as opposed to grid electricity or diesel-run water pumps. The operation of solar powered pumps is more economical mainly due to the lower operation and maintenance costs and has less environmental impact than pumps powered by an internal combustion engine. Solar pumps are useful where grid electricity is unavailable and alternative sources (in particular wind) do not provide sufficient energy.

Solar pumping systems allow vital water resources to be accessed in remote rural locations. Solar water pumps require no fuel and minimal maintenance. Solar powered submersible pumps are used for wells, boreholes, water transfer, cattle and livestock watering and irrigation. Recently the price of solar photovoltaic modules has fallen dramatically around the world, making solar powered pumping systems increasingly affordable. There is also a natural relationship between the availability of solar power and the need for water. Solar pumps provide maximum water flow when it's needed most. Most solar water pumping applications don't use batteries; the water is simply pumped when there is enough daylight. The water is often pumped into a large raised storage tank, enabling access to water whenever needed.



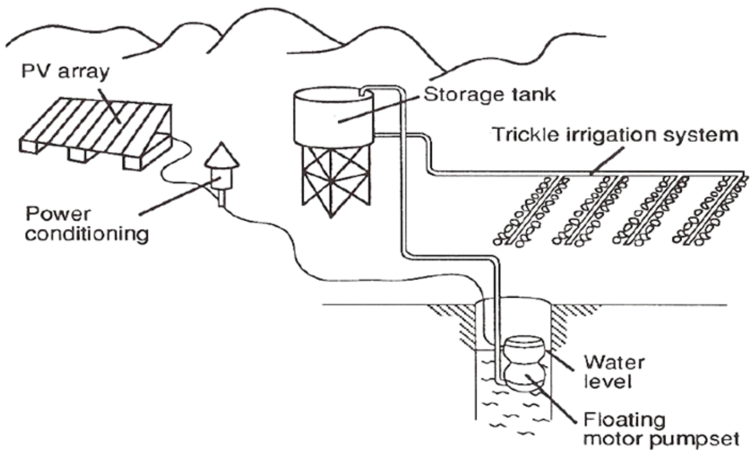
Solar irrigation system

A PV solar powered pump system has three parts: the pump, the controller and solar panels. The solar panels make up most (up to 80%) of the systems cost.

The size of the PV-system is directly dependent on the size of the pump, the amount of water that is required (m^3/d) and the solar irradiance available.

The purpose of the controller is twofold. Firstly, it matches the output power that the pump receives with the input power available from the solar panels. Secondly, a controller usually provides a low voltage protection, whereby the system is switched off, if the voltage is too low or too high for the operating voltage range of the pump. This increases the lifetime of the pump thus reducing the need for maintenance.

Voltage of the solar pump motors can be AC (alternating current) or DC (direct current). DC motors are used for small to medium applications up to about 3 kW rating, and are suitable for applications such as garden fountains, landscaping, drinking water for livestock, or small irrigation projects. Since DC systems tend to have overall higher efficiency levels than AC pumps of a similar size, the costs are reduced as smaller solar panels can be used.



Schematic layout of a solar powered irrigation system

Finally, if an alternating current solar pump is used, an inverter is necessary that changes the direct current from the solar panels into alternating current for the pump. The supported power range of inverters extends from 0.15 to 55 kW and can be used for larger irrigation systems. However, the panel and inverters must be sized accordingly to accommodate the inrush characteristic of an AC motor. Solar PV water pumping systems are used for irrigation and drinking water. The majority of the pumps are fitted with a 200-3000 watt motor that receives energy from an 1800 Wp PV array. The larger systems can deliver about 140,000 litres of water/day from a total head of 10 meters.

Contribution to climate resilience: The key benefits from this adaptation option are few owing to its high cost, low degree of scalability and complex nature of the technology. On the positive side it is highly relevant, and is environmentally friendly. It is considered to have a moderate impact on climate change adaptation because of its water saving attributes which are countered by its high cost and complexity. Overall the option is considered to have a medium relative score within the MCA.

Strengths

Solar powered water pumps can deliver drinking water as well as water for livestock or irrigation purposes. Solar water pumps may be especially useful in small-scale or community based irrigation, as large-scale irrigation requires large volumes of water that in turn require a large solar PV array. Other advantages include: (a) unattended operation, (b) no fuel costs, (c) low maintenance, (d) easy installation, and (e) long life (20 year). Furthermore, support for the pumps can easily be provided by the private sector in most provincial towns.

Limitations

As the water may only be required during some parts of the year, a large PV array would provide excess energy that is not necessarily required, thus making the system inefficient. Other important disadvantages include: (a) high capital costs, (b) water storage required for cloudy periods, and (c) repairs often require skilled technicians.

Sources

Simalenga and Mark Hankins. 1995. Solar electric systems for Africa: a guide for planning and installing solar electric systems in rural Africa. London: Commonwealth Science Council. p. 117. ISBN 0850924537.

Practical Action. 2010. Solar (Photovoltaic) Water Pumping. http://infohub.practicalaction.org/oknowledge/bitstream/11283/314192/1/535e1143-5804-4c58-b561-18590a000075.pdf

6.4 WINDMILL WATER PUMP

Application: Government extension staff, private sector, small-scale farmers and farmer groups

Description: Only a small percentage of farmers in Cambodia grow two seasons/crops per year due to the fact that few have pumping equipment and the cost of the principal sources of energy available − diesel and electricity − are high. One way to address this is to use windpumps. Cambodia has a small number of entrepreneurs manufacturing windpumps to order. However, the standard of locally built machines is poor and they are unreliable. There are many windpumps available on the global market, but their cost, installed in Cambodia, is prohibitively high, and they are not generally designed for the low wind speeds in Cambodia.

The Cambodian Development Institute (CDI) developed a prototype of a wind-water pump using 'rope pump' technology. Over the last few years, CDI has developed ten different models and has recently installed several demonstration model windmills along major roads on the outskirts of Phnom Penh. CDI has also received technical support from Development Technology Workshop (DTW), a British NGO, to improve some of its limitations. The idea has been able to generate interest from private investors and landowners and consequently over 20 wind-water pumps have been sold and private farmers have secured more orders.

The technology is simple and can be easily used by Cambodian farmers. Metal poles are used as a supporting frame for 24 steel-sheet wind blades that can be activated by a wind speed of six metres per second. Once the blades start to turn, the pump then draws up water through a pipe connected to an underground or river-based water source. The operational life span of a windpump is between three to five years, after which the tool may require some maintenance.

Recently, Cambodian Farmer Association Federation of Agricultural Producers (CFAP) with support from SNV partnered with CDI to install two windmill water pipes in Svay Rieng province to test their feasibility in irrigation of small plots of land for vegetable growing. The windmills are expected to irrigate up to two hectares of land owned by up to seven or eight households.

Purchasing a wind-powered pump and receiving training on how to operate it will cost a group of seven to eight farmers about US$500 each (a total of US$3,500 including installation). The tool is a one-time investment when compared to a standard generator, which requires regular expenses on fuel, as well as ongoing maintenance, potentially saving around USD$200 per year on operational costs. Furthermore, a windpump has no fuel costs and no polluting emissions during service. However, the windmill pump may also require periodical maintenance. Furthermore, it requires access to technical knowhow in case the windmill breaks.

Contribution to climate resilience: The key benefits from this adaptation option are few owing to its high cost, low degree of scalability and complex nature of the technology. On the positive side it is highly relevant, and is environmentally friendly. It is considered to have a moderate impact on climate change adaptation because of its water saving attributes which are countered by its high cost and complexity. Overall the option is considered to have a low relative score within the MCA.

Strengths

A key benefit of the windpump is that, if working properly, it would facilitate increased rice production and enable farmers near water sources to grow vegetables in the dry season. This can lower the cost of diversifying the agricultural enterprises into dry season crops, and also provide supplementary irrigation during drought periods or to bring about timelier planting. From a climate change perspective, one main advantage is that windmills provide a low-cost method for pumping water.

Limitations

One of the main disadvantages of the windmill is its relatively high cost. Furthermore, given that it needs to be bought collectively it poses challenges for marketing. In addition, there is not always enough wind in Cambodia to power the windmill, and the amount of water pumped by the current version of the windmill is not enough to irrigate seven vegetable plots, which is equivalent to the suggested number of farmers contributing to the group purchase of a windmill. Farmers therefore need to be well organised and have clear rules on how to use the windmill and the water. Finally, as water levels change the base of the windmill needs to be adjusted, requiring support from staff with some technical knowledge.

Sources

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation. http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

WikiWater article on wind pumps: http://www.wikiwater.fr/e42-wind-powered-pumps.html

6.5 RAINWATER HARVESTING

Application: Government extension staff, small-scale farmers and farmer groups

Description: Rainfall can provide some of the cleanest naturally occurring water that is available. There is considerable scope for the collection of rainwater when it falls, before huge losses occur due to evaporation, transpiration, and runoff and drainage – before it becomes contaminated by natural means or man-made activities. Rainwater harvesting is a particularly suitable technology for areas where there is no surface water, or where groundwater is deep or inaccessible due to hard ground conditions, or where it is too salty or acidic.

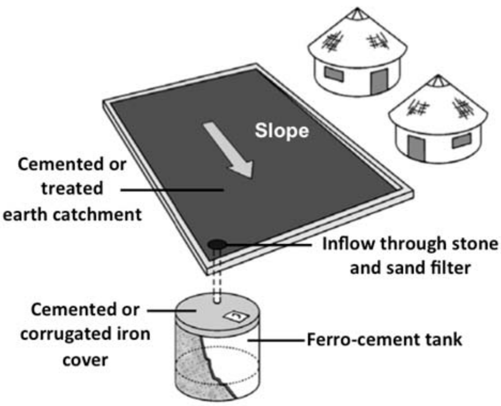
Climate change is disrupting global rainfall patterns meaning some parts of the world are suffering from a drastic drop in precipitation leading to a fall in water levels in many reservoirs and rivers. In sub-Saharan Africa where two-thirds of the region is desert and dry land, the need for improving water management in the agriculture sector is particularly critical. Rainwater harvesting represents an adaptation strategy for people living with high rainfall variability, both for domestic supply and to enhance crop, livestock and other forms of agriculture.

Generally, the amount of water made available through rainwater harvesting is limited and should be used prudently to alleviate water stress during critical stages of crop growth. Supplemental irrigation is a key strategy and can help increase yields by more than 100%. A small investment providing between 50-200 mm of extra water per hectare per season for supplemental irrigation, in combination with improved agronomic management, can more than double water productivity and yields in small-scale rain fed agriculture.

Rainwater harvesting is defined as a method for inducing, collecting, storing and conserving local surface runoff for agriculture in arid and semi-arid regions. Both small and large-scale structures are used for rainwater harvesting collection and storage including water pans, tanks, reservoirs and dams. Commonly used rainwater harvesting systems are constructed from three principal components: (a) catchment area; (b) conveyance system; and (c) storage device.

Catchment area: the area where the rainfall or water runoff is initially captured and is in most cases either the rooftop of a house or building, ground surface or rock surface:

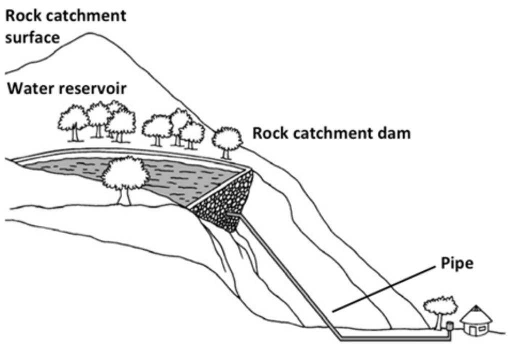
Typical rainwater catchment system



Ground catchment system

Rooftop method: this method collects rainfall in vessels at the roof edge or channels it into a storage system via gutters and pipes. Roofs can be constructed with a range of materials including galvanised corrugated iron, aluminium cement sheets, tiles and slates. Thatch or palm leafed roofs are a low-cost alternative but can be difficult to clean and can taint the runoff. Tiled roofs, corrugated mild steel or other materials are preferable, as they are easiest to construct and give the cleanest water. Health hazards can arise from asbestos sheeting, metallic paint or other coverings that can contaminate the water. It is suitable for household application and can provide freshwater for domestic purposes and small-scale farming.

Ground surface method: Rainwater flowing along the ground is usually diverted to a tank below the surface in the ground surface method. There is greater chance of water loss than the rooftop system due to infiltration into the ground and it is generally of lower quality than rainfall collection. Techniques for increasing runoff within ground catchment areas include: clearing or altering vegetation cover; increasing the land slope with artificial ground cover; and reducing soil permeability by soil compaction and application of chemicals. Impermeable membranes can also be used. It can be used in low topographic areas and is suitable for large-scale agricultural production as it allows in-situ storage and irrigation.



Rock catchment

Rock surface method: Rock surfaces can also be used as collection catchments. Bedrock surfaces found within rocky top slopes or exposed rock outcrops in lowlands often have natural hollows or valleys that can be turned into water reservoirs by building a dam. It typically involves clearing the site from vegetation and enclosing the catchment area with gutters. Rock surfaces should not be fractured or cracked, as this may cause the water to leak away to deeper zones or underneath the dam. Water is generally of lower quality than direct rainfall collection but can be improved if access to the area (e.g. by animals and children) is limited.

Conveyance System: Several types of conveyance systems exist for transporting water from the catchment to the storage device, including gutters, pipes, glides, and surface drains or channels. Larger-scale conveyance systems may require pumps to transfer water over larger distances. These should be constructed from chemically inert materials such as wood, bamboo, plastic, stainless steel, aluminium, or fibreglass, in order to avoid negatively affecting on water quality. In the case of rock catchments, gutters can be stonewalls built with rough stones/hard-core and joined with mortar. For household-level rainwater harvesting, gutters, down pipes, funnels and filters are required to transfer and clean collected water before it enters the storage device.

Storage Device: Storage devices are used to store the water that is collected from the catchment areas and are classified as (i) above-ground storage tanks and (ii) cisterns or underground storage vessels. These facilities can vary in size from one cubic metre to up to hundreds of cubic metres for large projects. Common vessels used for small-scale water storage are plastic bowls, buckets, jerry cans, clay or ceramic jars, cement jars, and old oil drums. Devices can be made cheaply with locally available materials such as bamboo and steel and coated with a sand and cement mix. Increasingly popular are Ferro-cement tanks in which mortar is applied to a cylindrical wire frame, which helps to control cracking. These tanks are feasible up to a size of 100m³. For storing larger quantities of water the system will usually require a bigger tank or cistern with sufficient strength and durability. Typically, these tanks can be constructed out of bricks coated with cement. For water captured from a rock catchment, a dam is the more common form of storage device. Maintenance is required for the cleaning of the tank and inspection of the gutters, pipes and taps and typically consists of the removal of dirt, leaves and other accumulated materials. Such cleaning should take place annually before the start of the major rainfall season with regular inspections. In regions with unpredictable rainfall, more regular maintenance and cleaning will be required to ensure that the equipment is maintained in good working order. Cracks in the storage tanks can create major problems and should be repaired immediately to avoid water loss. In case of ground and rock catchments, additional care is required to avoid damage and contamination by people and animals and to keep the area free from vegetation.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high potential for scalability and flexibility, (b) high relevance at community level, (c) high degree of equity among communities, (d) high institutional feasibility, and (e) low negative impact on environment, and health and safety. It is considered to have a moderately high impact on climate change adaptation because of its water saving and storage attributes. Overall the option is considered to have a high relative score within the MCA.

Strengths

Rainwater harvesting technologies are simple to install and operate. Local people can be easily trained to implement such technologies, and construction materials are usually readily available. Rainwater harvesting is convenient because it provides water at the point of use and farmers have full control of their own systems. Use of rainwater harvesting technology promotes self-sufficiency and has minimal environmental impact. Running costs are reasonably low. Construction, operation and maintenance are not labour-intensive. Water collected is of acceptable quality for agricultural purposes. Other benefits include increasing soil moisture levels and increasing the groundwater table via artificial recharge. Rainwater harvesting and its application to achieving higher crop yields can encourage farmers to diversify their enterprises, such as increasing production, upgrading their choice of crop, purchasing larger livestock animals or investing in crop improvement inputs such as irrigation infrastructure, fertilisers and pest management.

Limitations

The main disadvantage of rainwater harvesting technology is the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source in dry periods or in time of prolonged drought. Low storage capacity will limit rainwater harvesting potential, whereas increasing storage capacity will add to construction and operating costs making the technology less economically viable. The effectiveness of storage can be limited by the evaporation that occurs between rainfall events. In water basins with limited surplus supplies, rainwater harvesting in upstream areas may have detrimental impact downstream and can cause serious community conflict. Also, when runoff is generated from a large area and concentrated in small storage structures, there is a potential danger of water quality degradation, through introduction of agro-chemicals and other impurities.

Sources

Boers, T. M. and J. Ben-Asher. 1982. "A review of rainwater harvesting". In Agriculture Water Management. 5:145-158.

Gould, J. E. 1992. "Rainwater Catchment Systems for Household Water Supply" in Environmental Sanitation Reviews, No. 32, ENSIC, Asian Institute of Technology, Bangkok.

Practical Action, Rainwater Harvesting Technical Brief. http://practicalaction.org/food-productioN/Agriculture_rainwater

UNEP. 1982. Rain and Storm Water Harvesting in Rural Areas, Tycooly International Publishing Ltd.

UNEP-IETC. 1998. Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Asian Countries. IETC Technical Publication Series 8b, UNEP IETC/UNEP-IETC/Danish Hydraulic Institute

UNEP. 1997. Sourcebook of Alternative Technologies for Freshwater Augmentation in Some Countries in Asia, UNEP, Unit of Sustainable Development and Environment General Secretariat, Organisation of American States, Washington, D.C.

UNEP and SEI (Stockholm Environment Institute). 2009. Rainwater harvesting: a lifeline for human wellbeing, United Nations Environment Programme and Stockholm Environment Institute.

6.6 CROP WATER REQUIREMENT PLANNING

Application: Government extension staff, small-scale farmers, farmer groups, water user groups

Description: The term Crop Water Requirement (CWR) is defined as the "amount of water required to compensate for evapotranspiration loss from the cropped field". It is also described it as the "total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield". Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. A full understanding of CWR is essential for the farmer growing irrigated crops to be able to get the best and most economical use of available water while not impacting negatively on crop yield. This is important where water is a constraint, especially in the dry season in Cambodia and where climate change has reduced the amount of available water even during the monsoon season.

Precipitation, and in particular its effective portion, provides part of the water crops need to satisfy their transpiration requirements. The soil, acting as a buffer, stores part of the precipitation water and returns it to the crops in times of deficit. In humid climates, this mechanism is sufficient to ensure satisfactory growth in rain-fed agriculture. In arid climates or during extended dry seasons, irrigation is necessary to compensate for the evapotranspiration (crop transpiration and soil evaporation) deficit due to insufficient or erratic precipitation. Irrigation consumptive water use is defined as the volume of water needed to compensate for the deficit between potential evapotranspiration on the one side, and effective precipitation over the crop growing period and change in soil moisture content on the other side. It varies considerably with climatic conditions, seasons, crops and soil types.

For a given month, the crop water balance can be expressed as:

$$ICU = ETc - P - DS$$

ICU = irrigation consumptive water use needed to satisfy crop water demand (mm)

ETc = potential crop evapotranspiration (mm)

P = effective precipitation (mm)

DS = change in soil moisture (mm)

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) low cost to farmer and high economic efficiency, (b) low labour requirement, (c) high potential for scalability and flexibility, (d) high relevance at community/farmer level, and (e) low negative impact on environment, and health and safety. It is considered to have a moderately high impact on climate change adaptation because of its water saving and management attributes. Overall the option is considered to have a high relative score within the MCA.

Strengths

Farmers and growers need to recognise that water is an important and valuable resource, which contributes significantly to production of high quality crops to specification and on schedule. Both crop performance and efficient use of the available water can be optimised by:

- knowing the water holding capacity of the soil in each field and the water requirements and response of each crop grown;
- using an effective soil moisture monitoring system and using it to schedule irrigation accurately;
- choosing the right application equipment for your situation and knowing how to get the best out of it in terms of uniform and timely delivery;
- managing water application for maximum economic benefit with minimum impact on the environment; and
- auditing performance afterwards to seek ways of improving the efficiency of water use and application.

Environmental considerations are increasingly playing a part in the growing and marketing of crops. Careful and effective crop monitoring and irrigation control will be critical to profitable cropping in the future.

Limitations

The key constraint is the level of training required for the farmers to be best able to utilise this technology. Presently the level of understanding of CWR and water use across a range of important irrigated crops grown in Cambodia is minimal even for staff within the concerned departments of MOWRAM and MAFF. The main issues are the need to train staff and subsequently farmers and water user groups so that the latter can better plan and manage their collective water use.

Sources

Sources

FAO. 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, FAO, Rome. http://www.fao.org/docrep/X0490E/x0490e00.htm

Dorenbos, J. and W.O. Pruitt, 1984 and 1992. Crop Water Requirements - Guidelines for Predicting Crop Water Requirements. - FAO Irrigation and Drainage Paper 24, FAO, Rome.

Land and Water Development Division, FAO.CROPWAT - A computer program for irrigation planning and management (free to download), for MS Windows, FAO, Rome.
http://www.fao.org/nr/water/infores_databases_cropwat.html

USDA, Soil Conservation Service. 1993. Irrigation Water Requirements. - National Engineering Handbook (NEH), Part 623, Chapter 2, National Technical Information Service.

6.7 DEFICIT IRRIGATION

Application: Government extension staff, small-scale farmers and farmergroups

Description: Deficit irrigation (DI) is a watering strategy that can be applied by different types of irrigation application methods. The correct application of DI requires thorough understanding of the yield response to water (crop sensitivity to drought stress) and of the economic impact of reductions in harvest. In regions where water resources are restrictive it can be more profitable for a farmer to maximize crop water productivity instead of maximizing the harvest per unit land. The saved water can be used for other purposes or to irrigate extra units of land. DI is sometimes referred to as incomplete supplemental irrigation or regulated DI.

Deficit irrigation is defined as follows: Deficit irrigation is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited or even unnecessary if rainfall provides a minimum supply of water. Water restriction is limited to drought tolerant phenological stages, often the vegetative stages and the late ripening period. Total irrigation application is therefore not proportional to irrigation requirements throughout the crop cycle. While this inevitably results in plant drought stress and consequently in production loss, DI maximizes irrigation water productivity, which is the main limiting factor. In other words, DI aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields.

If crops have certain phenological phases in which they are tolerant to water stress, DI can increase the ratio of yield over crop water consumption (evapotranspiration) by either reducing the water loss by unproductive evaporation, and/or by increasing the proportion of marketable yield to the totally produced biomass (harvest index), and/or by increasing the proportion of total biomass production to transpiration due to hardening of the crop - although this effect is very limited due to the conservative relation between biomass production and crop transpiration, and/or due to adequate fertilizer application and/or by avoiding bad agronomic conditions during crop growth, such as water logging in the root zone, pest and diseases, etc.

Crop water productivity (WP) or water use efficiency (WUE) expressed in kg/m^3 is an efficiency term, expressing the amount of marketable product (e.g. kilograms of grain) in relation to the amount of input needed to produce that output (cubic meters of water). The water used for crop production is referred to as crop evapotranspiration. This is a combination of water lost by evaporation from the soil surface and transpiration by the plant, occurring simultaneously. Except by modelling, distinguishing between the two processes is difficult. Representative values of WUE for cereals at field level, expressed with evapotranspiration in the denominator, can vary between 0.10 and 4 kg/m³.

For certain crops, experiments confirm that DI can increase water use efficiency without severe yield reductions. For example, for winter wheat in Turkey, planned DI increased yields by 65% as compared to winter wheat under rain fed cultivation, and had double the water use efficiency as compared to rain fed and fully irrigated winter wheat. Similar positive results have been described for cotton. Experiments in Turkey and India indicated that the irrigation water use for cotton could be reduced to up to 60 percent of the total crop water requirement with limited yield losses. In this way, high water productivity and a better nutrient-water balance was obtained.

Certain underutilised and horticultural crops also respond favourably to DI, such as tested at experimental and farmer level for the crop quinoa. Yields could be stabilised at around 1.6 tons per hectare by supplementing irrigation water if rainwater was lacking during the plant establishment and reproductive stages. Applying irrigation water throughout the whole season (full irrigation) reduced the water productivity. Also in viticulture and fruit tree cultivation, DI is practiced. For other crops, the application of deficit irrigation will result in lower water use efficiency and yield, as is the case when crops are sensitive to drought stress throughout the complete season, such as maize.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) low cost to farmer and moderate economic efficiency, (b) high relevance at community/farmer level, and (c) low negative impact on environment, and health and safety. It is considered to have a moderately high impact on climate change adaptation because of its water saving and management attributes. Overall the option is considered to have a medium relative score within the MCA.

Strengths:

The correct application of DI for a certain crop:

- maximises the productivity of water, generally with adequate harvest quality;
- allows economic planning and stable income due to a stabilization of the harvest in comparison with rain fed cultivation;
- decreases the risk of certain diseases linked to high humidity (e.g. fungi) in comparison with full irrigation;

- reduces nutrient loss by leaching of the root zone, which results in better groundwater quality and lower fertiliser needs as for cultivation under full irrigation; and
- improves control over the sowing date and length of the growing period independent from the onset of the rainy season and therefore improves agricultural planning.

Limitations:

A number of constraints apply to deficit irrigation:

- Exact knowledge of the crop response to water stress is imperative.
- There should be sufficient flexibility in access to water during periods of high demand (drought sensitive stages of a crop).
- A minimum quantity of water should be guaranteed for the crop; below which DI has no significant beneficial effect.
- An individual farmer should consider the benefit for the total water user's community (extra land can be irrigated with the saved water), when he faces a below-maximum yield.
- Because irrigation is applied more efficiently, the risk for soil salinization is higher under DI as compared to full irrigation.

Sources

English, M. 1990. Deficit Irrigation. I: Analytical Framework. J. Irrig. Drain. E.-ASCE 116, 399-412.

Fereres, E., Soriano, M.A. 2007. Deficit irrigation for reducing agricultural water use J. Exp. Bot. 58, 147-158

Geerts, S., Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. Agric. Water Manage 96, 1275-1284

Kijne, J.W., Barker, R., Molden, D. 2003. Improving water productivity in agriculture: editor's overview. In: Kijne, J.W., Barker, R.M.D. (eds.), Water productivity in agriculture: limits and opportunities for improvement. International Water Management Institute, Colombo, Sri Lanka, p. xi-xix.

Kirda, C. 2002. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. In: Food and Agricultural Organization of the United Nations (FAO) (ed.), Deficit irrigation practices. Rome, Italy, p. 3-10.

Pereira, L.S., Oweis, T., Zairi, A. 2002. Irrigation management under water scarcity. Agric. Water Manage 57, 175-206.

7. INTEGRATED SOIL MANAGEMENT

Major and widespread soil changes are expected as a result of climate change. Increases in CO_2, sea-level rise, changes in vegetative cover and agricultural practices, increases in temperature and changes in rainfall will have a positive or negative impact on the fertility and physical conditions of soils. However, the precise nature of these changes is subject to major uncertainties. Despite this uncertainty, a range of soil management technologies can help improve soil quality and resilience against negative effects of climate change in order to maintain agricultural productivity. These adaptation technologies include the following: (a) Sloping Agricultural Land Technology (SALT), (b) slow-forming terraces, (c) conservation tillage, (d) integrated nutrient management, (e) compost making, (f) soil salinity management, (g) vetiver grass, (h) live staking, and (i) mulching.

7.1 SLOPING AGRICULTURAL LAND TECHNOLOGY (SALT)

Application: Rural village communities, small-scale farmers and farmer groups

Description: Rapid depletion of forest cover is a region-wide problem. Reckless mass deforestation for economic reasons is taking place. Due to population pressures, cultivators are move into newly opened areas and practicing swidden (slash and burn) agriculture. Forest areas of generally fragile, sloping soils, are then subject to intensive agricultural practices, which rapidly degrade the land.

Soil erosion due to deforestation and heavy rains presents an extremely serious problem in many parts of Southeast Asia, including Cambodia. The Mindanao Baptist Rural Life Center (MBRLC), a NGO based in the southern region of the Philippines, has developed and spread an agroforestry scheme called Sloping Agricultural Land Technology (SALT) to help control soil erosion and increase crop yields. Basically, SALT utilizes nitrogen-fixing trees as soil binder, fertilizer generator, and livestock feed source. The system also includes annual and perennial diversified food crops grown in the spaces between the hedgerows. The SALT model has been tested both in demonstration plots and farmers' fields, and has proven to be appropriate for use by typical hilly-land farmers. The system can reduce soil erosion and restore moderately degraded hilly lands to a profitable farming system.

SALT is a technology package of soil conservation and food production that integrates several soil conservation measures. Basically, the SALT method involves planting field crops and perennial crops in bands 3-5 m wide between double rows of nitrogen-fixing shrubs and trees planted along a contour. These minimize soil erosion and maintain the fertility of the soil. Field crops include legumes, cereals, and vegetables, while the main perennial crops are cacao, coffee, banana, citrus and fruit trees. SALT helps considerably in the establishment of a stable ecosystem. The double hedgerows of leguminous shrubs or trees prevent soil erosion. Their branches are cut every 30-45 days and incorporated back into the soil to improve its fertility. The crop provides permanent vegetative cover which aids the conservation of both water and soil. The legumes and the perennial crops maintain soil and air temperatures at levels favourable for the better growth of different agricultural crops.

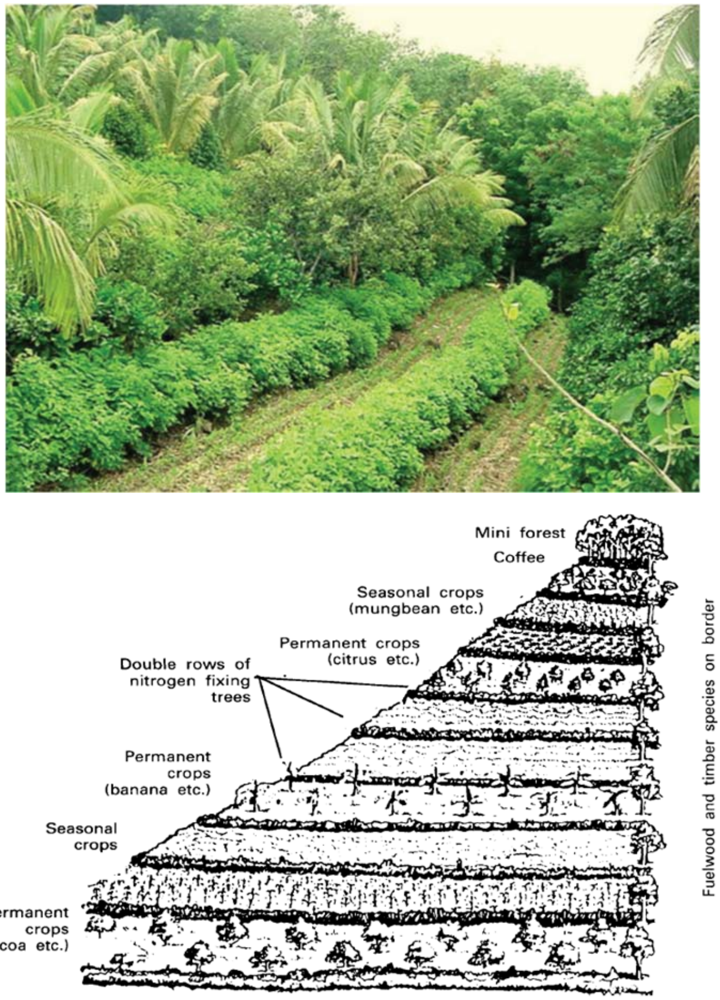
In Cambodia, the recommended hedgerow species used in SALT are *Flemingia macrophylla, Desmodium rensonii, Gliricidia sepium, Leucaena diversifolia*, and *Calliandra calothyrsus*.

SALT is an improvement over existing technologies. It is a simple, effective method of farming uplands, without losing topsoil to erosion. It consists of the following ten basic steps:

- *Making the A-frame:* The A-frame is a simple device for laying out contour lines across the slope. It is made of a carpenter level and three wooden or bamboo poles nailed or tied together in the shape of a capital letter A with a base about 90 cm wide. A carpenter's level is mounted on the crossbar.
- *Determining the contour lines:* One leg of the A-frame is planted on the ground, and the other leg is swung until the carpenter's level shows that both legs are touching the ground on the same level. A helper drives a stake beside the frame's rear (first) leg. The process is repeated across the field. The contour lines should be spaced four to five metres apart.
- *Cultivating the contour lines*: One-metre strips along the contour lines should be ploughed and harrowed to prepare for planting. The stakes serve as a guide during ploughing.
- *Planting seeds of different nitrogen fixing trees and shrubs:* Along each prepared contour line, two furrows should be laid out. Two to three seeds are planted per hill, with a distance of 12 cm between hills. The seeds should be covered firmly with soil. When the hedgerows are fully grown, they hold the soil and serve as a source of fertilizer. Examples of suitable hedgerow species are *Flemingia macrophylla* (syn. *congesta*), *Desmodium rensonii, Calliandra calothyrsus, Gliricidia sepium, Leucaena diversifolia*, and *L. leucocephala.*
- *Cultivating alternate strips:* The space between the rows of nitrogen fixing trees on which the crops are to be planted is called a strip or alley. Cultivation is done on alternate strips (strips 2, 4, 6 and so on). Alternate

cultivation prevents erosion because the unploughed strips will hold the soil in place.

- *Planting permanent crops*: Permanent crops such as coffee, cacao, banana, citrus and others of the same height may be planted when the nitrogen fixing species are sown. Only the spots for planting, however, are cleared and dug, and later only ring weeding is employed until the hedgerows are large enough to hold the soil in place. Permanent crops are planted in every third strip. Tall crops should be planted at the bottom of the farm while the short ones are planted at the top.
- *Planting short-term crops.* Short and medium-term income producing crops (such as pineapple, ginger, taro, sweet potato, peanut, mung bean, melon, sorghum, corn and upland rice) should be planted between the strips of permanent crops as a source of food and regular income while farmers are waiting for the permanent crops to bear fruit.
- *Trimming of nitrogen-fixing trees.* Every 30 to 45 days, the growing hedgerows are cut to a height of 1.0-1.5 m from the ground. The cut leaves and twigs should be piled on the soil around the crops, where they serve as an excellent organic fertilizer. In this way, only a minimal amount of commercial fertilizer (about 1/4 of the total fertilizer requirements) is necessary.
- *Practicing crop rotation*: A good way of rotating is to plant cereals such as corn or upland rice, tubers and other crops on strips where legumes were planted previously, and vice versa. This practice will help maintain the fertility and good condition of the soil. Other management practices in crop growing, such as weeding and pest control should be carried out regularly.
- *Building green terraces*: To enrich the soil and effectively control erosion, organic materials such as straw, stalks, twigs, branches and leaves, and also rocks and stones, are piled at the base of the rows of nitrogen fixing trees. As the years go by, strong, permanent terraces will be formed which will anchor the precious soil in its right place.



Typical sloping agricultural land technology (SALT) farm

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) very high relevance at community/farmer level, and (b) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of its perceived benefit from improved land and farm management as a result of improved micro-watershed management. The negative aspects of this technology are its high cost and high labour demand, impacting on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

The benefits of the system are considered to be as follows:

- Adequately protect soil against erosion
- Help restore soil structure and fertility
- Increased efficiency in food crop production
- Easily duplicated by upland farmers using local resources and if possible, without the need for loans
- Focuses on the small family farm and food production as top priorities, while fruit trees and forest, for example, are regarded as of secondary importance
- Economically feasible and ecologically sound

Limitations

SALT is not a miracle farming system or a panacea for all upland problems. To establish a 1 ha SALT farm requires much hard work and discipline - there is no easy way. It takes three to ten years to deplete the soil of nutrients and to lose the topsoil; no system can bring depleted, eroded soil back into production in a few short years. Soil loss leads to low yields and poverty, but land can be restored to a reasonable level of productivity by using SALT to establish competition and shading between field crops and planting hedgerows along contours.

Sources

ECHO. 2012. Sloping Agricultural Land Technology (SALT). How to Farm Hilly Land without Losing Soil. Technical Note #72. Mindanao Baptist Rural Life Center (MBRLC), Philippines. ECHOcommunity.org

Tacio, H.D. 1992. Sloping Agricultural Land Technology: NGO-developed agroforestry technology in the Philippines. Unasylva 8, 171: FAO, Rome, Italy.

7.2 SLOW-FORMING TERRACES

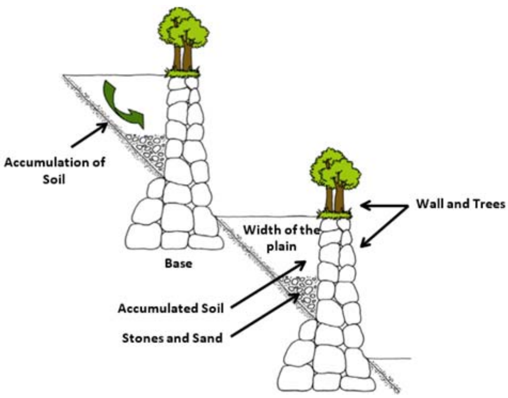
Application: Small-scale farmers and farmer groups

Description: A terrace is a levelled surface used in farming to cultivate sloping, hilly or mountainous terrain. They can be used on relatively flat land in cases where soil and climate conditions are conducive to erosion. Terraced fields are effective for growing a wide range of crops such as rice, potatoes, maize, olive trees, and vineyards. Terraces have four main functions: (a) improve the natural conditions for agricultural production; (b) decrease the rate of erosion; (c) increase soil moisture; and (d) generate positive environmental benefits. This technology facilitates adaptation to climate change by optimising water use.

Climate variability also affects the soil, since heavy rainfall coupled with poor soil management give rise to landslides and mudslides. In this respect, slow-formation terraces reduce soil erosion and, consequently, the danger of large landslides occurring. Terraces also regulate the micro-climate for agricultural production. By capturing the sun's heat in the rock walls, terraces absorb heat during the daytime and release it during the night, helping to create a slightly warmer internal micro-climate which can protect crops from frost, prolong the growing season and allow for crop diversification. This technology is also an important component of SALT.

Slow-forming terraces are constructed with a combination of infiltration ditches, hedgerows, and earth or stonewalls. This technology decreases superficial water run-off, increases water infiltration and intercepts soil sediment. Slow-forming terraces are called as such because they take between three and five years, and possibly even ten years, to fully develop. They can be built on land with marginal to steep inclines and where soil is sufficiently deep to create a drag effect. This leads to the formation of steps as sediment accumulates due to rainfall and natural gravity. Level ditches are traced and excavated along the contour of a slope, and embankments of earth, stones or plants are constructed at regular intervals. Eroded soil accumulates in these buffer strips every year and terraces slowly form. A 1-2 % inclination is recommended to avoid the buffer strips breaking during intense rain. Depending on soil type, ditches should generally be dug 40 cm wide and 40 cm deep. The recommended length of the terrace is between 50-80 m and the height of the slope should be the same as the height of the earth or stone ditches. The best plants to cultivate along the buffer strips are resistant to local conditions and grow well and fast. Where possible, plants that can provide added benefits such as fuelwood and livestock feed should be used. Leguminous species are preferred as they improve the soil nitrogen content.

Lower cost options that also effectively trap sediment but do not require the building of physical structures have also been developed. One option contour planted hedgerows. This system has been used on 10,000 ha of land in the Philippines, Rwanda and Haiti. Double hedges of *Leucaena, Gliricidia* or similar shrubs are planted four to eight metres apart along the contour. The shrubs are pruned two or three times per year and the leaf and branch material applied to the soil or against the stems of the shrubs, to trap the moving sediment. This leads to the formation of terraces up to 50 cm high in the first two to three years. Another alternative is to use deep rooting grass species such as Vetiver or *Panicum* bunch grass often used for cut and carry fodder. An even simpler method is to leave natural vegetative strips when preparing the soil for planting, which gradually form the stabilised edges of terraces. These different live-barrier methods of terracing can reduce erosion from 50% to just 2% of the level without live-barriers. Rainfall infiltration is also significantly improved.



Structure of slow-forming terraces

Planting hedgerows along sloping land in Philippines

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) very high relevance at community/farmer level, and (b) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of its perceived benefit from improved land and farm management as a result of improved micro-watershed management. The negative aspects of this technology are high costs and labour demand, impacting on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

Slow-forming terraces allow for the development of larger areas of arable land in rugged terrain and can facilitate modern cropping techniques such as mechanisation, irrigation and transportation on sloping land. The moisture content of the soil is increased by retaining a larger quantity of water. Run-off that can be diverted through irrigation channels at a controlled speed is captured, preventing soil erosion. More soil is exposed to sunlight, and the soil is replenished and fertilised as the sediments are deposited in each level, increasing organic content and preserving biodiversity. Slow-forming terraces have also been shown to increase crop productivity. Research conducted in Peru found that the production of peas benefited most from the impact of slow formation terraces, although production of maize, fava beans and potatoes also improved. The most important reason for this increase is assigned to increased/enhanced water retention.

Limitations

In terms of limitations, an economic analysis of terrace investments in some hilly tracts has shown that if implemented on a regional-scale, slow-forming terraces can produce varied and sometimes limited returns. Where farmers must pay the full costs of investments, returns can be as low as 10%. Profitability will depend on additional factors such as interest rates, investment costs and maintenance costs. Cost-benefit analysis should, however, take account of other factors including increased soil productivity and conservation benefits. In addition, slow-formation terraces are formed over a long period of between three and five years, which means that their positive effects are not immediate. Terraces formed with hedgerows or grasses can also compete with associated crops if they are not sufficiently pruned. Generally, this technology is less effective on slopes steeper than 30% if hedges are more than four meters apart.

Sources

Antle, J. M., J. J. Stoorvogel and R. O. Valdivia. 2004. Assessing the economic impacts of agricultural carbon sequestration: Terraces and agro-forestry in the Peruvian Andes, Agriculture, Ecosystems & Environment, Vol 122 (4) December 2004, Pp. 435-445

Fantappiè M. (no date) Conservation and Reclamation of Volcanic Deteriorated Soils in Ecuadorian Andes.

ICRAF. 1996. International Center for Research in Agroforestry, Annual Report 1996. ICRAF Nairobi, 240p

Mars, R. 2005. The Basics of Permaculture, Chelsea Green Publishing Company, 2005

Valdivia, R. O. 2002. The Economics of Terraces in the Peruvian Andes: AN application of sensitivity analysis in an integrated assessment model. Montana State University, Bozeman, Montana, April 2002

Young. 1997. Agroforestry for Soil Management. 2nd Edition. CABI/ICRAF Wallingford UK, 320p

7.3 CONSERVATION TILLAGE

Application: Large and small-scale farmers and farmer groups

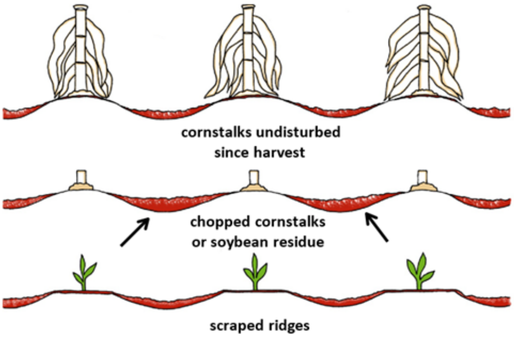
Description: Tillage is the agricultural preparation of the soil by mechanical, draught animal or human-powered agitation, such as ploughing, digging, overturning, shovelling, hoeing and raking. Small-scale farming tends to use smaller-scale methods, employing hand-tools and in some cases draught animals, whereas medium-, to large-scale farming tends to use larger-scale instruments such as tractors. The overall goal of tillage is to increase crop production while conserving resources (soil and water) and protecting the environment. Conservation tillage refers to a number of strategies and techniques for establishing crops in a previous crop's residues, which are purposely left on the soil surface. Conservation tillage practices typically leave about one-third of crop residue on the soil surface. This slows water movement, which reduces the amount of soil erosion. Conservation tillage is suitable for a range of crops including grains, vegetables, root crops, sugar cane, cassava, fruit and vines. There is great potential to bring this technology to Cambodia, although limiting factors have to be taken into account (see limitations below).

The most common conservation tillage practices are no-till, ridge-till and mulch-till.

No-till is a way of growing crops without disturbing the soil. This practice involves leaving the residue from last year's crop undisturbed and planting directly into the residue on the seedbed. No-till requires specialised seeding equipment designed to plant seeds into undisturbed crop residues and soil. No-till farming changes weed composition drastically. Faster growing weeds may no longer be a problem in the face of increased competition, but shrubs and trees may begin to grow eventually. Cover crops, or green manure, can be used in a no-till system to help control weeds. Cover crops are usually leguminous which are typically high in nitrogen can often increase soil fertility.

Ridge-till is a practice where the soil is left undisturbed from harvest to planting and crops are planted on raised ridges. Planting usually involves the removal of the top of the ridge. Planting is completed with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges. Weed control is accomplished with cover crops, herbicides and/or cultivation. Ridges are rebuilt during row cultivation.

Mulch-till techniques involve disturbing the soil between harvesting one crop and planting the next but leaving around a third of the soil covered with residues after seeding. Implements used for mulch-till techniques include chisels, sweeps, and field cultivators.



Ridge-till systems for conservation tillage

Disc harrow used for conservation tillage

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high scalability, (b) high relevance at community/farmer level, and (c) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of the perceived benefits from improved land and soil management as a result of improved management of water and organic matter. The negative aspects of this technology are the high cost and high labour demand, resulting on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

Conservation tillage benefits farming by minimising erosion, increasing soil fertility and improving yield. Ploughing loosens and aerates the soil to facilitate some deeper penetration of roots. Tillage is believed to help in the growth of microorganisms present in the soil and helps to blend the residue from the harvest, organic matter and nutrients evenly in the soil. Conservation tillage systems also benefit farmers by reducing fuel consumption and soil compaction. By reducing the number of times the farmer travels over the field, farmers make significant savings in fuel and labour. Labour inputs for land preparation and weeding are also reduced once the system becomes established. In turn, this can increase time available for additional farm work or off-farm activities for livelihood diversification. Once the system is established, requirements for herbicides and fertilisers can be reduced.

Limitations

Conservation tillage may require the application of herbicides in the case of heavy weed infestation, particularly in the transition phase, until the new balance of weed populations is established. The practice of conservation tillage may also lead to soil compaction over time, which can be prevented with chisel ploughs or sub-soilers. Initial investment of time and money along with the purchases of equipment and herbicides will be necessary for establishing the system. Higher levels of surface residue may result in higher plant disease and pest infestations, if not managed properly. There is a strong relationship between this technology and appropriate soil characteristics, which is detrimental in high clay content and compact soils.

Sources

Derpsch, R. 2001. Keynote: Frontiers in conservation tillage and advances in conservation practice, in Stott D. E., Mohtar, R. H., and Steinhart G. C (Eds.) Sustaining the global farm. Selected papers from the 10th International Soil Conservation Organisation Meeting held May 24-29, 1999 at Purdue University and the USSA-ARS National Soil Erosion Research Laboratory.

FAO (Food and Agriculture Organisation) (no date) Conservation Agriculture: Matching production with sustainability, FAO.

GTZ. 1998. Conserving natural resources and enhancing food security by adopting no-tillage. An assessment for the potential for soil-conserving production systems in various agro-ecological zones of Africa, GTZ Eschborn, Tropical Ecology Support Programme, TÖB Publication.

IBSRAM (International Board for Soil Research and Management). 1990. Organic-matter management and tillage in humid and sub-humid Africa. IBSRAM Proceedings No. 10. Bangkok: IBSRAM

Sorrenson, W. J., C. Duarte, and J. López-Portillo. 1998. Economics of non-till compared to conventional cultivation Systems on small farms in Paraguay, policy and investment implications, Report Soil Conservation Project MAG-GTZ, August 1998.

7.4 INTEGRATED NUTRIENT MANAGEMENT

Application: Government extension staff, small-scale farmers and farmer groups

Description: Soil is a fundamental requirement for crop production as it provides plants with anchorage, water and nutrients. A certain supply of mineral and organic nutrient sources is present in soils, but these often have to be supplemented with external applications, or fertilisers, for better plant growth. Fertilisers enhance soil fertility and are applied to promote plant growth, improve crop yields and support agricultural intensification.

Fertilisers are typically classified as organic or mineral. Organic fertilisers are derived from substances of plant or animal origin, such as manure, compost, seaweed and cereal straw. Organic fertilisers generally contain lower levels of plant nutrients as they are combined with organic matter that improves the soils physical and biological characteristics. The most widely used mineral fertilisers are based on nitrogen, potassium and phosphate.

Optimal and balanced use of nutrient inputs from mineral fertilisers will be of fundamental importance to meet growing global demand for food. Mineral fertiliser use has increased almost fivefold since 1960 and has significantly supported global population growth – it is estimated that nitrogen-based fertiliser has contributed an estimated 40% to the increases in per capita food production in the past 50 years. Nevertheless, environmental concerns and economic constraints mean that crop nutrient requirements should not be met solely through mineral fertilisers. Efficient use of all nutrient sources, including organic sources, recyclable wastes, mineral fertilisers and bio-fertilisers should therefore be promoted through Integrated Nutrient Management (INM).

The aim of INM is to incorporate the use of natural and man-made soil nutrients to increase crop productivity and preserve soil productivity for future generations. Rather than focusing on nutrition management practices per crop, INM entails the optimal use of nutrient sources on a cropping-system or crop rotation basis. This encourages farmers to focus on long-term planning and consider environmental impacts.

Organic manure

Inorganic fertiliser

INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers. Boosting plant nutrients can be achieved by a range of practices covered in this guide such as terracing, alley cropping, conservation tillage, intercropping, and crop rotation. Given that these technologies are covered elsewhere in this guide; this section will focus on INM as it relates to appropriate fertiliser use. In addition to the standard selection and application of fertilisers, INM practices include new techniques such as deep placement of fertilisers and the use of inhibitors or urea coatings that have been developed to improve nutrient uptake.

Key components of the INM approach include:

- *Testing procedures to determine nutrient availability and deficiencies in plants and soils:*
  - Plant symptom analysis – visual clues can provide indications of specific nutrient deficiencies. For example, nitrogen deficient plants appear stunted and pale compared to healthy plants
  - Tissue analysis and soil testing – where symptoms are not visible, post-harvest tissue and soil samples can be analysed in a laboratory and compared with a reference sample from a healthy plant
- *Systematic appraisal of constraints and opportunities in the current soil fertility management practices* and how these relate to the nutrient diagnosis (for example, insufficient or excessive use of fertilisers)
- *Assessment of productivity and sustainability of farming systems*: Different climates, soil types, crops, farming practices, and technologies dictate the correct balance of nutrients necessary. Once these factors are understood, appropriate INM technologies can be selected
- *Participatory farmer-led INM technology experimentation and development*: The need for locally appropriate technologies means that farmer involvement in the testing and analysis of any INM technology is essential.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high economic efficiency, (b) high scalability; (c) high relevance at community/farmer level; (d) institutionally, highly feasible; and (e) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of its perceived benefit from improved land and soil management as a result of improved nutrient availability and organic matter. The negative aspects of this technology are its high cost and high labour demand, impacting on affordability and equity issues. Overall, the technology has a high relative score within the MCA.

Strengths

INM enables the adaptation of plant nutrition and soil fertility management to site characteristics in a farming systems. It takes advantage of the combined and harmonious use of organic and inorganic nutrient resources to serve the concurrent needs of food production and economic, environmental and social viability. INM empowers farmers by increasing their technical expertise and decision-making capacity. It also promotes changes in land use, crop rotations, and interactions between forestry, livestock and cropping systems as part of agricultural intensification and diversification. In Cambodia, the ongoing research and development of CARDI (working with FAO/IAEA) is helping to develop appropriate fertiliser management systems (refer to Annex 3).

Limitations

As well as facilitating adaptation to climate change in the agriculture sector, the INM approach is also sensitive to changes in climatic conditions and could produce negative effects if soil and crop nutrients are not monitored systematically and fertiliser practices changed accordingly. In Asia, high transport costs in land-locked countries contribute to prohibitively high fertiliser prices. In the case of small-scale farmers these costs may represent too high a proportion of the total variable cost of production, thus ruling out inorganic fertiliser as a feasible option.

Sources

FAO. 1995. Integrated plant nutrition system. FAO Fertiliser and Plant Nutrition Bulletin No. 12. FAO, Rome. 426 pp.

FAO. 2008. Current world fertiliser trends and outlook to 2011/12, FAO, Rome

IFPRI 1995. Biophysical limits to global food production (2020 Vision). International Food Policy Research Institute. Washington, DC. 2 pp.

Roy, R. N., A. Finck, G. J. Blair and H. L. S. Tandon. 2006. Plant nutrition for food security, FAO Rome

7.5 COMPOST MAKING

Application: Government extension staff, small-scale farmers and farmer groups

Description: The need for maintaining and improving soil fertility in Cambodia in relation to climate change has never been greater. Yet, this needs to be done without recourse to expensive inorganic fertilisers. Teaching farmers how to use waste organic materials as sources of crop nutrients is key to more sustainable agriculture. That is what this publication sets out to do. Compost is organic matter (plant and animal residues) that has rotted due to bacteria and other organisms over a period of time. Many types of organic matter, such as leaves, fruit and vegetable peelings and manures can be used to make compost. The end product is very different from the original materials. It is dark brown, crumbly and has a pleasant smell. Compost is cheap, easy to make and is a very effective material that can be added to the soil, to improve soil and crop quality.

Compost is an effective and long-term improvement of soil to grow better crops. Various commonly available materials such as those mentioned above are excellent for compost making, but many other waste materials produced by households and farms or other activities can be used. Maize stalks used for construction or from kitchen waste can be necessary to feed livestock, but can also be used for the compost heap. Time and effort are necessary to manage a compost heap, and leaving organic matter to pile up, for example, will result in a long time before compost is produced, with nutrients being lost. In a managed heap nutrient loss will be reduced, leaving more nutrients to feed plants. A properly managed compost heap will often generate enough heat to kill weed seeds and plant diseases.

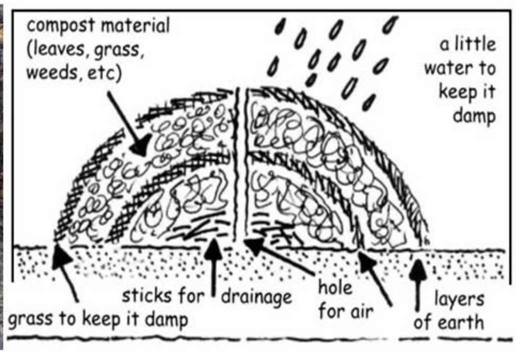
Principles of composting applicable to most methods are:

- Compost making requires a balance between easily decomposable materials (fruit and vegetable skins and young leaves) and material that is difficult to decompose (crop residues and small twigs). This is to make sure that the structure of the compost is suitable and that it has a good balance of nutrients.
- Decomposition happens due to the activity of micro-organisms and other insects. These need certain conditions to live. This includes moisture and air. In most cases the compost heap will need to be watered if it becomes too dry. In some cases, aeration is not needed but if it is, this will be stated in the method.
- All compost heaps heat up. Temperature and evaporation (water loss) need to be assessed and can be done with a stick. It should be pushed deep into the compost heap, left there for a few minutes and then taken

out and felt with the hand. It should feel warm and damp. If it is cold and dry, the heap is not functioning as it should and will need watering or aerating.

An unmanaged heap is one in which materials that could be used for compost are not sufficiently utilised. Kitchen scraps and sweepings are often piled in a corner and left unmanaged. The activity of the organisms in the heap is very slow and no heat is created. The material will eventually break down into compost but will take a long time and much of the goodness of the compost is lost.

Typical well-managed compost heap



Cross section pf well managed compost heap

In a well-managed heap, the activity of the organisms increase because the heap heats up and produces useful and fertile compost, quicker. The various methods to accelerate the breakdown process are provided in HDRA (2002) and listed as follows:

- The Indore Composting Method
- The Bangalore Composting Method
- The heating process/block method
- The Chinese high temperature stack
- Pit composting
- Trench composting
- Basket composting
- Boma composting
- Composting domestic waste, seaweed, coffee pulp, water plants and human waste

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high scalability; (b) high relevance at community/farmer level; (c) institutionally highly feasible; and (d) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved land and soil management as a result of improved availability of nutrients and organic matter. The negative aspects of this technology are high costs and labour demand, affecting affordability and equity issues. Overall the option is considered to have a high relative score within the MCA.

Strengths

- Improves the structure of the soil: allows more aeration, improves drainage and reduces erosion.
- Helps to stop the soil from drying out in times of drought by holding more water.
- By improving soil structure, compost makes it easier for plants to take up the nutrients already in the soil. It may also improve soil quality by adding nutrients, which can increase yields.
- Increases crop strength and health, which results in more resistance to pests and diseases.
- More efficient way of feeding plants than chemical fertilisers, which do not also improve soil structure or quality. Chemical fertilisers usually improve yields for one season only.
- Benefits last longer as compost is not washed away through the soil.
- Plants grown with chemical fertilisers are more attractive to pests.

Limitations

- Labour intensive.
- Relatively small amounts of compost can be produced, limiting application for field crops.
- Best applied to high value crops like vegetables and certain cash crops.

Sources

CTA. 1989. Compost-making manual for the Tropics. Spore 24. CTA, Wageningen, The Netherlands.

FAO. 1987. Soil Management: Compost Production and Use in Tropical and Subtropical Environments. Food and Agriculture Organization of the United

Nations (FAO) Soils bulletin 56. FAO, Via delle Terme di Caracalla, 00100 Rome, Italy

HDRA. 2002. Composting in the Tropics (volumes I and II). HDRA the organic organisation Ryton Organic Gardens, Coventry CV8 3LG, United Kingdom. Website: www.hdra.org.uk

Inckel, M. et al. 1990. The Preparation and Use of Compost; Agrodok 8. GROMISA, PMB 41, 6700 AA, Wageningen, The Netherlands

7.6 SOIL SALINITY MANAGEMENT

Application: Government extension staff, small-scale farmers and farmer groups

Description: Accumulation of excess salts in the root zone results in a partial or complete loss of soil productivity and is a worldwide phenomenon. The problems of soil salinity are most widespread in arid and semi-arid regions but salt-affected soils are also prevalent in sub-humid and humid climates. In particular, it is found in coastal regions where the ingress of seawater through estuaries, rivers and groundwater causes large-scale salinization. Soil salinity is also a serious problem in areas where groundwater of high salt content is used for irrigation. Serious salinity problems are being faced in the irrigated arid and semi-arid regions of the world, where irrigation is essential to increase agricultural production to satisfy food requirements. However, irrigation is often costly, technically complex and requires skilled management. Failure to apply efficient principles of water management may result in wastage of water through seepage and over-watering. Inadequate drainage results in water logging and salinity problems which reduce the soil productivity, eventually leading to loss of cultivable land. Managing salinity involves striking a balance between the volume of water entering the groundwater system (recharge) and the volume of water leaving it (discharge).

Soil cracks as result of high salinity

Foliar effects of salinity on paddy

Typical salt-affected rice paddy

Salinity affects the respiration and photosynthesis of plants. It decreases biological nitrogen fixation and soil nitrogen mineralization. Salinity can cause damage throughout the growth cycle of the crop. Effects on rice growth include: (a) reduced germination rate; (b) reduced plant height and tilling; (c) poor root growth; and (d) increased spikelet sterility. It can also lead to excess Sodium (Na) uptake that decreases 1,000-grain weight and total protein content in grain (but does not alter major cooking qualities of rice). The major causes of salinity or sodicity (the amount of sodium in the soil) include poor irrigation practice, insufficient irrigation water in seasons/years with low rainfall and high evaporation. Salinity is often associated with alkaline soils in inland areas where evaporation is greater than precipitation. More causes are increased levels of saline groundwater and salt-water intrusion in coastal areas (e.g., Mekong Delta, coastal India). Examples of salt-affected soils are: (i) saline coastal soils (widespread along coasts in many countries); (ii) saline acid sulphate soils (e.g., Mekong Delta, Vietnam); (iii) neutral to alkaline saline, saline-sodic, and sodic inland soils (e.g., India, Pakistan, Bangladesh); and (iv) acid sandy saline soils (Korat region of northeast Thailand).

Symptoms of soil salinity first manifest in the first leaf, followed by the second, and then in the growing leaf. Check the field for the following symptoms: (a) tips of affected leaves that have turned white, (b) pale, yellow, or yellow-white patches as a result of chlorosis have appeared on some leaves, (c) plant stunting and reduced tillering has taken place, and (d) patchy field growth. Salinity or sodicity may be accompanied by deficiencies in phosphorus, zinc and iron and boron toxicity.

To prevent the damaging effects of salinity:

- Grow salt-tolerant varieties (e.g., Pobbeli, Indonesia; IR2151, Vietnam; AC69-1, Sri Lanka; IR6, Pakistan; CSR10, India; Bicol, Philippines).
- Change to double-rice cropping in rice-upland crop systems if sufficient water is available and climate allows.
- Submerge the field for two to four weeks before planting rice. Do not use sodic irrigation water or alternate between sodic and non-sodic irrigation water sources. Leach the soil after planting under intermittent submergence to remove excess salts. Collect and store low saline rainwater for irrigation of dry-season crops. In coastal areas, prevent intrusion of salt water.
- Use fertilizers efficiently.
- Apply gypsum (calcium sulphate).
- Treat rice seeds with calcium chloride to increase seed calcium ion concentration. Apply rice straw to recycle potassium. Apply farmyard manure.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high economic efficiency; (b) high relevance at community/farmer level; and (c) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved land and soil management in areas at risk of salinity increase, due to sea-level rise or groundwater mismanagement. The negative aspects of this technology are very high costs and labour demands which has an impacting on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

The benefits to ameliorating salinity and sodicity are higher crop yields and improved plant vigour and germination. Consequently, household livelihoods are improved.

Limitations

Generally, it takes many years to rectify the problem of soil salinity where labour costs and other inputs are high. In many cases the economics of bringing saline affected land back into production are not affordable and as a result, many areas are left fallow.

Sources

Dobermann A, Fairhurst T. 2000. Rice: Nutrient disorders & nutrient management. Handbook series. Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute. 191 p.

FAO. 1988. Salt-Affected Soils and their Management. Soil Resources, Management and Conservation Service. FAO Land and Water Development Division. FAO Soils Bulletin 39. Food and Agriculture Organization of the United Nations, Rome, Italy. http://www.fao.org/docrep/x5871e/x5871e00.htm

MacMillan, R.A. and L. C. Marciak, Alberta Agriculture, Food and Rural Development. 2001. Procedures Manual for Watershed Based Salinity Management. A comprehensive manual for assessing and addressing salinity on a watershed basis http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag2419/$file/salinityproceduresmanual.pdf?OpenElement

Queensland Government, Department of Environment and Resource Management. 2011. Salinity Management Handbook. https://publications.qld.gov.au/dataset/salinity-management-handbook

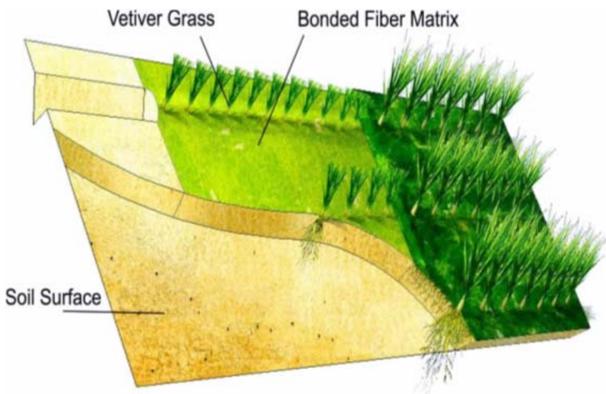
Westside Resource Conservation District. 2004. A Technical Advisor's Manual: Managing Irrigation Drainage Water. Developed for the State Water Resources Control Board by the Westside Resource Conservation District http://www.water.ca.gov/pubs/drainage/integrated_onfarm_drainage_management__a_technical_advisors_manual/ifdm_tmanl.pdf

7.7 VETIVER AND SOIL STABILISATION GRASSES

Application: Government extension staff, small-scale farmers and farmer groups

Description: Vetiver grass (*Chrysopogon zizanioidesis*) bunches planted as a hedgerow across a slope to form a very dense vegetative barrier to slow down and spread runoff. The benefits of Vetiver are multiple: The plant has a deep and strong root system, a wide range of pH tolerance, resistance to both drought and immersion, a high tolerance to most heavy metals and an ability to remove nitrates, phosphates and farm chemicals from soil and water. Vetiver grass can be used for soil and water conservation, to stabilise engineered construction sites, for pollution control (constructed wetlands) and many other uses where soil and water come together. The technology is not limited to vetiver grass, but includes aromatic species such as Panicum spp., lemon grass (*Cymbopogon citratus*), citronella (*Cymbopogon nardus*, *C. winterianus*), palmarosa (*Cymbopogon martinii*), and Napier grass (*Pennisetum purpureum*).

A vetiver hedge traps particles that can lead to a build-up of natural terraces behind it. It is ideal for roadside slopes, coastal slopes, dams, bridge abutments, river and stream sidings, exposed earthwork areas, agricultural erosion control, and landslide control.



Diagrammatic illustration of vetiver soil stabilisation

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high relevance at community/farmer level; and (b) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved land and soil management in sloping areas at risk of soil erosion. The negative aspects of this technology are its high costs and labour, which impacts on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

- A non-invasive species.
- Detoxifying capacity helps clean areas like industrial sites and landfills.
- Drought and frost tolerant, can withstand brief periods of submergence.
- Requires little maintenance once the hedge is established.

Limitations

Vetiver is intolerant to shading, especially in its establishment phase. Vetiver must be grown in full sun to succeed.

Sources

http://www.vetiver.org

http://www.vetiversystems.co.nz/

http://www.betuco.be/coverfodder/Vetiver%20System%20%20-Technical%20reference%20 manual%202007.pdf

7.8 LIVE STAKING

Application: Government extension staff, small-scale farmers and farmer groups

Description: Live staking and joint planting involves the insertion of woody shrub cuttings into the ground in a manner that allows the cutting (stake) to take root and grow. Live stake cuttings can be used to repair small earth slips and slumps. The stakes can help buttress the soil.

Live stakes can be used to anchor and enhance the effectiveness of willow wattles, straw rolls, coir rolls, turf reinforcement mats, coir mats, continuous berms and other erosion control materials.

Live stakes also work very well as a means of introducing a particular plant species to a site.

Live staking on sloping land in Mondulkiri

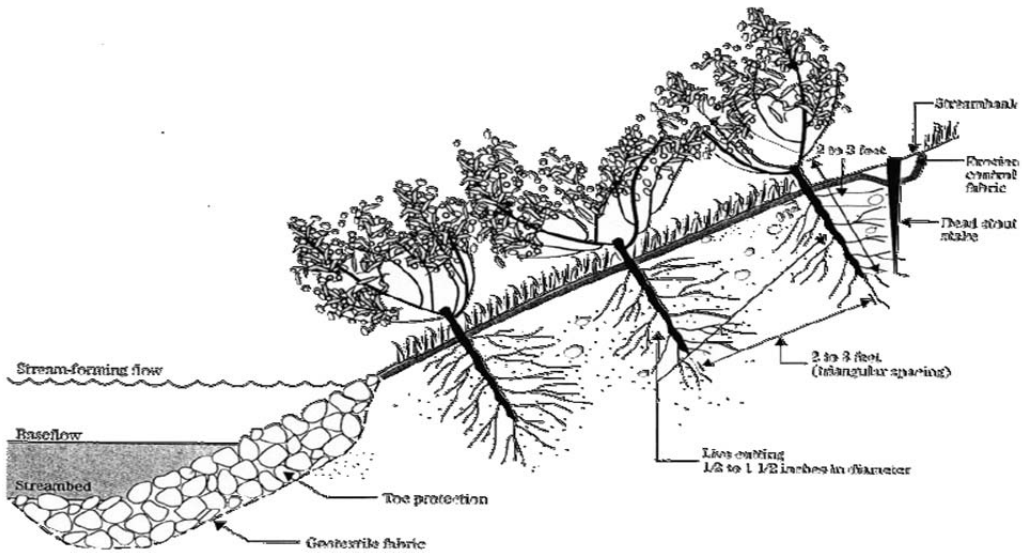


Diagram of cross section of livestaking

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high relevance at community/farmer level, and (b) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved land and soil management in sloping land areas at risk of soil erosion. The negative aspects of this technology are its high cost and labour demand, impacting on affordability and equity issues. Overall the option is considered to have a medium relative score within the MCA.

Strengths

- Stakes can improve aesthetics and provide wildlife habitat.
- Slows the flow of water during high water levels.
- Staking a wet streambank helps to dry it out and stabilise it.
- Staking is most useful in conjunction with other more complex erosion control methods.

Limitations

Live staking must be carried out when plants are dormant. Live stakes provide very little initial site protection during the establishment period.

Sources

http://www.fs.fed.us/publications/soil-bio-guide/guide/chapter5.pdf

MAFF Adaptation Technologies Guide – Agriculture

http://www.ontariostreams.on.ca/PDF/OSRM/Tech8.pdf
http://www.ernstseed.com/products/bioengineering/live-stakes-and-whips/
http://projects.geosyntec.com/NPSManual/Fact%20Sheets/Live%20Stakes.pdf
http://www.ctre.iastate.edu/erosion/manuals/streambank_erosion.pdf

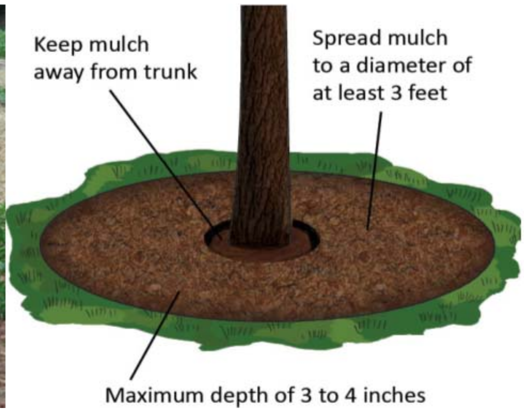
7.9 MULCHING

Application: Government extension staff, small-scale farmers and farmer groups

Description: Mulch is a layer of material applied to a soil surface area. Its purposes can be to conserve moisture, to improve the fertility and health of the soil, to reduce weed growth, and to enhance the visual appeal of the area. Mulch can be organic, recycled plastic, rubber, rock, gravel, cardboard and/or paper. It may be permanent or temporary. Manure or compost mulch will be incorporated naturally into the soil.

Elements of successful mulching include:

- Mulching is crucial for the maintenance of an urban tree canopy.
- Most mulching can be done anytime during growing season, but generally the earlier the better.
- Regularly refresh and form mulch to ensure water can penetrate.



Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high degree of flexibility and scalability; (b) high relevance at community/farmer level; and (c) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved land and soil management. The negative aspects of this technology are relatively high cost and labour demand, impacting on affordability and equity. Overall the option is considered to have a high relative score within the MCA.

Strengths

- Material which would have ended up in landfills is recycled.
- Reduces evaporation from soil surface, cutting water use by 25-50%.

- Stabilizes soil moisture and soil temperature.
- Prevents soil compaction.
- Reduces erosion.
- Controls weeds, which rob soil moisture.
- Adds an aesthetic finish to the urban landscape.

Limitations

The mulch must be kept at least 150 mm from the trunk in order to avoid soil borne diseases.

Sources

http://www.ext.colostate.edu/mg/gardennotes/245.html

http://en.wikipedia.org/wiki/Mulch

http://www.horticare.net/PDF%20Files/UsefulGardeningInfo/The%20Facts%20about%20Mulch.pdf

8. SUSTAINABLE CROP MANAGEMENT

Crop productivity will not only be affected by changes in climate related abiotic stresses (i.e. increasing temperatures, salinity and inundation and decreasing water availability) and biotic stresses (such as increases in pests and diseases), but also changes in the atmospheric concentration of CO_2, acid rain and ground level ozone. Hence a key challenge is to assess how crops will respond to simultaneous changes and the full range of possible stresses. Responding to unpredictable environments will require advances in crop research and the adoption of appropriate technologies based on principles of sustainable production and resource conservation. These include: (a) new crop varieties and diversification; (b) new varieties from biotechnology; (c) ecological/integrated pest management; (d) seed and grain storage; (e) rice crop intensification; and (f) alternate wet and dry rice irrigation.

8.1 CROP DIVERSITIFICATION AND NEW VARIETIES

Application: Government research and extension staff, small-scale farmers and farmer groups

Description: The introduction of new cultivated species and improved varieties of crops is a technology aimed at enhancing plant productivity, quality, health and nutritional value. Resilience to diseases, pests and environmental stresses is built. Crop diversification refers to the addition of new crops or cropping systems to agricultural production on a particular farm taking into account the different returns from value-added crops with complementary marketing opportunities. Major driving forces for crop diversification include:

- Increasing income on small farm-holdings.
- Withstanding price fluctuation.
- Mitigating the effects of increasing climate variability.
- Balancing food demand.
- Improving fodder for livestock animals.
- Conservation of natural resources.
- Minimising environmental pollution.
- Reducing dependence on off-farm inputs.
- Depending on crop rotation, decreasing pests, diseases and weeds.
- Increasing community food security.

Farmer experimentation with new varieties: Farmers have introduced new and improved species over centuries, mainly in regions that constitute world centers of cultivated crop diversification, such as Meso-America, the Andes, Africa and parts of Asia, in response to environmental stress conditions. There are many thousands of existing varieties of all of the important crops, with wide variation in their abilities to adapt to climatic conditions. Agricultural researchers and extension agents can help farmers identify new varieties that may be better adapted to changing climatic conditions, and facilitate farmers to compare these new varieties with those they already produce. In some cases, farmers may participate in crossing select seeds from plant varieties that demonstrate the qualities they seek to propagate to develop new varieties with the characteristics they desire.

The introduction of new crop species to diversify the crop production systems needs to take into account the following inter-related categories:

- Availability and quality of resources including irrigation, rainfall and soil fertility.
- Access to resources such as seed, fertiliser, water, marketing, storage and processing.
- Household related factors, such as food and fodder self-sufficiency and investment capacity.
- Price and market related factors including output and input prices as well as trade and other economic policies that affect these prices directly or indirectly.
- Institutional and infrastructure related factors such as farm size and tenancy arrangements, research, extension and marketing systems and government regulatory policies.

How this technology contributes to climate change adaptation: Breeding new and improved crop varieties enhances the resistance of plants to a variety of stresses that could result from climate change. These potential stresses include water and heat stress, water salinity, water stress and the emergence of new pests. Varieties that are developed to resist these conditions will help to ensure that agricultural production can continue and even improve despite uncertainties about future impacts of climate change. Varieties with improved nutritional content can provide benefits for animals and humans alike, reducing vulnerability to illness and improving overall health.

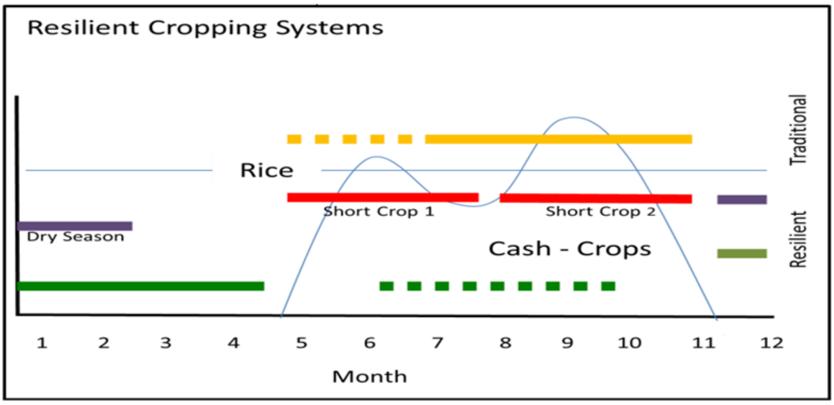
The aim of crop diversification is to increase the crop portfolio so that farmers are not dependent on a single crop to generate their income. When farmers only cultivate one crop type they are exposed to high risks in the event of unforeseen climate events that could severely impact agricultural production, such as emergence of pests and the sudden onset of frost or drought. Introducing a greater range of varieties also leads to diversification of agricultural production, which can increase natural biodiversity, strengthening the ability of the agro-ecosystem to respond to these stresses, reducing the risk of total crop failure and also providing producers with alternative means of generating income. With a diversified plot, the farmer increases his/her chances of dealing with the uncertainty and/or the changes created by climate change. This is because crops will respond to climate scenarios in different ways. Whereas the cold may affect one crop negatively, production in an alternative crop may increase.

In Cambodia through the Australia Center for International Agricultural Research (ACIAR) Climate Change Resilient Cropping Systems project, new agricultural options are being tested that could address future climate change stresses, while either maintaining or improving the income of farmers. The general idea is to try systems that are more diversified, spread risk, and allow adaptive decision making as the season progresses, depending on the specific climatic conditions. Trials in Svay Rieng province (2011-13) consist of replacing the traditional single medium rice crop with two short crops, and then following with a range of cash crops. The inputs and knowledge on how to use shorter term rice seeds will be disseminated through iDE’s Farm Business Advisor network and other existing networks in Cambodia. Both the 2011 and 2012 seasons offered ‘good’ demonstrations of climatic extremes – one in ten-year flooding and a minor drought, respectively. In each case, crop yields were affected. However, the risk strategy meant that the other crop still delivered similar yield to the previous traditional crops, and so farmers’ food security was protected.

The cost for ACIAR and any other implementing organisations to implement this system is US$500 a year per farmer, which includes training, staff and administration costs. As the economic data below shows, there are good profits to be made from modest yields, relative to the traditional systems.

The strategy of using new varieties of rice seeds and the best timing for cultivation of cash crops are easily adaptable to different landscapes and resources. It requires some testing and research to find the ideal way to implement it. The strategy is also suitable for different types of farmers, including the poorest. However, a key issue is access to water, even for the drought resistant rice varieties.

The system of using new shorter rice seed varieties along with cash crops is market friendly. Prices for inputs are similar to those of traditional inputs and produce better results. Furthermore, there is a current need to use rice seeds that are adaptable to climate change and the variability in access to water. This system requires minimal investment in technology and is adaptable to varied access to technology.



Climate resilient on-farm strategy

Farmers implementing this strategy require some support for the first two to three crops to ensure they are able to understand the new system and have ways to address any challenges, such as pest management. It is critical that such support is made available through the implementing organisation. The strategy also supports the government's rice export and diversification policies.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) relatively low cost; (b) high economic efficiency; (c) high degree of flexibility and scalability; (d) high relevance at community/farmer level; (e) high level of institutional feasibility; (f) low negative impact on environment, and health and safety, and (g) market orientated. It is considered to have a high impact on climate change adaptation because of improved crop management and diversity. The negative aspects of this technology are minimal. Overall the option is considered to have a very high relative score within the MCA.

Strengths

The process of farmer experimentation and the subsequent introduction of adapted and accepted varieties can potentially strengthen farmers' cropping systems by increasing yields, improving drought resilience, boosting resistance to pests and diseases and also by capturing new market opportunities. To make the products of the research process more relevant to the needs of smallholder farmers, research organisations are increasingly engaged in participatory research in recognition of the potential contribution to marginal areas with low agricultural potential. There is a need to identify crops and varieties that are suited to a multitude of environments and farmer preferences. Participatory approaches increase the validity, accuracy and particularly the efficiency of the research process and its outputs. Researchers are better informed of the traits that should be incorporated in improved varieties. Participatory processes also enhance farmers' capacity to seek information, strengthen social organisation, and experiment with different crop varieties and management practices.

Crop diversification increases food security and income, by enabling farmers to grow surplus products for sale at markets. Crop diversification can enable farmers to gain access to national and international markets with new products, food and medicinal plants. Diversifying from the monoculture of traditional staples can have important nutritional benefits for farmers in developing countries and can support a country to becoming more self-reliant in terms of food production. Diversification can also manage price risk, on the assumption that not all products will suffer low market prices at the same time. Compared to producing monocultures, management techniques for diversified crops generally consist of more sustainable natural resource practices.

Limitations

Farmer experimentation using only native varieties can limit the range of benefits and responses that may be found amongst the materials being tested, although local adaptation and acceptance are ensured. At the same time, problems can arise with the introduction of exotic species (from other origin centers) that turn into pests after being introduced. There are several examples of introduced species that have escaped control and became pests or agricultural weeds.

A limitation of crop diversification is that it may be difficult for farmers to achieve a high yield in terms of tons per hectare given that they have a greater range of crops to manage. In terms of commercial farming, access to national and international markets may be limited by a range of factors including government policy and subsidies, the price and supply of inputs and infrastructure for storage and transportation. Farmers also run the risk of poor economic returns if crops are not selected based on market assessment. For example, drought tolerant crop varieties may fetch a low price at market if there is not sufficient demand.

Sources

Hall, J. 2003. Environment: Alien plant species invade Southern Africa. Global Information Network. June 27: 1–2.

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

8.2 NEW VARIETIES FROM BIOTECHNOLOGY

Application: Government research and extension staff, small-scale farmers and farmer groups

Description: Water stress already affects 1.5-2 billion people worldwide. In addition to increasing drought and elevated CO_2 and ozone levels, climate change will also result in greater flooding of low-lying lands and increased flooding and runoff from tropical storms. This will result in salinity changes and waterlogging. Conventional breeding of crops tolerant to these effects has had considerable success, but has been slow and largely limited to exploiting existing genetic variation in crop plants and close relatives. Biotechnology and genetic engineering provide the opportunity for more dramatic changes, quicker, to crop responses to stress than is possible with conventional breeding.

Since their first introduction in 1996, genetically modified versions of soy, maize and cotton have shown impressive results across the globe in the fields of pest control and improved yield. More moderate results have been seen with transgenic alfalfa, canola, papaya and squash. To date these commercialised genetic modifications have involved genetically simple (single or double gene) traits. A major reason why conventional breeding has been relatively slow to respond to climate change stresses is because plant adaptation to, for example, the impact of drought or salinity, are not likely to be single gene changes. Whole metabolic pathways or cascades of pathways are likely to be involved. Making such changes is a challenge for biotechnology-supported breeding as much as for conventional breeding. Even the most promising biotechnology-supported crop plant products are only now reaching large-scale field-testing by farming communities. No drought tolerant transgenic crop variety has yet been released. Nevertheless, the underpinning research and development process has considerable scale and momentum. Invaluable techniques are more commonly used and a wide suite of technologies and products are under development, the impact of which will exponentially increase on agricultural strategies in the near future. Of course, these technologies are relatively new and there are considerable concerns regards their potential long-term impact, safety and the power shifts that their adoption may bring to the agro-industrial complex in traditional seed markets.

Breeding for improved performance under environmental stress involves activities that accumulate favourable alleles (different forms of a gene) that contribute to stress tolerance. Biotechnological contributions to crop adaptation to climate change do not only, or even mainly, concern the placement of one or more genes from an organism into crops that could not normally breed (i.e. genetically modified crops). With biotechnological tools, genes of interest can be detected and transferred from other plant lines or organisms into the crop of interest, without needing the appearance or stress response of the plant (its phenotype) as a proxy for the presence of that gene. Phenotyping (measurement of the response of a plant line in a given environment) is still a vital part of the selection process but when a genetic region with an adaptive advantage has been identified, it can be transferred (even across species barriers) much more rapidly and efficiently than has been previously possible.

Superior genes or alleles can often be found within other lines or races of the same crop. Their efficient accumulation can be greatly sped up by molecular breeding where the presence of desirable genes or alleles can be directly and immediately identified, even in seeds or very young plants not exposed to the stress in question. Marker-assisted backcrossing (MAB) and marker-assisted recurrent selection (MARS) techniques are more complex, allowing exact identification of pieces of DNA (individual alleles, genes or qualitative trait loci (QTLs)) to be included in the desired plant line while minimising the transfer of other, less desirable, genes. Whole genome sequences are now available for soybean, maize, rice, sorghum and, recently, potato. High throughput 'next-generation sequencing' means that this process is rapidly accelerating, allowing the sequencing of large and complex genomes of crops such as wheat and barley.

Improved rice varieties, CARDI: Considering the high dependence of Cambodia's rural population on rice growing, devising adaptation strategies and solutions is of utmost urgency. Furthermore, improving rice varieties to increase rice production is in line with the government's long-term goal of turning Cambodia into a major rice exporter. Specifically, for rice, adaptation can occur through improving rice varieties, making current varieties more resistant to droughts and floods, and increasing their tolerance to heat and salinity.

In 2011, CARDI conducted a number of On-Farm Adapted Trials (OFAT) in Preah Vihear and Kratie provinces for drought and submergence tolerance of rice varieties, and to demonstrate rice seed purification. The objectives of these trials were a) to identify rice varieties that are tolerant to drought and submergence conditions and to promote the adoption of such varieties among farmers for use in specific agro-ecosystems in the targeted villages of the project; and b) to ensure a continuous supply of quality rice seeds of different improved varieties to the farmer groups in the targeted villages of the project. The tests included three short training courses on rice seed purification for the vegetative, reproductive and ripening stages of rice varieties.

In order to do this, the project followed the following strategy: i) selection of target areas highly affected by floods; ii) conducted Vulnerable Reduction Assessments (VRAs); iii) selected farmers interested in the project and affected by floods; iv) worked closely with commune councils and especially the chiefs; v) mainstreamed some of the activities related to climate change adaptation into the commune investment plan; vi) created awareness of the consequence of climate change on production and livelihoods; vii) organised farmers into Farming System Intensification (FSI) groups, especially those who are in water user associations (WUA); and viii) introduced the rice seeds varieties tolerant to floods and droughts, i.e. IR66 Sen Pidor, Pkar Romduol, Pkar Romdenh, Pkar Romeat, Reang Chey, CAR3 and CAR4. Around 650 households were involved in the trials.

The new rice seed varieties can be used in a number of different regions and landscapes, although it may require some initial testing to identify optimal use. This strategy is market friendly. The new rice varieties are sold at competitive prices in markets in different parts of the country. The studies showed that in Kratie Province farmers liked the CAR4 rice variety more than the CAR3 rice variety. In Preah Vihear Province, the rice varieties for submergence tolerance that farmers liked the most were Phka Rumduol and Raing Chey, whereas Phka Rumdeng and Phka Romeat rice varieties may have been preferred less because they mature earlier than farmers' local variety. Similar to Kratie Province, farmers preferred the CAR4 rice variety more than the CAR3 rice variety during on-farm trials for drought tolerance.

In seed purification experiments in Preah Vihear and Kratie provinces, the rice varieties that farmers liked the most were the Phka Rumduol variety which had an 18% higher yield than the local rice variety, and the Sen Pidao rice varieties from CARDI that had a 55% higher yield than the local rice variety. The cost to implement a simple farmer field school (FFS, described in section 10.2) for 25 farmers would be approximately US$100 per farmer.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) relatively low cost; (b) moderate economic efficiency; (c) high degree of flexibility and scalability; (d) high relevance at community/farmer level; (e) high level of institutional feasibility; (f) low negative impact on environment, and health and safety; and (g) market orientated. It is considered to have a high impact on climate change adaptation because of improved crop management and diversity. The negative aspects of this technology are minimal. Overall the option is considered to have a very high relative score within the MCA.

Strengths

If biotechnological solutions which mitigate the harmful effects of climate change can be delivered to farmers, there is great potential for maintaining food and fibre production in a degrading environment and for expanding the farmable area into currently marginal environments. This is not to imply that environmental remediation is unnecessary but it provides a buffer in urgent situations. The major benefit of molecular breeding to date is the speed with which multiple traits can be identified, captured and incorporated into plants and then be tested for stability and efficacy. This has increased exponentially in the last 15 to 20 years. Genetic engineering technologies allow us to utilise capacities outside the range of our crop plants normally available. Because gene insertions can now be targeted and checked in ways that were not previously possible, we can have more confidence in the safety of the new plant lines and can be sure that other functional plant genes have not been disrupted by the insertion. We can expect similar scale benefits from a whole range of molecular breeding (including genetic engineering) products in the short to medium-term future.

Limitations

Drought and flooding are unpredictable. Ensuring that the developed plants perform well in a wide range of environmental conditions is a challenge that will require even deeper understanding of the molecular basis of responses to stress. As with other areas of modern technology, molecular breeding is becoming more and more complex and inaccessible as a science for those of modest means. The financial investment needed for efficient molecular breeding is high and companies are recouping their investment through higher seed prices and selling their material only as hybrids, effectively preventing replanting any of the seeds produced.

Sources

International Rice Research Institute. 2010. IRRI Annual Report 2009, published in in 2010.available at http://irri.org/about-irri/annual-reports/annual-report-2009

Karaba, A, S. Dixit, R. Greco, K.R. Trijatmiko, N. Marsch-Martinez, A. Krishnan, K.N. Nataraja, M. Udayakumar, and A. Pereira. 2007. Improvement of water use efficiency in rice by expression of HARDY and Arabidopsis drought and salt tolerance gene. Proceedings of the National Academy of Sciences (USA) 104: 15270-15275

Ortiz, R., M. Iwanaga, M. P. Reynolds, H. Wu, and J. Crouch. 2008. Overview on crop genetic engineering for drought prone environments. Journal of Semi-Arid Tropical Agricultural Research 4 http://www.icrisat.org/jornal/SpecialProject/sp3.pdf

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

Varshney, R.K., K.C. Bansal, P.K. Aggarwal, S. Datta and P.Q. Craufurd. 2011. Agricultural biotechnology for crop improvement in a variable climate: hope or hype? Trends in Plant Science 16(7): 363-371

8.3 ECOLOGICAL / INTEGRATED PEST MANAGEMENT

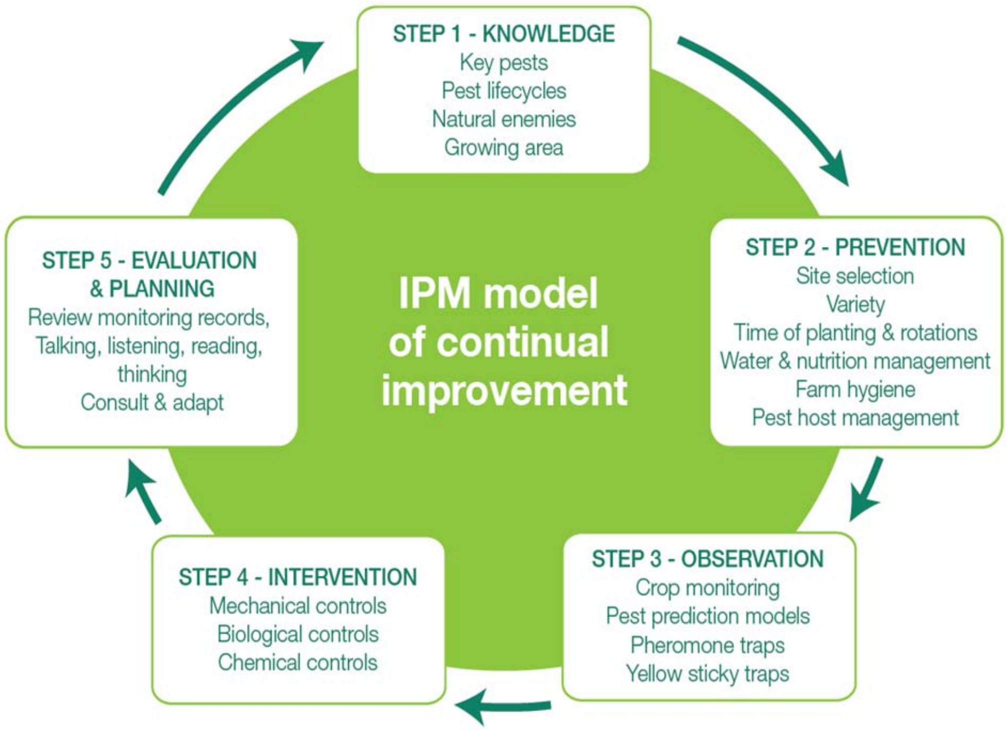
Application: Government extension staff, small-scale farmers and farmer groups

Description: Ecological Pest Management (EPM) is an approach to strengthen a natural system's capacity to regulate pests and improve agricultural production. Also known as Integrated Pest Management (IPM), this practice can be defined as the use of multiple tactics in a compatible manner to maintain pest populations at levels below those causing economic injury, while providing protection against hazards to humans, animals, plants and the environment. IPM is thus ecologically based pest management that makes full use of natural and cultural processes and methods, including host resistance and biological control. IPM emphasises the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms. Chemical pesticides are used only where and when these natural methods fail to keep pests below damaging levels.

Since the United Nations Conference on Environment and Development held in Rio de Janeiro in June 1992, worldwide public attention has been focused on the importance of EPM. Agenda 21, the blueprint for action prepared by the conference, recognised pesticide pollution as a major threat to human health and the environment and identified IPM as a key element in sustainable agricultural development.

EPM is a biotechnology belonging to the denominated 'clean' technologies which combines the lifecycle of crops, insects and implicated fungi with natural external inputs (i.e. bio-pesticides). It allows a better guarantee of good harvesting even in conditions conducive to pests and diseases, such as changes in temperature and water levels (increase of relative atmospheric humidity and runoff) typical of climate change. Thus, it is a biotechnology for facing uncertainty caused by climate change.

EPM contributes to climate change adaptation by providing a healthy and balanced ecosystem in which the vulnerability of plants to pests and diseases is decreased. By promoting a diversified farming system, the practice of EPM builds farmers' resilience to potential risks posed by climate change, such as damage to crop yields caused by newly emerging pests and diseases.



IPM model of continual improvement

The basis of this natural method of pest control is the biodiversity of the agro-ecological system. The greater the diversity of natural enemy species, the lower the density of the pest population, and as diversity of natural enemy species decreases, pest population increases. The key components of an EPM approach are:

Crop management: selecting appropriate crops for local climate and soil conditions. Practices include:

- Selection of pest-resistant, local, native varieties and well adapted cultivars
- Use of legume-based crop rotations to increase the soil's nitrate content, improve fertility and create favourable conditions for robust plants more resilient to pests and diseases
- Use of cover crops, such as green manure, to reduce weed infestation, disease and pest attacks
- Integration of intercropping and agroforestry systems
- Use of crop spacing, intercropping and pruning to create conditions unfavourable to the pests.

Soil management: maintaining soil nutrition and pH levels to provide the best possible chemical, physical, and biological soil habitat for crops. Practices include:

- building a healthy soil structure according to the soil requirements of the different plants (such as deep/shallow soil levels or different mineral contents);
- using longer crop rotations to enhance soil microbial populations and disrupt disease, insect and weed cycles;
- applying organic manures to help maintain balanced pH and nutrient levels. Adding earthworm castings, colloidal minerals, and soil inoculants will supplement this. Microbes in the compost will improve water absorption and aeration;
- reactivating soil nutrients by alleviating soil compaction;
- reducing soil disturbance (tillage) – undisturbed soil with sufficient supply of organic matter provides a good habitat for soil fauna; and
- keeping soil covered with crop residue or living plants.

Pest management: using beneficial organisms that behave as parasitoids and predators. Practices include:

- releasing beneficial insects and providing them with a suitable habitat;
- managing plant density and structure so as to deter diseases;
- cultivating for weed control based on knowledge of the critical competition period;
- managing field boundaries and in-field habitats to attract beneficial insects, and trap or confuse insect pests.

IPM strategies can exist at various levels of integration (note that integration at all four levels are not common): (a) control of a single pest on a particular crop; (b) control of several pests on the same crop; (c) several crops (and non-crop species) within a single production unit (farm); and (d) several farms in a region (area-wide pest management).

These practices, if well implemented, result in systems that are:

- self-regulating, maintaining populations of pests within acceptable boundaries;
- self-sufficient, with minimal need for 'reactive' interventions;

- resistant to stresses such as drought, soil compaction, pest invasions; and
- capable of recuperating from stresses.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high degree of flexibility and scalability; (b) high relevance at community/farmer level; (c) high level of institutional feasibility; (d) highly equitable; (e) low negative impact on environment, and health and safety; and (g) high level of acceptance. It is considered to have a high impact on climate change adaptation because of improved crop management and pest/disease control. The negative aspects of this technology are its high labour requirements. Overall the option is considered to have a high relative score within the MCA.

Strengths

With the EPM approach, farmers can avoid the costs of pesticides as well as the fuel, equipment and labour used to apply them. A 22-year trial comparing conventional and organic corn/soybean systems found that organic farming approaches use an average of 30% less fossil fuel energy. Although this can cause a slight drop in productive performance, the risk of losing an entire crop is reduced dramatically. There are also reports that production levels have increased when there has been a reduction in the use of pesticides. In Cambodia, IPM and EPM are fully supported through FFS and other training programs to MAFF.

Limitations

There are very strong pests for which the 'biological controller' has not yet been identified (i.e. an insect that destroys it). When these pests emerge, it is common for producers to turn to pesticides. EPM is not easy to implement and requires substantial knowledge and monitoring of the combined components to be successful. Perhaps the biggest drawback to the EPM approach is that biological control is not a 'quick fix'. In most cases, biological controllers will take several years to successfully establish a population and begin making a significant contribution. In addition, no single biological controller works in every situation. A controller that works well in one soil type, for example, may not work at all in another soil type. In the long run, more than one type of biological controller may have to be used to achieve uniform control across a variety of different situations and land types.

Sources

Frison E. A., C.S. Gold, E. B. Karamura, R. A. Sikora. 1998. Mobilizing IPM for sustainable banana production in Africa Proceedings of a workshop on banana IPM held in Nelspruit, South Africa, 23-28 November 1998, INIBAP.

Jahn, GC, B. Khiev, C Pol, N. Chhorn and V Preap. 2001. Sustainable pest management for rice in Cambodia. In P. Cox and R Chhay [eds.] "The Impact of Agricultural Research for Development in Southeast Asia" Proceedings of an International Conference held at the Cambodian Agricultural Research and Development Institute, Phnom Penh, Cambodia, 24-26 Oct. 2000, Phnom Penh (Cambodia): CARDI.

LEISA. 2007. Ecological Pest Management, LEISA Magazine, Volume 23, Issue 4

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel. 2005. Environmental, Energetic, and Economic Comparisons of Organic and Conventional Farming Systems, Bioscience Vol. 55 No. 7.

8.4 SEED AND GRAIN STORAGE

Application: Government extension staff, small-scale farmers and farmer groups

Description: Seed security is key to the attainment of household food security among resource poor farmers in Cambodia. Good storage helps ensure household and community food security until the next harvest and commodities for sale can be held back so that farmers can avoid being forced to sell at low prices during the drop in demand that often follows a harvest. While considerable losses can occur in the field, both before and during harvest, the greatest losses usually occur during storage. Therefore, the basic objective of good storage is to create environmental conditions that protect the product and maintain its quality and its quantity, thus reducing product and financial loss. There are two reasons for food storage: domestic security and maintaining value prior to sale. Farmers may not accept improvements that incur costs when storing primarily for home consumption because an improvement in the quality of a food produced for home consumption does not achieve a higher monetary value for the farmer. As regards to this technology's contribution to climate change adaptation, grain storage buffers against the impacts of drought to stave off hunger and malnutrition. Grain storage ensures availability of feed for livestock, as well as seed, following poor harvests due to drought. Efficient harvesting can reduce post-harvest losses and preserve food quantity, quality and the nutritional value of the product. The establishment of safe storage for seeds, food reserves and agricultural inputs are used as indicators of adaptive capacity in the agriculture sector.

In order to reduce the amount of food lost, the environment in the store needs to be controlled so as to lower the possibility of:

- biological damage by insects, rodents and micro-organisms;
- chemical damage through acidity development and flavour changes; and
- physical damage through crushing and breaking.

Good storage thus involves controlling the following factors: temperature, moisture, light, pests and hygiene. The table below is an overview of the storage condition requirements of certain food commodities. Most developing countries are in the tropics. They are often in areas of high rainfall and humidity, which are ideal conditions for the development of micro-organisms and insects, causing high levels of crop deterioration in storage. Thus, an assessment of different storage methods has to be undertaken before investing. Existing local methods are usually low-cost; adapting the existing, rather than introducing new technology, is often a more realistic economic option for households.

Commodities	Moisture/humidity	Temperature/light	Other
Cereals and pulses	Can be stored below their safe moisture level for periods of a year or more. Do not raise moisture levels	Under a wide range of temperatures	N/A
Seed for sowing	Moisture levels need to be low. Decrease of 1% in moisture content below 14% doubles storage time. Maximum drying temperature of 35°C. Full sun drying is not recommended	Cool storage is necessary 5°C decrease in temperature doubles storage time	Seed harvested when not fully ripe will lose its viability sooner than mature seed
Oil-bearing products	Keep moisture below 7% because fungal grows above that level	High temperature and exposure to light accelerates rancidity	N/A
Root and tuber crops	Keep humidity low to avoid rotting	Ventilation is needed to avoid rotting Yams can be stored for four months at normal temperatures (25-35°C), potatoes for only five weeks as they are sensitive to sunlight Use chill rooms for large-scale storage Ventilate store during coolest part of the day and isolate during hottest time	To increase storage life, use special treatment called 'curing' which consists of letting tubers grow layers of cork cells around the surface
Fruit and vegetables	N/A	Keep better when cooled but damaged by freezing. Simple evaporative air-cooled cabinets allow small farmers to store them. Underground storage in pits and cellars is used.	Surface waxing or wrapping prevents the spread of rot from one fruit to another. Keep in CO_2 rich atmosphere

Traditional and improved storage techniques are presented in the following table.

	Suitable for	Capacity/ storage time	Cost/materials
Traditional storage methods			
Earthenware pots and gourds	Cereals, beans, groundnuts, dried fruit and vegetables and seed material	5-30 litres Up to 1 year	Very low
Leaves	Dried fruits, vegetables and treacle	Variable Up to 1 year if unopened.	Low Banana leaves, string of sisal or other plant material
Bark	Cereals, particularly paddy and shelled maize	100 kg Up to 3 months	Labour
Baskets	Cereals, pulses, oilseeds, potatoes	Variable Up to 9 months	Low but considerable labour involved Reeds, grasses, palm leaves, bamboo
Sacks	Cereals, pulses and dried fruit	Up to 60kg Up to 1 year	Low Jute, sisal and cotton
Basket silos	Cereals and pulses	Up to a tonne Up to 1 year	Local material, time spent on construction Elephant grass, reeds, sorghum stalks
Roof storage	Cereals	Variable Up to 1 year	Wood for platform and labour Wood for platform
Maize cribs	Maize	Variable Up to 6 months	Labour and materials Variable
Underground pits	Cereals, pulses and root crops	Variable Up to 1 year	Labour Grass, straw, chaff and clay
Clamp storage	Tubers	Up to 500kg Up to 6 months	Labour Grass, straw
Small storehouses	Cereals and pulses	Variable Up to 1 year	Labour and materials Variable
Earth silos	Cereals and pulses	Variable Up to 1 year	Labour Earth, straw

	Suitable for	Capacity/ storage time	Cost/materials
Improved storage techniques			
Plastic bags	Sowing seed, cereals, pulses, groundnuts, copra	Up to 60 kg 6 to 9 months	Fairly high.\
45-gallon metal drums	Cereals, pulses and seeds	50-200 l Up to 1 year	Low, depending on availability Oil drums and water tanks
The Pusa bin	Cereals and pulses	400kg to 3 tons 6 to 12 months for well-dried crops	Medium/high, skill required Mud, cement or concrete, wood, plastic
Metal silos	Cereals and pulses	Up to 5 tons Approx. 1 year	Medium/high Sheet metal
Brick silo	Cereals and pulses	Up to 5 tons Up to 1 year	Medium/high Bricks, cement, reinforcing rod, wood for moulds, sheet metal
Cement-stave silo	Cereals and pulses	Up to 10 tonnes Up to 1 year	Medium/high Cement, sand, iron and wire
Thai ferro-cement silo	Cereals and pulses	4-6 tons 9 to 12 months	Medium/high Cement, sand, aggregate, mortar plasticiser, sealant for base, paint, chicken wire, rod, water pipe
Storage in ventilated huts	Cereals, pulses, root crops	Variable	Medium/high Local building materials
Improved pit storage	Cereals, pulses, root crops	Variable Up to 1 year	Medium Metal sheet, mud/dung/straw or plastic or ferro-cement lining

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high economic efficiency; (b) high degree of flexibility and scalability; (b) high relevance at community/farmer level; (c) high level of institutional feasibility; (d) highly equitable; (e) low negative impact on environment, and health and safety, (g) high level of acceptance; and (h) market orientated. It is considered to have a high impact on climate change adaptation because of improved post-harvest crop management and storage pest control. The negative aspects of this technology are minimal. Overall the option is considered to have a very high relative score within MCA.

Strengths

The establishment of safe, long-term storage facilities ensures that grain supplies are available during times of drought. It is important to be able to store food after harvest to prevent forced sales at low prices. Appropriate storing techniques can prolong the life of foodstuffs, and/or protect the quality, thereby preserving stocks year-round.

Limitations

The cleaning and drying of grain for storage are essential measures. However, difficulties to achieve the desired lack of excess moisture and foreign matter are frequently encountered. Failure to adequately clean and dry grain can lead to pest infestations. Over-drying of grains can also negatively impact seed quality. Losses of seeds from insects, rodents, birds and moisture uptake can be high in traditional bulk storage systems. Controlling or preventing pest infestation may require chemical sprays. Some markets will not accept seeds and grains treated with these chemicals.

Sources

BIAC (Business and Industry Advisory Committee to the OECD). 2009. Agriculture and climate change, Issues for consideration. November 2009, Paris, France

CARE. 2010. Guide for Integrating Climate Change Adaptation into Development Projects – Digital Guide – Version 1.0 CARE International, with technical input by the International Institute for Sustainable Development (IISD), July 2010.

FAO. 2010. “Climate-Smart” Agriculture – Policies, Practices and Financing for Food Security, Adaptation and Mitigation, FAO, Rome.

8.5 SYSTEM OF RICE INTENSIFICATION (SRI)

Application: Government extension staff, small-scale farmers and farmer groups

Description: The System of Rice Intensification (SRI) is a farming system that aims to help poor farmers increase yields with little external inputs, while being environmentally friendly. At its core, it is based on two main ideas: (a) as little irrigation as possible, with non-flooded fields to obtain a higher air flow to the soil and roots, and (b) the use of young seedlings transplanted one by one with wider spacing than normal (25cm x 25cm minimum). It suggests transplanting one seedling per hill as opposed to several seeds, as for traditional rice, and managing a drying and flooding regime of the soil leading to alternately anaerobic and aerobic conditions.

A new and modernised SRI technology could have the following characteristics:

- Use of young seedlings of 8-12 days old per hill, planted at a minimum distance of 25cm x 25cm apart.
- Regular hand weeding.
- Irrigation managed on a daily basis in order to maintain wet but not flooded soil in the vegetative stage. During the panicle stage the fields are flooded with 1-2 cm of water and 10-15 days before harvest time the fields are drained.
- Application of compost or organic residues in big quantities. If this is not possible or not present, no compost or organic residues should be applied or, mineral fertilizers should be applied.

SRI has been adopted by many resource poor farmers throughout the world. In Cambodia, Oxfam America began to introduce SRI to farmers as a pro-poor technique in 2000 and has found that Cambodian farmers can reduce the amount of seeds they need by 75% while increasing their yields from 30% to 150%. The organization also reports that rice plants grown using the SRI method are generally healthier, have better roots, and are more resistant to pests and diseases

During 2000, only 28 farmers participated in the SRI experimentation. Due to the early successes of SRI, MAFF has officially started endorsing and promoting SRI in 2005. Since then, SRI has been promoted in all provinces of Cambodia. Subsequently, SRI was included in the National Strategic Development Plan (NSDP) for 2006-2010 to raise productivity in the rice sector, and then in the revised NSDP for 2009-2013. Oxfam America now estimates that approximately 140,000 farmers practice some sort of SRI. Oxfam America reaches farmers through partner organisations, such as Center d'Etude et de Development (CEDAC), Preak Leap National School of Agriculture, and Rachana (a local NGO), that train and supervise farmers in the implementation of the system. Oxfam America and its partners fund training and supervision of farmers. There are at least 47 NGOs and development projects involved in promoting SRI in different parts of Cambodia. Since 2004, there is a national SRI secretariat hosted by MAFF's Department of Agronomy and Agriculture Land Improvement with technical support from CEDAC and funding support from GTZ, Oxfam America and Great Britain, FAO and HEKS (a Swiss NGO). Since then, the secretariat has been playing an important role in coordinating and assisting SRI activities in Cambodia, especially through the Provincial Departments of Agriculture. According to MAFF's Rice Department, by the end of 2009 there were 110,530 farmers employing SRI methods in Cambodia on 59,785 ha in 4,534 villages. The average SRI yield was calculated at 3.48 t/ha, about 1 t/ha more than the national average. CEDAC estimates that as of 2011, 100,000 families in Cambodia have applied SRI through the promotion of MAFF, their own NGO and other NGOs in Cambodia. During 2011, CEDAC promoted

SRI with 75,395 families on 24,293 ha of arable area in 2,317 villages across 268 communes in 45 districts of 13 provinces.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high economic efficiency; (b) high relevance at community/farmer level; (c) high level of institutional feasibility; and (d) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved crop and water management and high productivity per unit area of land. The negative aspects of this technology are its high labour requirements and low degree of scalability. Overall the option is considered to have a high relative score within the MCA.

Strengths

One major advantage of adopting SRI is that it can immediately improve the livelihoods of small-scale farmers. The system requires a minimal use of inputs and thus minimises farmers' dependency on suppliers and distributors of chemical inputs. It also benefits the activities generally under the charge of women, in particular if it is used in conjunction with other technologies, such as the hand-held weeding tool. Furthermore, from a climate change perspective, SRI may offer various benefits, such as reducing greenhouse gas emissions through the manipulation of aerobic and anaerobic growing conditions. In an environment where water supply can be controlled, this can lead to decreased water use. Compared with conventional farming, SRI produces higher yields. For instance, a study conducted in 2008 in Cambodia found that 80% of farmers surveyed in three villages in Kandal Province and two villages in Kampong Chhnang Province had better rice yields when using SRI compared with conventional rice farming systems. Interviews conducted for this study in Takeo Province revealed that lead farmers at least doubled their yields after two years of following the SRI completely. They also claimed to have reduced the use of chemical fertilizers by at least 50% and the need for labour decreased substantially as well.

Limitations

Other studies have found that farmers required more labour time for weeding (usually done by women) when applying the SRI system. Preparation of land was more difficult and more time was spent managing water in the field. It required a high level of water management, and plots had to be independently irrigated; hence an irrigation system should be properly designed and managed by farmers and water user groups.

Sources

Reissig, W.H., E. A. Heinrichs, J. A. Litsinger, K. Moody, L. Fiedler, T. W. Mew, and A.T. Barrion. 1986.

Illustrated Guide to Integrated Pest Management in Rice in Tropical Asia. International Rice Research Institute, Los Baños, Laguna, Philippines.

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

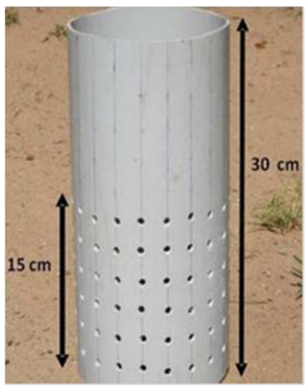
8.6 ALTERNATE WETTING AND DRYING RICE IRRIGATION

Application: Government extension staff, private sector, small-scale farmers and farmer groups

Description: Saving water with alternate wetting and drying (AWD) has a positive impact on water use especially in drought prone areas of Cambodia. AWD is a water-saving technology that farmers can apply to reduce their water use for irrigation in rice fields without decreasing yield. In AWD, irrigation water is applied a few days after the disappearance of the ponded water. Hence, the field is alternately flooded and non-flooded. The number of days of non-flooded soil between irrigations can vary from one to more than 10 days depending on a number of factors such as soil type, weather and crop growth stage.

How to implement AWD? A practical way to implement AWD safely is by using a 'field water tube' ('pani pipe') to monitor the water depth. After irrigation, the water depth will gradually decrease. When the water level has dropped to about 15 cm below the surface of the soil, irrigation should be applied to re-flood the field to a depth of about 5 cm. From one week before to a week after flowering, the field should be kept flooded, topping up to a depth of 5 cm as needed. After flowering, during grain filling and ripening, the water level can be allowed to drop again to 15 cm below the soil surface before re-irrigation. AWD can be started a few weeks (one to two weeks) after transplanting. When many weeds are present, AWD should be postponed for two to three weeks to assist suppression of the weeds by the ponded water and improve the efficacy of herbicide. Local fertilizer recommendations as for flooded rice can be used, and fertilizer applied preferably on the dry soil just before irrigation.

The field water tube or pani pipe (right), can be made of 30 cm long plastic pipe or bamboo, and should have a diameter of 10-15 cm so that the water table is easily visible, and it is easy to remove soil inside. Perforate the tube with many holes on all sides, so that water can flow readily in and out of the tube. Hammer the tube into the soil so that 15 cm protrudes above the soil surface. Take care not to penetrate through the bottom of the plough pan. Remove the soil from inside the tube so that the bottom of the tube is visible. When the field is flooded, check that the water level inside the tube is the same as outside the tube. If it is not the same



Field water tube made up of PVC (note the holes on all sides) after a few hours, the holes a probably blocked with compacted soil and the tube needs to be carefully re-installed. The tube should be placed in a readily accessible part of the field close to a bund, so it is easy to monitor the ponded water depth. The location should be representative of the average water depth in the field (i.e. it should not be in a high spot or a low spot).

A field tube in flooded field

Water at 15cm below the soil surface: Time to irrigate the field again

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high economic efficiency; (b) high relevance at community/farmer level; (c) high level of institutional feasibility; and (d) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation because of improved crop and water management and high productivity per unit area of land. The negative aspects of this technology are its high labour requirements and low degree of scalability. Overall the option is considered to have a high relative score within the MCA.

Strengths

The obvious benefit is water savings, which is particularly useful in the dry season when water is scarce and where there are droughts. This is particularly relevant to provinces of Cambodia at risk to the impact of climate change, especially Mondulkiri and north eastern Cambodia.

Limitations

Though the methodology is relatively simple it requires a degree of training for both the agriculture extension staff and the farmers. In this case, simple FFSs are appropriate.

Sources

IRRI. 2015. Riced Knowledge Bank.

http://www.knowledgebank.irri.org/training/fact-sheets/water-management/saving-water-alternate-wetting-drying-awd

9. SUSTAINABLE FARMING AND LIVELIHOOD SYSTEMS

In Cambodia, farming systems are more complex than just one single crop or livestock species. Ecological and productive resilience to climate change depends on managing a diversity of integrated production systems combining crops, livestock and trees. Mixed farming systems that integrate livestock, fisheries and crops, and agroforestry systems that can mix crops, trees and livestock present these integrated farming systems.

9.1 INTEGRATED RICE-FISH SYSTEMS

Application: Government extension staff, artisanal fishermen, small-scale farmers and farmer groups

Description: A rice-fish system is an integrated rice field or rice field/pond complex, where fish are grown concurrently or alternately with rice. Fish may be deliberately stocked (fish culture), or may enter fields naturally from surrounding waterways when flooding occurs (rice field fisheries), or a bit of both. Fish yields can range widely, from of 1.5 to 174 kg/ha/season depending on the type of rice fish system, the species present, and the management employed.

Indigenous fish capture systems in Tonle Sap

The most common indigenous fish [common name (Genus)] found in Cambodian rice fields include:

- White fish (small plant or plankton eating species) such as danios (*Rasbora*), barbs (*Puntius*), snakeskin gourami (*Trichogaster*), and half beaks (*Xenentodon*).
- Black fish (often carnivorous air breathers that can survive low or no oxygen levels) such as snakehead (*Channa*), catfish (*Clarias*), climbing perch (*Anabas*), spiny eels (*Mastacembelus*), and sheatfish (*Ompok*).
- Introduced exotic fish species such as common carp (*Cyprinus*), tilapia (*Oreochromis*), and silver carp (*Hypophthalmichthys*).

- Other wild aquatic species such as crabs, shrimp, snails, and insects may also be harvested.

Wild fish can be encouraged to enter rice fields by keeping entrances to fields open, and bunds low. They can be attracted by placing branches in the field, which provide shelter for the fish, or by placing buffalo or cow skins to attract catfish and eels. Wild fish may be harvested from rice fields by netting, hooking, trapping, harpooning, throwing nets, or by draining the field. As water levels fall, fish may be channelled into adjacent trap pond areas where they can be held alive until required. Black fish from trap ponds are often marketed live in local markets.

If water sources are more secure and the risk of flooding is low, farmers may invest in fish stock for their paddies or adjacent pond areas. Fish can be stocked at rates of 0.25-1 fish/m^2. An example stocking rate for Cambodia is: 2,500 common carp, 1,250 silver barbs and 1250 tilapia per hectare. Predatory fish, particularly snakehead, should be absent from the system when fish seed is introduced. If available and economic, feed supplements such as duckweed, termites, earthworms, and rice bran can be supplied. Similar harvesting methods as for rice field fisheries can be used. Harvests usually include a percentage of wild fish that have entered the system themselves.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high relevance at community/farmer level; (b) highly equitable; (c) high level of institutional feasibility; (d) low negative impact on environment, and health and safety; (e) market orientated; and (f) likelihood of acceptance. It is considered to have a low impact on climate change adaptation as a result of its high cost to the farmer, low economic efficiency, and low degree of scalability. Overall the option is considered to have a high relative score within the MCA.

Strengths

Rice-fish systems allow for the production of fish and other aquatic animals, as well as rice, from the same rice field area and generally without causing reductions in rice yields. This source of animal protein may be important for household nutrition and farm income.

Limitations

- Water control is crucial and rice fields cannot be allowed to dry up while fish stocks are present.
- Stocked fish may escape if fields flood. Flood control can be difficult in rain fed rice systems.

- Areas of rice fields deepened for fish culture may result in less rice growing area.
- Having fish present may help dissuade farmers from using pesticides. Pesticides have the potential for poisoning fish and some types can be absorbed by the fish and then ingested by humans.

Sources

Visit FishBase at: http://www.fishbase.org

Gregory R. 1997. Rice Fisheries Handbook, Cambodia-IRRI-Australia Project, Cambodia, 38p.

9.2 MIXED FARMING

Application: Government extension staff, small-scale farmers and farmer groups

Description: Mixed farming is an agricultural system in which a farmer conducts different agricultural practices together, such as cash crops and livestock. The aim is to increase income through different sources and to complement land and labour demands throughout the year. Mixed farming technology contributes to adaptation to climatic change because the diversification of crops and livestock allows farmers to have a greater number of options to face uncertain weather conditions associated with increased climate variability. Mixed farming can also result in more stable production because if one crop or variety fails, another may compensate for it. Livestock represents a means by which families can save and invest in the future. Livestock is a walking bank of assets that can be sold during periods of need such as when crops fail due to drought or flooding.

Mixed farming systems can be classified in many ways. They can be based on land size, type of crops and animals, geographical distribution, market orientation, and so on. Three major categories are distinguished here.

On-farm versus between-farm mixing: On-farm mixing refers to mixing on the same farm, and between-farm mixing refers to exchanging resources between different farms. On-farm mixing enables the recycling of resources generated on a single farm. Between-farm mixing can be used to resolve waste disposal problems whereby crop farmers use waste from animal farms for fertiliser.

Mixing within crops and/or animal systems: This practice involves multiple cropping or keeping different types of animals together. For example, grain/legume association can provide the grain with nitrogen. With plant inter-cropping, farmers can make the most of the space available to them by selecting plants and cropping formations that maximise the advantage of light, moisture and soil nutrients. Examples of mixed animal systems include chicken-fish production where chicken waste serves as fish fodder.

Diversified versus integrated systems: In a diversified system, some components exist as independent units. In an integrated system, maximum use is made of resources, making the system highly interdependent.

Implementing mixed farming improves and guarantees the range of products a farmer has available to sell at market. Specialisation is one option to increase productivity while maintaining economic and environmental benefits of mixed farming. Partnerships with specialised farms are formed to facilitate the exchange of crops and waste products from manure. An example is the traditional association between nomads and farmers. Farmers reap where nomadic cattle converted crop residues into manure, ready for cultivation. More recent developments include partnerships between dairy farmers and vegetable growers. Similarly, specialised organic farms in Europe exchange secondary products and crop residues for manure.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high relevance at community/farmer level; (b) high level of institutional feasibility; (c) low negative impact on environment, and health and safety; (d) market orientation; and (e) likelihood of acceptance. It is considered to have a high impact on climate change adaptation as a result of improved integration of the farming system. Overall the option is considered to have a very high relative score within the MCA.

Strengths

This technology also allows greater food security and improved household nutrition levels. In addition, farmers can generate a surplus of some products that can be sold at market. Among other benefits, this technology also allows farmers to grow fodder for livestock and poultry. An additional benefit of mixed rice-fish culture systems is that the fish may help reduce populations of existing and emerging disease vectors such as mosquitoes.

In many areas, the hungry season on farms arrives in the months just after the rains start, when producers need to invest labour in the planting and management of crops, but before they start to produce. Conversely, grass production starts with the rains, and livestock quickly gain weight and increase milk production. The high milk production during the wet season can greatly help support the nutrition of farmers while they are tending their crops and waiting for harvest. The advantages of mixed farming systems for the environment are as follows.

- Soil fertility is maintained by recycling soil nutrients. The introduction and use of rotations between various crops, forage legumes and trees are allowed, while land can remain fallow, allowing grasses and shrubs to re-establish.
- Soil biodiversity is maintained, soil erosion minimised, water conserved and suitable habitats provided for birds.
- The best use is made of crop residues. When they are not used as feed, stalks may be incorporated directly into the soil, which may temporarily trap nitrogen, creating nitrogen deficiency. Alternatively, burning the crop residues increases carbon dioxide emissions.

- Intensified farming is allowed, with less dependence on natural resources and preservation of more biodiversity than would be the case if food demands were to be met by crop and livestock activities undertaken in isolation.

Limitations

One limitation is that production levels in mixed systems (tons per hectare, daily milk per animal, increase and reproduction rates) can be lower than in specialised systems (monoculture). Another disadvantage is that when farmers depend on wild rather than domesticated species, they may face increased vulnerability when these species' numbers are affected by climate change. Partly because of overgrazing, some mixed farming systems in the tropical highlands of Asia are among the most eroded and degraded systems of the world. Integrating crops and livestock can help improve soil nutrient and reduce the stress on farming land.

Sources

European Commission. 2010. Mixed crop-livestock farming could help adaptation in Africa, Science for Environment Policy, DG Environment News Alert Service, EC, 18 March 2010

FAO. 1996. Livestock and the environment: Finding a balance, FAO, Rome.

FAO. 1999. Manual on Livestock Disease Surveillance and Information Systems, FAO, Rome.

FAO. 2001. Animal Production and Health. FAO. Rome.

9.3 AGROFORESTRY

Application: Government extension staff, small-scale farmers and farmer groups

Description: Agroforestry is an integrated approach to the production of trees and non-tree crops or animals on the same piece of land. The crops can be grown together simultaneously, in rotation, or in separate plots when materials from one are used to benefit another. Agroforestry systems take advantage of trees for many purposes: to hold the soil; to increase fertility through nitrogen fixation, or through bringing minerals from deep in the soil and depositing them by leaf-fall; and to provide shade, construction materials, foods and fuel. In agroforestry systems, every part of the land is considered suitable for the cultivation of plants. Perennial, multi-purpose crops that are planted once but yield benefits over a long period of time are given priority. The design of agroforestry systems prioritises beneficial interactions between crops. Trees, for example, can provide shade and reduce wind erosion. According to the World Agroforestry Center, "agroforestry is uniquely suited to address both the need for improved food security and increased resources for energy, as well as the need to sustainably manage agricultural landscapes for the critical ecosystem services they provide". Agroforestry is already widely practiced on all continents. Using a 10% tree cover as threshold, agroforestry is most important in Central America, South America, and South-East Asia.

Agroforestry can improve the resilience of agricultural production to current climate variability as well as long-term climate change through the use of trees for intensification, diversification and buffering of farming systems. Trees have an important role in reducing vulnerability, increasing resilience of farming systems and buffering agricultural production against climate-related risks. Trees are deep rooted and have large reserves, and are less susceptible than annual crops to inter-annual variability or short-lived extreme events like droughts or floods. Thus, tree-based systems have advantages for maintaining production during wetter and drier years. Second, trees improve soil quality and fertility by contributing to water retention and by reducing water stress during low rainfall years. Tree-based systems also have higher evapotranspiration rates than row crops or pastures and can thus maintain aerated soil conditions by pumping excess water out of the soil profile more rapidly than other production systems if there is sufficient rainfall/soil moisture.

Trees can reduce the impacts of weather extremes such as droughts or torrential rain. For example, a combination of Napier grass and leguminous shrubs in contour hedgerows reduced erosion by up to 70% on slopes above 10% inclination without affecting maize yield. Research has also demonstrated that the tree components of agroforestry systems stabilise the soil against landslides and raise infiltration rates. This limits surface flow during the rainy season and increases groundwater release during the dry season. Agroforestry can also play a vital role in improving food security through providing a means for diversifying production systems.

There is a broad range of classifications for agroforestry systems. These include: structural classification (composition, stratification and dimension of crops); classification based on the dominance of components (such as agriculture, pasture, and trees); functional (productive, protective or multi-purpose); ecological; and, socio-economic. Generally, however, agroforestry systems can be categorised into three broad types: agro-silviculture (trees with crops), agri-silvipasture (trees with crops and livestock) and silvo-pastoral (trees with pasture and livestock) systems. Agroforestry is appropriate for all land types and is especially important for hillside farming where agriculture may lead to rapid loss of soil. The most important trees for incorporating into an agroforestry system are legumes because of their ability to fix nitrogen and make it available to other plants. Nitrogen improves the fertility and quality of the soil and can improve crop growth. Some of the most common uses of trees in agroforestry systems are:

- Alley cropping: growing annual crops between rows of trees.
- Boundary plantings/living fences: trees planted along boundaries to mark them.
- Multi-strata: including home gardens and agroforests that combine multiple species and are particularly common in humid tropics such as in South East Asia.
- Scattered farm trees: increasing the number of trees, shrubs or shaded perennial crops (such as coffee and cocoa) scattered among crops or pastures and along farm boundaries.

Any crop plant can be used in an agroforestry system. When selecting crops, the following criteria should be prioritised:

- Potential for production.
- Can be used for animal feed.
- Already produced in the region, preferably native to the zone.
- Good nutritional content for human consumption.
- Protect the soil.
- A lack of competition between the trees and crops.

The table below shows the five stages of the design and implementation of an agroforestry system.

Stage	Basic Tasks
Diagnostic	Definition of the land-use system, site selection and physical characteristics (including altitude, rainfall, slopes, water supplies, soil condition, visible erosion) - basic background for evaluating the need for agroforestry and the local suitability of various techniques. Current uses of trees and shrubbery - suggests the kind of subsistence products that an agroforestry system would be expected to provide. Sales and purchases of agroforestry products (including poles, fruit, firewood, fodder, etc.) - provides data for economic analysis, and indicates opportunities to replace purchased items or to expand sales by raising agroforestry products Current tree planting (including species, source of seedlings, and intended use) - shows the present state of silvicultural knowledge. Farmers' perceptions of deforestation and erosion (including any perceived impact on crop yields) - gives a sense of how critical farmers think their problems are, and indicates current awareness of agroforestry relationships. Land and tree tenure - shows whether farmers have a right to their trees, and therefore whether they have an incentive to plant. Current yields Limitations to technology and finance access, farmer capacities and markets Survey of local knowledge and scope for domestication of wild food and medicinal plants.
Design and evaluation	How to improve the system? List potential benefits of an agroforestry system List agricultural production needs (meet food security, increase production to meet market demands and so on) Adoptability considerations: social and cultural acceptance; importance of local knowledge, practice and capacity; as well as equity and gender issues Characterise the crops desired by minimum space requirements, water and fertiliser needs, and shade tolerance Select the trees, shrubs, or grasses to be used.
Planning	If the system is temporary:

Stage	Basic Tasks
	- Plan the features of soil erosion control, earthworks, and gully maintenance - Plan spacing of fruit trees according to final spacing requirements - Plan a succession of annual or short-lived perennials beginning with the most shade tolerant for the final years of intercropping If the system is permanent: - Plan the proportion of the permanent fruit and lumber trees on the basis of relative importance to the farmer - Plan the spacing of long-term trees on the basis of final space requirements x 0.5 - Plan succession of annual and perennial understory crops, including crops for soil protection and enrichment - As large permanent trees grow, adjust planting plan to place shade tolerant crops in most shady areas
Implementation	On-farm trials of proposed agroforestry models to analyse impacts of trees on crops, testing harvesting regimes
Monitoring	On-going study and analysis of soil nutrition, moisture, and so on Watershed design study Measure the inputs and outputs of the system (including yields of trees and crops, and labour requirements) Survey of land-use Socio-economic benefit assessment

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) high relevance at community/farmer level; (b) moderate level of institutional feasibility; and (c) low negative impact on environment, and health and safety. It is considered to have a moderate impact on climate change adaptation as a result of its improved integration of forestry into the farming system. Negative issues are its high cost and high labour requirements. Overall the option is considered to have a medium relative score within the MCA.

Strengths

Agroforestry has a broad application potential and provides a range of advantages, including:

- Agroforestry systems make maximum use of the land and increase land-use efficiency.

- The productivity of the land can be enhanced as the trees provide forage, firewood and other organic materials that are recycled and used as natural fertilisers.
- Increased yields. For example, millet and sorghum may increase their yields by 50-100% when planted directly under *Acacia albida.*
- Agroforestry promotes year-round and long-term production.
- Creates employment – longer production periods require year-round use of labour.
- Protection and improvement of soils (especially when legumes are included) and of water sources.
- Livelihood diversification.
- Provides construction materials and cheaper and more accessible fuel wood.
- Agroforestry practices can reduce needs for purchased inputs such as fertilisers.

Limitations

Agroforestry systems require substantial management expertise. Incorporating trees and crops into one system can create competition for space, light water and nutrients and can impede the mechanisation of agricultural production. Management is necessary to reduce the competition for resources and maximise the ecological and productive benefits. Yields of cultivated crops can also be smaller than in alternative production systems, however agroforestry can reduce the risk of harvest failure.

Sources

FAO. 1991. Energy for sustainable rural development projects – Vol 1: A reader in Training Materials for agricultural Planning 23/1, Food and Agriculture Organisation, Rome.

Martin, F. W. and S. Sherman. 1992. Agroforestry Principles. ECHO (Educational Concerns for Hunger Organization).

Mutegi, J. K., D. N. Mugendi, L. V. Verchot, J. B. Kung'u. 2008. Combining Napier grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. Agro-forestry Systems, DOI 10.1007/s10457-008-9152-3.

Raintree, J. B. 1986. An Introduction to Agro-forestry Diagnosis and Design, International Council for Research in Agroforestry, Kenya.

10. CAPACITY BUILDING AND STAKEHOLDER ORGANISATIONS

As highlighted in the introduction, it is important to understand local contexts – especially social and cultural norms – when working with national and subnational stakeholders in Cambodia to make informed decisions about appropriate technology options. Furthermore, this is important for implementation of the various adaptation technologies at the grass roots community and farmer levels. Taking this into account, five key capacity building and stakeholder organisation interventions are detailed in this section: (a) community based agriculture extension; (b) farmer field schools; (c) forestry user groups; (d) water user associations; and (e) community based seed systems.

10.1 COMMUNITY BASED AGRICULTURAL EXTENSION

Application: Provincial and district Departments of Agriculture, NGOs, small-scale farmers and farmer groups

Description: 'Agricultural extension' describes the services that provide rural people with access to the necessary knowledge and information to increase productivity, sustain their production systems and improve their quality of life and livelihoods. Recent developments in agricultural policies have re-emphasised the importance of extension services[25]. However, models of extension based on government services or private agro-dealers and service providers are not sufficient to meet the needs of farmers in less favoured areas. This is due to a number of factors including the necessity to respond to the specific technological needs of farmer in different agro-ecological zones; high transaction costs of reaching remote areas; the need for localised crop and livestock management solutions suited to tough environmental conditions, which are often not well understood by extension agents trained for work in high potential areas; and the challenges of finding professional extension specialists willing to live and work in remote, and sometimes insecure areas.

The community-based rural agricultural extension model is based on the idea of providing specialised and intensive technical training to one or two people in a community to promote a variety of appropriate technologies and provide technical services (referred to as rural extensionists). A supporting organisation provides occasional support and review. This model is demand-based. The service providers are contracted directly by farmers' groups or communities to deliver information and related services that are specified by the farmers. These models have generally experienced a high degree of success in terms of discovering or identifying productivity enhancing technologies, which are then widely adopted. They have also been able to do so at relatively low cost.

The community-based rural extension model contributes to climate change adaptation and risk reduction by building the capacity of communities to identify and select appropriate strategies, in response to observed impacts of climate variability on their livelihoods. The model promotes a rural outreach programme that provides assistance to many communities that would otherwise not receive technical support services. As a result of these services, farmers have generally been able to increase crop and livestock production. This, in turn, has positive effects on family health and food security. In addition, rural extensionists have been instrumental in supporting local communities to develop affordable new products for local markets.

Farmer-to-farmer systems of extensions are based upon key principles:

- Motivate farmers to experiment with new technologies on a small scale;
- Use rapid, recognisable success in these experiments to motivate others to innovate;
- Use technologies that rely on inexpensive, locally available resources;
- Begin with a limited number of technologies to retain focus; and
- Train villagers as extensionists and support them in teaching other farmers.

In general, there are five stages to implementing the rural extensionists model:

Stage 1: Creating a space for public debate and institutional coordination

As a first step, it is necessary to stimulate debate around the role of rural extension services and technical capacity building in rural areas. This space should be created between communities and local public and private institutions. These could include state entities working on agricultural/livestock development, producer's associations, water user boards, agricultural/livestock research institutes, local universities, private agriculture and/or livestock companies and NGOs.

Stage 2: Establishment of training center

The next step is to establish an appropriate training entity with inter-institutional support. The design should be decentralised and sensitive to the local socio-cultural context. A group of technical experts is required to design and provide the training modules. A budget will be required for their remuneration, for materials and equipment and training activities.

Stage 3: Training rural extension agents

Training is designed to reflect the livelihoods of the local communities. In Cambodia, training could focus on fisheries, agriculture and livestock, particularly on rice production systems. Communities elect candidates against a list of agreed criteria and a consensus is reached on the best individual or individuals to be put forward. Training is organised with the participation of relevant district-level government staff, whose fees are paid from project budgets. Activities include visits to technology development and research centers, the establishment of trial testing and experimentation plots, and problem-solving workshops. Upon completing the training, participants should receive official certification from a state body.

Stage 4: On-going technical support and evaluation

Technical experts should be available to provide ongoing support to rural extensionists and undertake follow-up impact evaluation via household surveys. This information should be systematised and documented to feed into future programmes.

Stage 5: Knowledge refresher courses

Periodic refresher courses should be made available to rural extensionists. These courses should provide a space for participants to give feedback on their experiences and contribute to the improvement and refinement of training materials. This can be undertaken at the training center hub or through visits to extensionists' places of work in their respective communities.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) low costs to farmers; (b) low labour requirement; (c) high scalability/flexibility; (d) high relevance at community/farmer level; (e) highly equitable; (f) high level of institutional feasibility; (g) low negative impact on environment, and health and safety; and (h) high level of acceptance by community. It is considered to have a moderately low impact on climate change adaptation as a result of its indirect effect on this factor. Negative issues are few. Overall the option is considered to have a high relative score within the MCA.

Strengths

Rural agricultural extension programmes can help reduce the costs of extension services that emanate from the scale and complexity of centralised systems. Rural extensionists themselves benefit from the accumulation of new knowledge and technical skills and, through this, are able to generate additional income by charging for their services. The strengthening of social and professional networks via this model provides vital access to information and, by working directly with local producers and passing on acquired knowledge, rural extensionists are building the technical capacity of their communities. They learn, for example, to detect illnesses amongst livestock and implement preventive measures, thereby reducing the need for costly veterinary services. Other benefits include improved self-confidence and innovation on the part of rural extensionists.

Limitations

In terms of limitations, the model may face problems where rural farmers do not have the means or are not willing to pay for technical services. In societies where paying for information is not the norm, rural extensionists will have to work hard to earn trust and acceptance as a service provider who is able to charge and make profits within the community from which they originate. Wherever they work, it will take time for extensionists to build up the skills and client base and, providing inputs, establish their position and reputation. The model also depends on adequate technical expertise being available locally, either from civil society, NGOs, governmental or private entities, and the capacity of a local institution to adequately integrate this information into local know-how.

Sources

Bunch, R. 1982. Two Ears of Corn: A guide to people-centerd agricultural improvement, World Neighbours.

Coupe, S. 2009. Impact of Kamayoq (Community-Based Extensionists) in Canchis Province, Cusco Region, Peru, Internal Evaluation Report, Practical Action, Rugby, UK, 2009

FAO. 1997. Improving Agricultural Extension: A reference manual, FAO, Rome, 1997

Feder, G., J. R. Anderson, R. Birner and K. Deininger. 2010. Promises and Realities of Community Based Agricultural Extension, International Food Research Policy Institute, March 2010

Rivera, W. M., K. M. Qamar, and L. V. Crowder. 2001. Agricultural and rural extension worldwide: Options for institutional reform in developing countries. FAO. Rome. 2001

Scarborough, V. 1995. Farmer-led approaches to Extension, Papers presented at a Workshop in the Philippines, The Agricultural Research and Extension Network, ODI, July 1995

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

10.2 FARMER FIELD SCHOOLS

Application: Provincial and district Departments of Agriculture, NGOs, small-scale farmers and farmer groups

Description: A Farmer Field School (FFS) is a group-based learning process that has been used by a number of governments, NGOs and international agencies originally to promote IPM. The first FFS were designed and managed by the FAO in Indonesia in 1989, and has subsequently been used in Cambodia. They were developed in response to the perception that small farmers were not managing agrochemical-based agriculture well, particularly pest management through the use of pesticides. Many farmers did not have the resources to use pesticides, and sometimes incorrect use and storage caused poisoning. Furthermore, many pests seemed to rapidly develop resistance to the pesticides. FFSs bring together concepts and methods from agroecology, experimental education and community development, as a group-based learning process. Overall, FFSs look to reinforce farmer's understanding of the ecological processes that affect the production of their crops and animals, through conducting field learning exercises such as field observations, simple experiments and group analysis. The knowledge gained from these activities enables participants to make their own locally-specific decisions about crop management practices. Although FFSs were initiated as a training process for pest control in field crops, the principles have now been adapted to all agricultural production systems from livestock to coffee production.

The FFS approach represents a radical departure from earlier agricultural extension programmes, in which farmers were expected to adopt generalised recommendations that had been formulated by specialists from outside the community. The basic features of a typical rice IPM FFS are as follows:

- The IPM FFS is field-based and lasts for a full cropping season.
- A FFS meets once a week with a total number of meetings ranging from 10-16.
- The primary learning material at a FFS is the cropping field.
- The FFS meeting place is close to the learning plots, often in a farmer's home and sometimes beneath a tree.
- FFS educational methods are experiential, participatory, and learner centerd.
- Each FFS meeting includes at least three activities: the agro-ecosystem analysis, a 'special topic', and a group dynamics activity.

- In every FFS, participants conduct a study comparing plots with different management options.
- A FFS often includes several additional field studies depending on local field problems.
- Between 25 and 30 farmers participate in an FFS. To maximise participation, participants learn together in small groups of five.
- All FFSs include a field day in which farmers present the results of their studies.
- A pre- and post-test is conducted as part of every FFS for diagnostic purposes and to determine follow-up activities.
- The facilitators of FFSs undergo intensive, season-long residential training to prepare them for organising and conducting FFS.
- Preparation meetings precede a FFS to determine needs, recruit participants, and develop a learning contract.
- Final meetings of the FFS often include planning for follow-up activities.

The curriculum of the FFS was built on the assumption that farmers could only implement integrated crop management once they had acquired the ability to carry out their own analysis, make their own decisions and organise their own activities. The process of empowerment, rather than the adoption of specific management techniques, is what produces many of the developmental benefits of the FFS.

Climate change brings many complex and unpredictable changes that affect the viability and management of farming systems. Not only are there trends in the change of temperature and rainfall, but also increased climate variability especially in the duration and intensity of the seasons. This affects a whole range of conditions relating to the performance and management of different farming systems, from planting time, to flowering, to the prevalence of different pests and diseases. To cope with these increased variability farmers will need a greater understanding of the processes that affect the performance of the different production systems they manage. The production systems will need to undergo constant experimentation and adaptation. Even more than the agronomic knowledge that farmers acquire from participating in farmer field schools, the habits and abilities of constant adaptation are essential for farmers to be able to cope with climate change.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) moderately low costs to farmers; (b) high scalability/flexibility; (c) high relevance at community/farmer level; (d) high level equitable benefits; (e) high level of institutional feasibility; (f) low negative impact on environment, and health and safety; and (g) high level of acceptance by community. It is considered to have a moderately low impact on climate change adaptation because the effect on this factor is indirect. The impact stems from the type of FFS being implemented (e.g., integrated pest management). Negative issues are the difficulties of managing these types of trainings, especially if the farming community perceives there to be little economic benefit. Overall the option is considered to have a medium relative score within the MCA.

Strengths

FFSs represent an effective mechanism to disseminate knowledge and technical content to thousands of small-scale farmers, which can be adapted to their own unique circumstances. Beyond this, as has been indicated, these processes empower farmers, both individually and collectively, to more effectively participate in the processes of agricultural development.

Limitations

Educating farmers through FFS requires more time from both farmers and extensionists than simple technology transfer or technical recommendations. The experimentation conducted may initially generate more failures than successes, but so too have technical recommendations in the contexts of small farmer agriculture. In the medium-term, farmer participation in FFS leads to more sustainable impacts. FFSs require substantial changes to the capacity of agricultural extension services, both in terms of the policies of agricultural development and the abilities of those who execute it. Re-training of agricultural extension services represents an investment, but resistance at all levels can be a significant impediment. Also, since FFS has become a popular concept, there is the danger that the name is used for any kind of group training that does not follow the concepts of building the learning capacity of the participants.

Sources

Bartlett A. 2005. Farmer Field Schools to promote Integrated Pest Management in Asia: the FAO experience, Workshop on Scaling Up Case Studies in Agriculture. IRRI

Bijlmakers, H. 2005. Farmer Field Schools for IPM – Refresh your Memory, IPM DANIDA

Feder, G., R. Murgai, and J. B. Quizon. 2004a. “Sending Farmers Back to School: The Impact of Farmer Field Schools in Indonesia”. Review of Agricultural Economics 26, no. 1 (2004a): 45-62

Feder, G., R. Murgai, and J. B. Quizon. 2004b. ‘The acquisition and diffusion of knowledge: The case of pest management training in farmer field schools, Indonesia’. Journal of Agricultural Economics 55, no. 2 (2004b): 221-43

Global Farmer Field School Network and Resource Center: http://www.farmerfieldschool.info/and www. share4dev.info/ffsnet/documents/3155.pdf.

Pontius, J., R. Dilts, A. Bartlett. 2002. Ten Years of IPM Training in Asia – From Farmer Field School to Community IPM, FAO

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

10.3 FORESTRY USER GROUPS

Application: Government extension staff, small-scale farmers and farmer groups

Description: In many countries, forest governance has remained a centralised and top-down process. Policies ignore the role of forests in tribal livelihoods and cultures, violating the overlapping laws protecting the rights of these communities. Premises and procedures for identifying and defining forests are poor, resulting in land use conflicts, unclear boundaries, legal disputes and inappropriate management objectives for lands wrongly classified as 'forest'. Forest User Groups (FUGs) represent one mechanism for decentralising forest management and increasing community-based responsibility and authority. FUGs are based on the three principles of participation, collective action and long-term sustainability. They are formed through democratic processes whereby local residents are elected as community representatives to work as an autonomous body alongside existing government authorities to manage forest resources and to articulate the needs and priorities of local people. FUG members may receive training in resource management and participate in multi-stakeholder forest management mechanisms, develop land-use plans in line with national forest laws and regulations, and undertake forest patrols and awareness-raising with the aim of curbing illegal activities.

There are four, principal phases to implementing a FUG:

- Baseline information assessment of forest users and introductory community meetings to discuss and define objectives and processes and identification of forest boundaries and local needs and priorities
- Preparation of a FUG constitution (roles and responsibilities) and a forest management operational plan, in liaison with local government authorities
- Election of forest user executive committee
- Formal authorisation of the elected committee and FUG by local/district forest office and commencement of operations

FUGs provide a platform through which communities can directly participate in the identification of local problems, needs and possible solutions to climate change and disaster risk. If local communities have systematically assessed their situation and know clearly what they need to best adapt to climate change impacts, they can then effectively contribute to district level plans. These in turn can inform regional and national adaptation plans and programmes. In some contexts, FUGs can also provide an effective vehicle for collective community action on a broader range of development activities. These activities include initiatives for improved education, health, sanitation, rural infrastructure and safe drinking water – all of which build the capacity of a community to adapt to future challenges and opportunities presented by climate change.

When setting up a FUG it is important to understand the dynamics of the local communities and to ensure participation from a representative range of community members. A full forest resource assessment should be carried out, preferably using two methods: a participatory appraisal involving community members, and cross-referenced with quantitative data logged with GIS technology. This inventory can then be used for monitoring purposes. Knowledge of livelihood activities, labour inputs, forest products flows (including sources, species, and the timing of sales and expenditure), is vital for understanding the potential benefits of FUGs, for identifying FUG objectives and for making a basic economic calculation of the return from local forest resource management.

Undertaking a financial analysis of a FUG system, in which the benefits and costs to different stakeholders can be calculated, can make equity issues more transparent and can be used as a tool for consultation and negotiation within the FUG. Financial indicators can also be used to ensure on-going accountability and transparency of the FUG process, thereby empowering poorer members of the FUG. Awareness about forestry policy and procedures is also a fundamental requirement as understanding land rights is essential for formulating appropriate livelihood and conservation strategies. For example, a landless farmer is likely to be more interested in generating an income from cash crops than investing time and effort into practices (such as agro-forestry) that yield benefits over the longer term. Likewise, understanding local markets and the demand for forest products is essential for establishing an effective FUG strategy.

Contribution to climate resilience: The key benefits from this adaptation option are as follows:

- Low costs to farmers
- High economic efficiency
- High relevance at community/farmer level
- Moderate-level equitable benefits
- High level of institutional feasibility
- Low negative impact on environment, and health and safety
- High level of acceptance by community

It is considered to have a high impact on climate change adaptation as a result of its direct effect on improved forest management and conservation. Negative issues are few. Overall, the option is considered to have a very high relative score within the MCA.

Strengths

Where FUGs are recognised by local government authorities, restoration of land and forest rights can provide indigenous communities with vital access to resources to strengthen and diversify livelihood activities and build their resilience to possible impacts of climate change. Environmental benefits can include increased biodiversity and ecosystem resilience through local species conservation, reforestation schemes and decreased rates of illegal logging. Environmental improvements have also been experienced in cases where common property systems for forests have been introduced, leading to more sustainable use and collection of forest products. FUGs have been successfully established in many provinces of Cambodia through the Department of Forestry and Wildlife.

Limitations

Limitations of FUGs emerge when groups only consist of powerful community members and the poorest and most marginalised members receive the fewest benefits. Conflicts can arise where resource use amongst local residents is factionalised and diverse. In communities where there is less tradition of working communally, motivation to participate and to understand the benefits of joint-action can be difficult to stimulate and sustain.

Sources

Eagle, S. 1992. Experiences with a Heterogeneous Forest User Group in the Far West of Nepal, Rural Development Forestry Network Papers, 13 e-iv, Overseas Development Institute, London, UK, 1992

Ensor, J. 2009. Biodiverse agriculture for a changing climate. Practical Action, Rugby, UK. 2009

Mohan, A., N. Shin, and A. Murali. 2003. Decentralisation, Local Institutions and Forest Management in Chitwan District of Nepal, paper submitted to the XII World Forestry Congress, 2003, Canada

Regmi, B. R., A. Morcrette, A. Paudyal, R. Bastakoti and S. Pradhan. 2010. Participatory Tools and Techniques for Assessing Climate Change Impacts and Exploring Adaptation Options: A Community Based Tool Kit for Practitioners, Livelihoods and Forestry Programme, Nepal, 2010

Richards, M., K. Kanel, M. Maharjan and J. Davies. 1999. Towards participatory economic analysis by forest user groups in Nepal, ODI, June 1999

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

10.4 WATER USER ASSOCIATIONS

Application: Government agriculture and water resources extension staff, small-scale farmers and farmer groups

Description: A Water User Association (WUA) is an organisation for water management made up of a group of small and large-scale water users, such as irrigators, who pool their financial, technical, material, and human resources for operation and maintenance of a local water system, such as a river or water basin. The WUA is usually run out of a non-profit structure and membership is typically based on contracts and/or agreements between the members and the WUA. The WUAs play a key role in integrated approaches to water management that seek to establish a decentralised, participatory, multi-sectorial and multi-disciplinary governance structure, and in this way help to mitigate impacts of climate change.

A WUA is a unit of individuals that have formally and voluntarily associated for the purposes of cooperatively sharing, managing and conserving a common water resource. The objectives of a WUA commonly include:

- Conservation of water catchments
- Sustainable water resource management
- Increase availability of water resources
- Increased usage of the water for economic and social improvements
- Development of sustainable and responsive institutions

The core activity of a WUA is to operate the waterworks under its responsibility and to monitor the allocation of water among its members. Key functions of a WUA include:

- Exchange information and ideas on water resource use
- Monitor water availability and use
- Provide technical assistance in areas such as soil, water and crop management, livelihood diversification, marketing, finance and savings
- Discuss potential projects and developments that may affect water usage
- Operate and maintain a water service or structure (such as water mill, canal, or irrigation)
- Management of a water distribution system, including setting tariffs and collecting fees

- Resolve conflicts related to water use
- Representation of stakeholder needs at higher institutions of water management

A WUA can contribute to adaptation to climate change by providing a cooperative mechanism through which the following activities can be undertaken:

- Monitor the impact of climate change on water resources
- Empower water users and decision-makers to manage and allocate water resources with consideration for climate change, the environment and other technical information through consultative processes
- Promote basin-level participation in national climate change and water management processes
- Develop and disseminate awareness materials on the implications of climate change and various likely water resource scenarios among local authorities, decision makers, communities and the private sector
- Provide data for modelling possible environmental, economic and social impacts of climate change resulting from changes in water resources
- Prioritise investment needs for water management adaptation strategies, such as irrigation, and monitor their effectiveness

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) moderately low costs to farmers; (b) high economic efficiency; (c) high relevance at community/farmer level; (d) high level of institutional feasibility; and (e) low negative impact on environment, and health and safety. It is considered to have a high impact on climate change adaptation as a result of its direct effect on improved water management. Negative issues are related to equity. Overall the option is considered to have a high relative score within the MCA.

Strengths

WUAs can play a critical role in changing from centralised control of natural resources to local management. This is particularly important for climate change adaptation efforts whereby local monitoring of water resources, improvements in infrastructure (such as canals and irrigation) and public participation in decision-making leads to more reliable and equitable distribution of supplies. This can lead to improved agricultural productivity, which in turn helps to raise incomes and contributes to local and national food security. An analysis of several schemes in Cambodia found that by supporting livelihood diversification and making improvements to water management infrastructure, WUAs had a direct role in increasing agricultural productivity and income-earning opportunities of farmers. The formation of a WUA can also generate positive impacts for the environment. For example, improvements to canal and irrigation schemes can reduce water logging and salinity problems. By providing technical assistance to local farmers, WUA members can also have a direct impact on improving soil, water and crop management practices.

Limitations

The cooperative model of organisation on which the WUA approach is based can have disadvantages if the area of operation does not match a hydraulic boundary and may actually stimulate conflict over resource use (for example, in the Cauvery River in Southern India). Conflicts related to irrigation farming occur between upstream and downstream farmers when the upstream farmers are (perceived as) using too much water. A WUA could heighten conflict between users where its membership is based on an existing community boundary rather than a representative selection of all water users within a particular system.

Sources

Chambouleyron, J. 1989. The reorganisation of Water Users Associations in Mendoza, Argentina, Irrigation and Drainage Systems 3: 81-94. 1989

INPIM. 2010. Demonstrating Enhanced Productivity of Irrigated Agriculture System through Multifunctional Water Users Associations, Mid-Term Report, INPIM Nepal, July 2010

IWMI (International Water Management Institute) and SIC ICWC (the Scientific Information Center Interstate Commission for Water Coordination). 2003. How to Establish a Water Users Association, IWMI and SIC ICWC, March 2003

SNV. 2013. Study on Good Practices in Agricultural Adaptation in Response to Climate Change in Cambodia. SNV Netherlands Development Organisation.

http://www.snvworld.org/en/regions/asia/publications/Study-on-Good-Practices-in-Agricultural-Adaptation-in-Response-to-Climate-Change-in-Cambodia

UNESCO, Water Users Association for Sustainable Water Management: Experiences from the irrigation sector in Tamil Nadu, India, UNESCO, no date

10.5 COMMUNITY BASED SEED SYSTEMS

Application: Government extension and seed production staff, private sector, small-scale farmers and farmer groups

Description: Good seed underpins more sustained rice and other crop production systems and livelihoods. In marginal rice-based upland ecosystems, seed sourcing is generally a major concern. With low productivity, low income, and limited economic opportunities, farmers have limited access to seeds sourced off-farm or from formal seed systems; more so, their seeds are of inferior quality. Private seed growers usually do not find it feasible to invest in uplands and remote rain fed areas. Securing good seeds means securing farmers' livelihood but inaccessibility, lack of a market, and elusive agricultural information add upland farmers being considered as the poorest among the poor.

One reason why the informal seed system in the uplands has drawn attention among rural development workers, is that it protects biodiversity. There is an evolving focus on Community Based Seed Systems (CBSS), or community seed banks (CSBs) but many models are governed by common objectives, scope of services, elements and processes. The system is defined as an informal arrangement wherein a farming community or a group of farmers has established a scheme or collective system of producing and exchanging or selling good-quality seeds, especially in times of disasters or seed shortages. Arrangement can vary, from simple exchanges on agreed terms and conditions to a more systematic selling or trading of seeds within a locality or an extended geographic reach, such as in a seed network or seed Net.

Quality seeds refer to seeds produced in either formal or informal seed systems that pass a set of standards (formal) or their equivalent (agreed purification standard for an informal system).

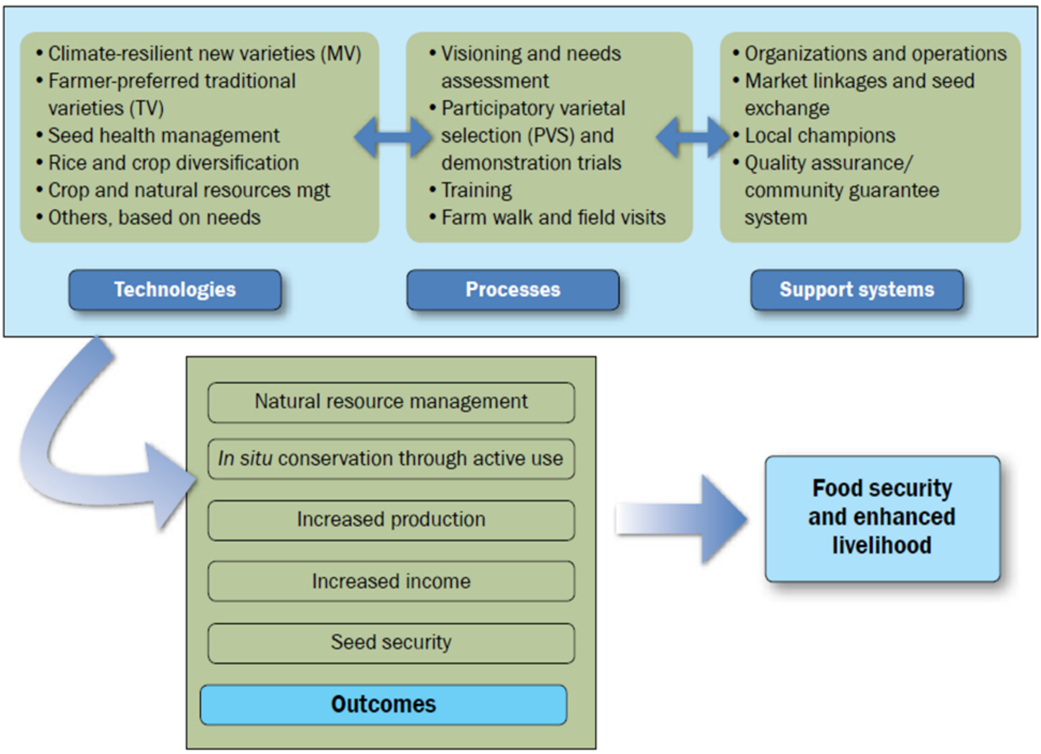
A better harvest of good quality seeds

As differentiated from a formal seed system, in community based seed systems, good quality of seeds is ensured under a "community-established guarantee" system that approximates seed certification under a formal system. In different countries, good-quality seeds are oftentimes labelled or referred to as "truthfully labelled seeds," "extension seeds," "R3 seeds," "farmers' quality seeds," or "quality seeds," as differentiated from formal or commercial "certified seeds."

Formal seed systems cover seed production and supply mechanisms that are ruled by defined methodologies and controlled (stages of) multiplication, and are backed by national legislation and international standardization of methodologies. This also includes research, multiplication, processing, distribution and uptake, transport, and storage of seeds. The role of the formal seed sector (private and government) normally concentrates on seed production and marketing, with appropriate compliance with government policies and regulations. This may include direct government involvement and the public sector via national, provincial, or state seed corporations, accredited seed growers, multinational or transnational companies and seed movement, the local private sector with or without its own research and development, and joint ventures of local and foreign entities. Informal seed systems are systems wherein the farmers themselves produce (a certain portion of their own harvest), disseminate, or access seeds directly through exchange, barter, or purchase from within their communities or neighbouring villages through relatives, friends, and neighbours. The seeds may be of variable quality and the

Roguing a seed rice field and Inspecting a seed rice crop at harvest time distinction between seeds and grains is not always clear. This may include NGO-supported seed multiplication and supply programs, community seed production, CSBs, seed fairs, farmers' associations, farmer-to-farmer exchanges, and participatory plant breeding. These, in many developing countries, supply more than 80% of their seed needs.

Another definition is one in which a CSB stores seeds from a wide range of individuals, informal groups, and NGOs that share seeds among themselves, although at times only occasionally. In this case, farmers retain certain amounts for seeds from their own harvests for the next cropping season. CBSS can have as its secondary objective the in-situ conservation of traditional farmers' varieties; but the overriding objective is the supply of good quality seeds within the farm reach. In situ conservation refers to "the conservation of ecosystems and natural habitats and the maintenance and recovery of viable population and species in their natural surroundings and in the case of domesticated or cultivated species in the surroundings where they have developed their distinctive properties" (Article 2, International Treaty on plant genetic resources for food and agriculture, 2009. FAO). Farmers inspect the rice fields for any sign of pests and diseases, as part of ensuring better quality of seeds being produced.



Flow diagram of Community Based Seed Systems (CBSS)

CBSS house consolidated technologies—varieties and management practices—that are available, adaptable, and easily disseminated.

The farmer-to-farmer seed flow is imperative in genetic conservation and to introduce and spread new technologies and information for rural innovations. Hence, CBSS serve as an avenue for interventions that can drive livelihood improvements and that can capitalize on an organised system of farmers. A wider scale, even outside intervention or project support, can be reached in this way. Farmers not only exchange seeds but also information, derived from either external sources or their own experimentation. Through the CBSS mechanism, any transaction is built on trust and in-field trials with results that can be easily shared with other farmers.

Contribution to climate resilience: The key benefits from this adaptation option are as follows: (a) moderately low costs to farmers; (b) high economic efficiency; (c) high degree of saleability; (d) high relevance at community/farmer level; (d) high level of institutional feasibility; (e) low negative impact on environment, and health and safety; and (f) market orientation. It is considered to only have a moderate impact on climate change adaptation as a result of its indirect effect on seed supply. Negative issues are related to equity and the ease of use of the technology. Overall the option is considered to have a high relative score within the MCA.

Strengths

The CBSS is an extension tool that aims to increase farmers' access to quality seeds, controlled and operated by farmers within the community. CBSS encourages seed production and exchange among farmers within and outside the community and between farmers and breeding institutions for greater diversity. For this concept to work, the modality includes introduction through the participatory varietal selection (PVS) process. A basket of options is disseminated to meet varying farmers' preferences for a combination of modern variety (MV) and farmers' variety (FV) seed. Many communities combine the conservation of time-treasured traditional varieties that exhibit traits of significant socioeconomic value to farmers (FVs). This allows for the introduction of new climate-ready or stress-tolerant varieties (MVs) and the corresponding natural resource management options that maximize gains from the new varieties.

Limitations

The concept of CBSS relies on a strong and cohesive farm group in order to facilitate the production, storage and transfer of quality seed. Support is also required from technical departments in government or from NGOs. Marketing is also a big issue that needs to be addressed.

Sources

FAO. 2009. International Treaty on Plant Genetic Resources for Food and Agriculture. A global treaty for food security and sustainable agriculture.

Lewis V, Mulvany PM. 1997. A typology of community seed banks. Natural Resources Institute, University of Greenwich, United Kingdom. NRI Project A0595.

Manzanilla DO, Janiya JD, Johnson DE. 2013. Establishing community based seed systems: a training manual. Los Baños (Philippines): International Rice Research Institute. 215 p.

Manzanilla DO, Hondrade FD, Vera Cruz CM Johnson DE. 2011. Improving food security through community-based seed systems in the rainfed rice areas of Asia. SEARCA Policy Brief Series. 2011-4.

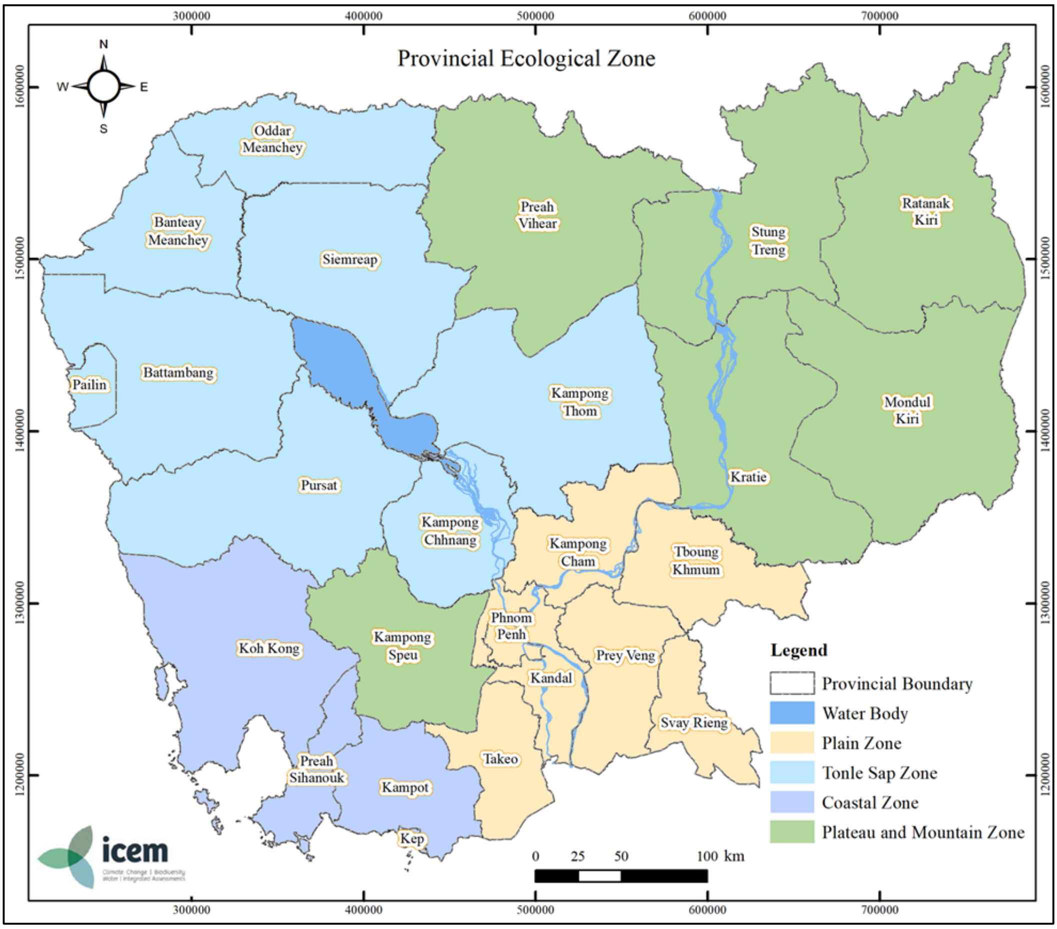
Proceso J. Alcala. 2009. Guidelines on the implementation of community-based seed banks (CSBs). FAO.

Redoña E. 2011. Varietal release systems in Asia: updates to enhance access of marginal farmers to seeds of new varieties. Presentation at the Mini-symposium on “Delivering seeds to farmers in the unfavourable rice areas through national and community seed systems.” 10th CURE Review and Steering Committee Meeting. Kathmandu, Nepal, 18-20 April 2011.

C ADAPTATION TECHNOLOGIES AND CAMBODIAN ECOZONES

11. INTRODUCTION

This section attempts to match the adaptation options discussed in Part B to the specific conditions and requirements of the four ecozones in Cambodia, namely: coast, delta, Tonle Sap, and plateau and mountains. The provincial location of these ecozones is presented in the figure below.



Cambodia's provincial ecological zones

The four ecozones can be briefly summarised as follows:

Coast: This zone includes areas of four provinces (Koh Kong, Preah Sihanouk, Kampot and Kep) and is projected to be vulnerable to sea-level rise and increased salinisation, with impacts anticipated for agriculture, fisheries and safe drinking water. Mangrove ecosystems and coastal areas are especially vulnerable, and their degradation can intensify climate change vulnerability. Poverty levels within the coastal zone are high, with few alternative employment options other than tourism in selected locations. Coastal resources are coming under greater pressure particularly from tourism development, industrialisation and urban expansion.

Delta: This area comprises of the four provinces from Phnom Penh to the Vietnam border (Takeo, Kandal, Prey Veng and Svay Rieng), which include the Mekong and Basac floodplains. It is one of the main agriculture production areas, already susceptible to floods, drought and siltation, all causing agricultural losses and soil degradation. While poverty levels are not as high as in other parts of the country, the relative high population density means that there are many people who are vulnerable to climate stress within this zone.

Plateau and mountain: This zone covers the upper stretches of the Mekong River and its tributaries (the Sekong, Sesan and Srepok rivers in the north-east) as well as other upland areas, such as the Cardamom Mountains. These forested uplands contain a diverse range of relatively undisturbed old-growth rainforest and support globally significant biodiversity. The zone consists of sparsely populated areas of semi-subsistence shifting cultivation, but recent land use change has given rise to increasing pressure from encroachment of agricultural land for plantations, grazing, deforestation and mining. More pressure is occurring with regard to livelihoods dependent on natural hydrological systems in the watersheds and productivity in the natural forests. The zones include some of the poorest areas of Cambodia and faces numerous development constraints.

Tonle Sap: This particular zone covers the central region of Cambodia which includes the provinces surrounding the Tonle Sap Lake, and those lowland areas along the Mekong above the delta ecozone. Agriculture is of central importance to this zone, particularly rice cultivation. Climate change it is anticipated will have serious implications for the farming communities around the lake, especially those which are reliant on the cultivation of recession rice. With a large concentration of poor people and heavy dependence on agriculture and fisheries, the Tonle Sap ecozone stands out as being particularly vulnerable to climate change, more especially drought in the dry season.

Adaptation responses proposed for the most vulnerable commodities and situations across the four ecozones are highlighted. For each response, a timeframe is defined, as well as a possible interaction (positive or negative) with other sectors.

An example of the main adaptation options for these ecozones are summarised in the table below. This broad list of options indicates the range of possible adaptation measures, many of which are not directly associated with infrastructure development. However, in order for climate change vulnerabilities to be reduced, an integrated development strategy and implementation program will in most cases be necessary.

	Coast	Delta	Tonle Sap	Plateau & mountains
Increased temperature	Minimal impact	Shift in cropping calendar to avoid peak temperature Early maturation varieties	Shift in cropping calendar to avoid peak temperature Early maturation varieties	Altitude shift Change crops to heat tolerance species Shading
Drought	Small-scale water storage: (i) Household water ponds (ii) Community ponds Groundwater wells and drip irrigation Early maturing & drought tolerant varieties	Small-scale water storage: (i) Household water ponds (ii) Community ponds Groundwater well and drip irrigation SRI technique Early maturing & drought tolerant varieties (dry season) Intercropping and rotating crops based on crop varieties, water requirements and water availability Drip irrigation	Small-scale water storage: (i) Household water ponds built (ii) Community ponds Groundwater well and drip irrigation Intercropping and rotating crops based on crop varieties, water requirements and water availability. Mulch/permanent cover SRI technique Conservation tillage Drought-tolerant varieties Drip irrigation	Small-scale water storage: (i) Household water ponds built (ii) Community ponds Drip irrigation Mulch/ permanent cover Alternative upland cropping systems Early maturing & drought tolerant varieties
Increased rainfall, storms and extreme events	Coastal protection infrastructure Seawater protection dike	SRI technique Improve drainage Shift to water logging-tolerant varieties Small-scale water storage:	SRI technique Improve drainage Shift to water logging-tolerant varieties Rainwater collection Small-scale water storage:	Mulch/ permanent cover Shift cropping calendar SALT Build reservoir to store water Small-scale water storage:

	Coast	Delta	Tonle Sap	Plateau & mountains
		(i) Household water ponds (ii) Community ponds	(i) Household water ponds (ii) Community ponds Shift in cropping calendar to avoid flood damage Early maturing & flood tolerant varieties	(i) Household water ponds (ii) Community ponds
Floods	Early maturation and submergence-tolerant varieties Flood protection infrastructure	Small-scale water storage: (i) Household water ponds (ii) Community ponds Shift cropping calendar Early maturation varieties Submergence-tolerant varieties Fish culture in flooded rice fields -rice field fisheries	Small-scale water storage: (i) Household water ponds built (ii) Community ponds Shift cropping calendar Early maturation varieties Submergence-tolerant varieties Fish culture in flooded rice fields - rice field fisheries	Minor importance Shift cropping calendar Develop small-scale water storage: (i) household water ponds (ii) community water ponds
Saline intrusion	Sea rise protection infrastructure Early maturation and saline-tolerant varieties	Early maturation and saline-tolerant varieties Small-scale water storage: (i) Household water ponds built (ii) Community ponds	N/A	N/A

Source: Adapted from USAID Mekong ARCC Agriculture Adaptation Report (2013)

The adaptation options presented here are both generic and detailed across the four main ecozones, and focus on the provincial level and below. Before preparing a project feasibly study for funding in agriculture, a precise and detailed diagnostic of the farming systems will be required, as will an evaluation of the needs and capacity of the targeted communities in order to fine-tune the field level approach. Past experience with related interventions in the target communities have to be assessed in order to understand underlying drivers of success and failure.

These adaptation options are based on previous experience within Cambodia and the region, and on the findings of MCRDP in the four ecozones. Each of the technical options identified is oriented towards developing more resilient production systems. Interactions with other sectors have not been explored in depth, particularly interactions with the economic sector. Extrapolation to a larger scale of crops or a production system shift is not an easy task since new varieties tolerant to climate stress, market drivers, and national policies concerning land use or agriculture, can have a larger impact on the local agriculture sector compared to changes in rainfall patterns or temperatures.

It should be noted that communities across Cambodia have varying levels of capacity to prepare for and manage flood- and drought-related issues due to climate change. Actions are presently mostly reactive, rather than proactive, and are uncoordinated. Better flood and drought impacts require preparedness in the following areas: (i) knowledge availability and sharing of potential changes to the spatial and temporal distribution of climate and hydrological variables over the basin as a whole; (ii) capacity for timely flood and drought forecasting and dissemination of warnings to communities at risk; (iii) engagement of at-risk communities in the identification, analysis, treatment, monitoring, and evaluation of disaster risks to reduce their vulnerabilities and enhance their coping capacities; and (iv) improved condition of water control infrastructure.

Improving the climate change preparedness of provinces and communities to manage and mitigate the potential impacts of extreme floods and droughts requires both structural and non-structural initiatives. In terms of non-structural measures that are the main purpose of this guide, institutional and technical capacity building activities can strengthen regional information and knowledge generation and sharing with regard to water resources management in general and flood and drought management in particular. Community-based disaster risk management (CBDRM) can equip communities, especially women, to access information on risks and enhance their preparedness. Two-way channels for information sharing between local communities, river basin management systems, national early warning centers, and disaster forecasting centers are necessary. Structural measures include rehabilitation of flood control embankments, water control structures, and irrigation and drainage structures.

Social aspects are key to enhance the capacity for community-based climate change risk management. CBDRM activities need to be implemented to ensure that communities are able to obtain the full benefit from upgraded water control infrastructure and improved flood warnings. Community driven flood and drought risk reduction measures should be implemented based on participatory local flood and drought risk assessment and analysis, and disaster risk reduction and management plans. FWUCs will receive training and support to effectively undertake their role as managers of the tertiary and distribution irrigation system. They will be supported in climate adaptation measures to diversify their crops and reduce crop irrigation requirements for dry and early wet season crops. All this needs to be taken into account when preparing the agricultural based feasibility studies particularly for prospective projects planned for in the delta and Tonle Sap ecozones.

Further information on the types of agriculture adaptation technologies and their suitability for each of the four ecozones in Cambodia is presented in Annex 1. In this table (Annex 1: Agriculture Adaptation Technologies in ecozones of Cambodia) key information is provided on the range of technologies best suited to an ecozone(s), which stakeholder would be involved in the application of the technology, and which of the SPCR Investment projects this scenario applies to.

12. COAST ECOZONE

As regards to agriculture and natural resource management in the coast ecozone, the key issues which impact on the communities and the natural environment are: (a) water shortage both for domestic and agriculture use; (b) increase in soil salinity, mainly due to sea-level rise and inundation of agricultural land; (c) mangrove depletion; (d) negative changes to the existing cropping patterns and practices; (e) erosion in the hilly coastal areas; (f) forest depletion and poor forest management; (g) use/misuse of timber and non-timber forest products (NTFP); and (h) eco-tourism. In addition, land grabbing by unscrupulous entrepreneurs, urban expansion, and industrial zone development also has an effect on coast ecozones and its resources.

Rice cultivation dominates in this ecozone, where primarily only a single crop of irrigated or rainfed rice is cultivated each year during the rainy season. For the most part, local varieties of rice are cultivated, producing low yields (1.5-2 tonnes/ha) with low or non-existent use of fertiliser. Areas of rice production located in close proximity to the coast are highly prone to saline water intrusion due to sea-level rise. The main threats, vulnerabilities and adaptation options for crops in the coast ecozone are presented in the table below.

Vulnerable crop	Threat	Impact summary	Vulnerability	Adaptation option
Irrigated rice	Increased temperature	Maximum temperature is expected to exceed the norms in both the wet and dry season, but less than in other ecozones. High temperatures result in heavy rain in the wet season that leads to flooding in the rice fields, reducing tillering, low productivity and low yields. In the dry season, high temperatures result in rivers, streams, ponds and wells drying out, affecting water availability for humans, animals and biodiversity	Medium to high	Heat tolerant and short duration varieties Shifting calendar to avoid April – May peak temperature Water management: (i) community water ponds; and (ii) small-scale water management system for the commune and district
Rainfed rice	Sea level rise, flooding & saline	Sea level rise causes saline intrusion and flooding inland through	High to very high	Saline-tolerant and/or short-growth duration varieties, adaptive rice

Irrigated rice	water intrusion	irrigation systems and breaching of sea wall infrastructure in both wet and dry seasons, which salinizes irrigation water and paddy soils and increases flood amplitude in the rainy season. The impact of this is saline intrusion is shortened favourable cropping period and constrained growth and yield of rice crops. The increase in flood amplitude will lead to water inundation or submergence, particularly in periods of locally high rainfall		farming practices (washing saline water, rice transplantation, agrochemical application, etc.), rotational rice-upland crop farming, fish culture in flooded rice fields, salinity and flood management structures Improved water management system in coastal areas

In relation to the threats depicted above adaptation to sea level rise will require a combination of technical changes and infrastructure development to protect crops from saline water intrusion and floods. Saline-tolerant and short-growth duration rice varieties with high yields and good-grain quality will be of great importance to farmers. In addition, other adaptive rice farming practices need to be undertaken, including appropriate land preparation for washing salt from the soil and the application of potassium, which enhances rice tolerance to saline intrusion. Lastly, the rehabilitation and reforestation of the mangrove belt can help to reduce erosion caused by wave action on sea dikes and can minimize the maintenance cost of such infrastructure.

Adaptation planning for the coast ecozone as presented in the table below illustrates the options for rice production systems in the short, medium and long term.

Level of response	Short-term (next 5 years)	Medium-term (5 to 10 years)	Long-term (more than 10 years)
Adaptation deficit	Heat tolerant and saline tolerant rice varieties Adaptive rice farming practices Improve capacity of farmers to build climate resilient practices in	Salinity and flood management infrastructure at the farm and community level (small-scale) Building household water management systems	Salinity and flood management and irrigation/drainage infrastructure at provincial and district scale Establishment of community-based natural resource & water management

	agriculture		
Additional adaptation	Improved saline and submergence-tolerant varieties and SRI techniques Building local saline tolerant varieties	Salinity and flood management infrastructure at the community level (small–scale) Catching and reserving rainwater for irrigation in the dry season Rehabilitation and development of mangroves Promoting household water management system.	
Adaptation to induce system shift	Shift to alternate rice-fish/upland crops Shift to dry season vegetable production with drip and groundwater irrigation	Improve markets for agriculture products	Develop the supporting policies in agriculture that support the system shift

13. DELTA ECOZONE

Rice-based systems in the delta, the predominant farming system, will face threats from increased temperature, droughts in the dry season, and floods (table below). Both irrigated and rain-fed rice cropping systems will be severely affected. Dry season rice and early wet season rice will be affected by heat and increased minimum temperature. In this context, heat tolerant varieties will be necessary over the medium to long-term. Shifting the cropping calendar to avoid the April-May period when maximum temperatures peak could improve yields. In irrigated and rain fed systems, SRI techniques can be applied to mitigate declining yields, since farmers' water management capacities are relatively high in the delta.

Adaptation to sea level rise in the lower Mekong in Vietnam, which impacts Cambodia, will require a combination of technical changes and infrastructure development to protect crops from floods. Improved coordination on flood control that could improve flood management and enhance agriculture productivity is required between the two countries. Short-growth duration rice varieties with high yields and good-grain quality will be of great importance to farmers. Moreover, land use plans can be modified and areas currently implementing two or three rice crops can shift to rice-fish (or short-growth duration upland crops) rotations.

Vulnerable Crop	Threat	Impact summary	Vulnerability	Adaptation options
Lowland rain fed rice and irrigated rice	Increased temperature	An increase in temperature in early wet season can cause heat stress, reducing rice tilling and yields High temperature in the main wet season would lead to heavy rain that will flood and damage rice crops In the dry season, high	Medium to high	Heat tolerant varieties Shifting calendar to avoid the highest temperature peak in dry season SRI techniques Improved water management is key to store water in the wet seasons for use in the dry season: (i) household water ponds; (ii) community

		temperature would cause water shortage for humans, livestock and biodiversity		water ponds; and (iii) small-scale water management system
Lowland rain fed rice	Flooding	Flood prone area around the Tonle Sap lake, floodplain and central part of Cambodia are affected by floods from the Mekong in the wet season, causing damage to rice fields and rice crops and lowering yield	High to very high	Short-term variety (early maturing) to avoid peak floods and to shift to double rice cropping Drought tolerant varieties Shift to dry season crop Dry season fish refuge in rice fields Improved transboundary water management system Building the flood control system and irrigation canal to store water for the uses in the dry season.

With the increase in flood amplitude, early maturation rice can be used in freshwater areas to reduce the risk of losing the crops to floods. Additional fish culture in individual flooded rice fields between the second rice harvest and the dry season crop in December could be an option that will add value to flooded rice fields. In the dry season, drip irrigation and the use of groundwater for vegetable production can be done in areas where freshwater is limited. These techniques can be combined with water storage and/or rainwater harvesting to allow for a vegetable crop.

Rice-fish culture systems will enhance the synergy between agriculture and aquaculture systems, as will fish culture in flooded rice fields. While rice field fisheries and aquaculture systems are well developed and were found to be a sustainable production system for farmers in the Mekong Delta, fish culture in flooded rice fields is not as well practiced and faces economic profitability issues.

For the delta ecozone, adaptation planning for the short, medium and long term are presented in the table below.

Level of response	Short-term (next 5 years)	Medium-term (5 to 10 years)	Long-term (more than 10 years)
Adaptation deficit	Heat tolerant and saline tolerant rice varieties and adaptive rice farming practices Building capacity of farmers to build climate resilient agriculture practice	Salinity and flood management infrastructure at the farm and community level (small–scale) Promote households and community pond development	Salinity and flood management and irrigation/drainage infrastructure at provincial and inter-provincial scale Establishment of community-based natural resource management Improve water management system
Additional adaptation	Improved water management: (i) household ponds (ii) Community based water management; (iii) small-scale water management system/irrigation system	Flood management infrastructure at the community level (small-scale) Catching and reserving rainwater for irrigation in the dry season Rehabilitation and development of mangroves Water management system: (i) household water pond; (ii) community water management; and (iii) small-scale water management system/irrigation system	Improved transboundary water management through improved coordination with Vietnam
Adaptation to induce system shift	Shift to alternate rice-fish Shift crops to dry season vegetable production with drip irrigation		

These changes in the production systems will be progressive and dependent on the presence of flood and saline protection infrastructure. The duration of both saline intrusions and floods will determine the spatial arrangement of the land use and cropping patterns. These adaptation options can be up-scaled in similar ecozones (e.g. coast ecozone) that are influenced by both floods and saline water intrusion.

14. TONLE SAP ECOZONE

Rice, maize and cassava are the most vulnerable commodities in provinces situated in the Tonle Sap ecozone, due to increased temperature and higher incidences of flood and drought. Drought appears to be much more difficult an issue to deal with than flood. From an agricultural perspective, the drought the farmers are faced with is when the monsoon starts late, or starts and then the rains stop for several weeks (no rain for more than 15 days becomes a problem). In 2015, some rainfed rice fields only yielded 300 kg/ha of rice compared to the usual 4 to 5 tonnes/ha. Even irrigated delivered a lower yield of 4 tonnes/ha compared to the normal 5 tonnes/ha.

There are three agricultural field situations or cropping systems in this ecozone: (1) lowland fields (Sre Krom) near the lake, including the recession rice growing areas, that is influenced by the water from the lake; (2) medium rice fields (Sre Kandal) are located between 8-10m above sea level and is influenced by rainfall and water from the Tonle Sap, and (3) upland areas (Sre Leu) that are influenced by rainfall for agriculture, and are more suitable for other crops (such as cassava, maize and fruit trees such as mangoes and oranges) as well as some rainfed rice. Some suggestions for non-infrastructural interventions for the three field situations are as follows:

- **Lowland rice fields (Sre Krom):** located close to the lake, cultivation is influenced by the floods from the lake. Farmers usually cultivate floating rice, for one crop a year. The floods often damage the floating rice and thus yields are low.
- **Medium rice fields (Sre Kandal):** traditionally, farmers cultivate the floating rice in this area. However, in recent years, farmers have shifted to early wet season rice, starting from April and harvesting in July, before water levels rise. Recession rice is then cultivated in late November or December when water from the lake recedes. Farmers have shifted from one crop to two crops per year, using short-term rice varieties which are better suited to being partially flooded and the shorter growing periods necessitated by climate change. It might also be possible after a single crop of short season rice to plant a short season catch crop of maize, legumes or vegetables, water availability permitting. If there is groundwater available through dug wells and tube wells, it will be possible to utilise this water source. Recently, worsening drought conditions and the overuse of groundwater have resulted in this option no longer being viable in some areas. If this is the case, a management plan for the use of groundwater needs to be established among the farmer and farmer groups, to collectively manage this water

resource. A full understanding of the hydrology of the area is required for this to take place.

- **Upland rainfed areas (Sre Leu):** farmers in this area cultivated one rice crop a year, dependent entirely on rainfall. This is the most difficult field situation with declining water availability and needs a radical change away from crops like upland rainfed rice and maize to more drought tolerant (cassava) and short season crops like soya bean/legumes and vegetables. Again, the involvement of the provincial agriculture staff and CARDI should be able to facilitate the availability of the necessary seed and other technologies. These experts should also be able to provide advice on IPM through FFS to address the issue of weed and pest infestations through the use of environmental friendly non-chemical control measures.

Adaptation options for rice at the farm level (table below) include access to heat tolerant short duration varieties developed by International Rice Research Institute (IRRI). These are improved varieties that can tolerate higher temperature. A second adaptation option is a double rice cropping systems to avoid floods in the lower floodplain. The aim of this approach is to shift from traditional, deep-water rice cultivation during the flood period to double rice crops of shorter periods that avoid the peak flood. Using SRI techniques where good water management is possible can improve yield and develop rice crops that are more resilient to extreme events. Introducing submergence tolerant varieties might not be a realistic option in all locations because the level of flooding will exceed the level of tolerance in some cases. The presence of frequent destructive floods will require a shift from a rainy season crop to a dry season crop when irrigation is possible. In addition, farmers are currently facing dry spells during the rainy season and the use of drought tolerant varieties will help to reduce yield gaps due to severe drought.

Vulnerable Crop	Threat	Impact summary	Vulnerability	Adaptation options
Lowland rainfed rice and irrigated rice	Increased temperature	Higher temperatures will reduce yield and offset CO_2 fertilization	Medium	Heat tolerant varieties Shifting calendar to avoid the highest temperature peak in dry season SRI & wet/dry techniques

Lowland rainfed rice and irrigated rice	Drought	The shortening of the duration of the rainy season and the lack of rains in the dry season, impacts heavily on rice production	Medium to high	Early maturation varieties Shifting calendar to include a short season rice crop in the rainy season followed by drought tolerant alternative crop Improve water management, improve irrigation system/small-scale water management that could tap water from the Tonle Sap Lake
Lowland rainfed rice	Flooding	Flood prone area around the Tonle Sap Lake and central part of the province	Medium to high	Short-term variety (early maturing) to avoid peak floods and to shift to double rice cropping Submergence tolerant varieties Shift to dry season crop Dry season fish refuge in rice fields Improve water management and flood control dykes, improve irrigation system

Other threatened crops include cassava, which face the same threats of increased temperature and flooding. Pilot testing of short-term varieties of cassava culture (seven to eight months) has shown that such varieties can be planted in order to avoid periods of flooding. This approach will generate a lower yield and the growth period might be too short to achieve an economically attractive yield. In order to avoid floods, the cropping system could also shift to the use of other crops, such as maize, which have a shorter growth cycle.

Adaptation options include shifting to the use of more heat tolerant crops like maize or cassava. Development of conservation agriculture with rotations of legumes, maize, or cassava with a cover crop (e.g., *Arachis pintoi* or *Stylosanthes* sp.) may also be a feasible option for medium-scale farmers that would improve the soil quality and diversify the cropping system. However, this option may require mechanization and increased use of herbicide.

Vegetable production in peri-urban areas or in areas well-connected to markets can be supported with water saving and storage techniques like drip irrigation, use of groundwater, and water harvesting. These techniques can be implemented in small areas, like homestead gardens, for intensive farming in the dry season. Farmers can learn from successful experiences with these approaches in other provinces of Cambodia such as Svay Rieng and Prey Veng.

Shifting the cropping calendar to avoid floods will not affect other sectors, while the shift to conversation agriculture might reduce the area available for grazing. Shifting from soybean culture to maize or cassava will reduce soil fertility without further nitrogen fixation over the medium to long-term. By providing access to water, the development of irrigation systems will create opportunities for integrated rice-fish culture. This development will increase wage labour availability in the dry season, which will provide new opportunities to households that seasonally migrate for casual labour. Beside rice-fish systems, flooded rice fields should include dry season refuges to increase fish stocks in rice fields during the flood season.

The geographical scope of the suggested adaptation options is small. On-farm and community trials for the introduction of new varieties, cropping techniques and water management practices should be designed for the community or commune level.

The potential benefit of these types of approaches is that investment requirements would be relatively small and implementation lead times would be relatively short when compared to other adaptation measures such as upgrading or installing new irrigation infrastructure (table below).

Level of Response	Short-term (next 5 years)	Medium-term (5 to 10 years)	Long-term (more than 10 years)
Adaptation deficit	On farm initiatives: Introduction of new varieties Introduction of drought tolerant varieties	Introduction of heat tolerant varieties	Policy on water management - a key to agriculture in this region
Additional adaptation	Introduction of conservation techniques and SRI Drip irrigation Water harvesting		Improve water management in the long-term
Adaptation		Development or	Policy on water

Level of Response	Short-term (next 5 years)	Medium-term (5 to 10 years)	Long-term (more than 10 years)
to induce system shift		rehabilitation and improvement of irrigation schemes for a shift to dry season crop (rice, maize, soya etc.)	management in the long-term

Up-scaling adaptation deficit responses could also be trialled at the ecozone level where similar threats and similar cropping systems exist. Climate suitability modelling shows similar responses for soya, cassava and maize within the ecozone. Shifting the cropping calendar or introducing heat tolerant or/and drought tolerant rice varieties are generic measures that are not geographically specific and could be considered for application in several ecozones.

Basically, farmers need to radically rethink how they are going to change their cropping systems to address the issue of decreased rainfall and shortened growing seasons, while still sustaining their livelihoods. This situation is much more critical in farmland where flood and drought amelioration projects are going to construct or rehabilitate irrigations systems. Water user groups in the command areas which are to be improved, stand a much better chance to make the best use of the available water resources, especially if water storage reservoirs are constructed and equitable field water management practices followed.

15. PLATEAU AND MOUNTAIN ECOZONE

In this ecozone there are three types of farming/livelihood systems: (1) shifting cultivation/forestry management and/or protection including the collection and use of NTFPs, (2) rainfed/irrigated lowland farming, and (3) plantations (rubber and coffee) and fruit orchards. The latter two have been particularly impacted by climate change, while the first system has been prone to land acquisition for conversion to commercial agro-enterprises, and deforestation.

In the plateau and mountain ecozone, the main threats to the agriculture sector are increases in temperature in both the dry and wet seasons and an increase of precipitation (particularly in October. Adaptation measures similar to those suggested for Kampong Thom Province in the Tonle Sap ecozone to cope with increased temperature and flooding could be tested. These include using heat tolerant varieties, using short-term varieties to avoid the storm season, and adopting a double rice crop in the rainfed lowlands. The introduction of drought tolerant varieties can help farmers cope with dry spells during the dry season.

At the household level, small-scale vegetable production can be integrated with water harvesting programs to diversify food production and improve food security. Access to the required inputs may be a constraint for communities in remote areas.

Vulnerable Crop	Threat	Impact Summary	Vulnerability	Adaptation Options
Rainfed rice	Increased temperatures Storms and increased precipitation	Reduce yield with higher maximum temperatures More frequent storms and extreme precipitation can create waterlogging and damage crops	Medium	Heat tolerant rice varieties Early maturing varieties, and double rice crop Improving drainage systems Erosion control and vegetal covers in uplands and slopes SRI and wet/dry techniques Drought resistant varieties Improve water management Introducing alternative cropping system

Vulnerable Crop	Threat	Impact Summary	Vulnerability	Adaptation Options
Cassava	Storm and increased precipitation Increased temperature	Because of field practices the crop is prone to erosion	Medium	Improving drainage system Erosion control system on slope
Fruit Trees **Coffee**	Storms and increased precipitation Increased temperature Drought	Long dry period impact on growth and yield	Medium	Improved varieties Conservation agriculture SALT
Rubber	Increased temperature	More days above 35^0C reduce growth and yield	Medium	Heat tolerant variety

Waterlogging and local floods will necessitate improved drainage systems in rice-based systems. The SRI and similar techniques should be tested to improve the resistance of rice plants to storms. For upland rice, increased rainfall and storms will increase erosion rates. SALT and Direct Mulch-seeding Cropping (DMC) are potential options to limit erosion and increase soil quality. Examples of the successful application of these techniques can be found in Vietnam and the uplands of Lao PDR.

Maize-millet rotations, maize-cowpea rotations or planting of grass (*Brachiaria* sp.) are options for new cropping systems. Intermediary crops can also provide additional forage and grain for livestock. Both soybean and maize require harvesting before the peak rainfall in October. Similar adaption measures are adequate for cassava monoculture crops, with diversified rotations over the years. The rotation of cash crops (cassava, maize, and soybean) can be rotated with a dry season forage crop when maize or soybean have been planted that year. These techniques have been widely tested in other provinces of Cambodia and can be replicated in this ecozone.

Rubber suitability will be lower, and threats due to high temperature might generate an altitude shift requiring new plantations at higher altitudes. Diversifying into Robusta coffee, cashew and fruit trees is possible but viable value chain and markets need to be assured.

As in the Tonle Sap ecozone, the investment requirements of the adaptation strategies identified here would be relatively small and implementation lead times would be relatively short (table below).

Level of response	Short-term (next 5 years)	Medium-term (5 to 10 years)	Long-term (more than 10 years)
Adaptation deficit	Introduction of new varieties (early maturing) and drought tolerant varieties	Introduction of heat tolerant varieties	
Additional adaptation	Introduction of the conservation technique and DMC with new crops and new crop rotation Rainwater harvesting for small-scale vegetable production	Improving drainage system in specific lowland areas (waterlogged) SALT	
Adaptation to induce system shift			Altitude shift for rubber Planting of fruit trees and cashew

A longer process of planning and implementation will be required to improve the drainage systems in waterlogged areas, to introduce heat tolerant varieties and shift the altitude for rubber plantations. The effect of increased temperature will not be immediate.

The introduction of forages within the crop rotation in DMC systems will benefit livestock. Improving pastureland with *Brachiaria* sp. provides pasture for cattle and buffalos. Improving the drainage capacities of rice fields will reduce the duration of floods and thus reduce the potential for rice-fish fisheries. However, this type of fishery is uncommon and not economically important in this province. Drainage improvements will require scoping for the selection of specific highly vulnerable areas.

The introduction of new cropping techniques, crops succession and crop rotation should be done at the farm and/or the community level. These technically oriented approaches can be up-scaled at the eco-zone level later (mid-elevation and low-elevation ecozone).

D REFERENCES

Presented below is a list of key references that are in addition to those cited for the adaptation interventions presented in the main body of the guide.

Ahmed, N. & Garnett, S.T. 2011. Integrated rice-fish farming in Bangladesh: meeting the challenges of food security. Food Security.

Barnes, R.D. & Fagg, C.W. 2003. Faidherbia albida: monograph and annotated bibliography. Tropical Forestry Papers No. 41. Oxford, UK, Oxford Forestry Institute.

Beddington, J., Asaduzzaman, M., Clark, M., Fernández, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., Van Bo, N., Nobre, C.A., Scholes, R., Sharmam R. & Wakhungu, J. 2012b. Achieving food security in the face of climate change: final report from the Commission on Sustainable Agriculture and Climate Change. Copenhagen, Denmark,

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). (available at www.ccafs.cgiar.org/commission)

Beddington, J.R., Asaduzzaman, M., Clark, M.E., Fernández Bremauntz, A., Guillou, M.D., Jahn, M.M., Lin, E., Mamo, T., Negra, C., Nobre, C.A., Scholes, R.J., Sharma, R., Van Bo, N. & Wakhungu, J. 2012c. The role for scientists in tackling food insecurity and climate change. Agriculture and Food Security, 1: 10.

Bellassen, V. & Gitz, V. 2008. Reducing emissions from deforestation and degradation in Cameroon: assessing costs and benefits, Ecological Economics: 68 (1–2): 336–344.

Bharucha, Z. & Pretty, J. 2010. The roles and values of wild foods in agricultural systems. Philosophical Transactions of the Royal Society B-Biological Sciences, 365: 2913–2926.

Bochu, J-L., Bordet, C., Metayer, N. & Trevisiol, A. 2010. Références planete. Fiche 2- Production: Bovins lait et cultures. Toulouse, SOLAGRO, 25 p.

Braatz, S. 2012. Building resilience to climate change through sustainable forest management. In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Brader, L., Djibo, H., Faye, F.G., Ghaout, S., Lazar, M., Luzietoso, P.N. & Ould Babah, M.A. 2006. Évaluation multilatérale de la campagne 2003–05 contre le criquet pèlerin. Rome, FAO. (available at http://www.clcproempres.org/fr/pdf/Evaluation_compagne200_2005_Fr.pdf).

Brazilian Agricultural Research Corporation (EMBRAPA). 2008. Aquecimento global e a nova geografia da produção agrícola no Brasil. Sao Paulo.

Bruinsma, J. 2009. The resource outlook to 2050. Expert Meeting on How to Feed the World in 2050. FAO, Rome.

Brundtland, G.H. 1987. Report of the World Commission on Environment and Development: our common future. (available at http://www.un-documents.net/our-common-future.pdf)

Burke, M.B., Lobell, D.B. & Guarino, L. 2009. Shifts in African crop climates by 2050, and the implications for crop improvement and genetic resources conservation. Global Envt. Change, 19(3): 317–325.

Burney, J.A., Davis, S.J. & Lobell, D.B. 2010. Greenhouse gas mitigation by agricultural intensification. Proceedings of the National Academy of Sciences, 107(26): 12052–12057.

Carpenter, S.R., Walker, B., Anderies, J.M. & Abel, N. 2001. From metaphor to measurement: resilience of what to what? Ecosystems, 4:765–781.

Cifdaloz, O., Regmi, A., Anderies, J. & Rodriguez, A.A. 2010. Robustness, vulnerability, and adaptive capacity in small-scale social–ecological systems: the Pumpa Irrigation system in Nepal. Ecology and Society, 15(3): 39. (available at http://www.ecologyandsociety.org/vol15/iss3/art39/)

Cirera, X. & Masset, E. 2010. Income distribution trends and future food demand. Phil. Trans. R. Soc. B., 365: 2821–2834.

Clements, R., J. Haggar, A. Quezada, and J. Torres. 2011. Technologies for Climate Change Adaptation – Agriculture Sector. X. Zhu (Ed.). UNEP Risø Center, Roskilde, 2011

Conforti, P., eds. 2011. Looking ahead in world food and agriculture: perspectives to 2050. Rome, FAO.

Cordier, J. 2008. La gestion des risques en agriculture. De la theorie a la mise en oeuvre: elements de reflexion pour l'action publique. Notes et etudes economiques – No. 30.

Cossée, O., Lazar, M. & Hassane, S. Rapport de l'evaluation a mi-parcours du Programme EMPRES composante Criquet pelerin en Region occidentale. Rome, FAO. (available at http://www.clcpro-empres.org/fr/pdf/Rapport_evaluation%20mi_parcourEMPRESro_Fr.pdf)

De Young, C., Soto, D., Bahri, T. & Brown, D. 2012. Building resilience for adaptation to climate change in the fisheries and aquaculture sector. In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Dey, M.M., Spielman, D.J., Mahfuzul Haque, A.B.M., Rahman, Md. S. & Valmonte-Santos, R.A. 2012. Change and diversity in smallholder rice-fish systems, recent evidence from Bangladesh. International Food Policy Research Institute.

Eldin, M. & Milleville, P., eds. 1989. Le risque en agriculture. Paris, ORSTOM. p. 619.

Ericksen, P.J. 2008. Conceptualizing food systems for global environmental change research. Global Environmental Change, 18(1): 234–245.

European Commission. 2006. Analysis of the life cycle environmental impacts related to the final consumption of the EU-25. Environmental Impact of Products (EIPRO). (available at http://ec.europa.eu/environment/ipp/pdf/eipro-report.pdf)

FAO. 2009a. The state of food and agriculture: livestock in the balance. Rome.

FAO. 2009b. Food security and agricultural mitigation in developing countries: options for capturing synergies. Rome.

FAO. 2009c. The investment imperative. Paper from the FAO High Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy. Rome.

FAO. 2010a. "Climate-smart" agriculture: policies, practices and financing for food security, adaptation and mitigation. Rome.

FAO. 2010c. Promoting the growth and development of smallholder seed enterprises for food security crops, case studies from Brazil, Côte d'Ivoire and India. FAO Plant production and protection paper No. 201.

FAO. 2010d. Biodiversity and sustainable diets: united against hunger. Rome.

FAO. 2011a. Potential effects of climate change on crop pollination, by M. Kjohl, A. Nielsen, & N.C. Stenseth. Rome.

FAO. 2011b. Save and grow: a policymaker's guide to the sustainable intensification of smallholder crop production. Rome.

FAO. 2011c. Energy-smart food for people and climate. Issue brief. Rome. (available at http://www.fao.org/docrep/014/i2454e/i2454e00.pdf).

FAO. 2012a. Improving food systems for sustainable diets. GEA Rio+20 Working Paper No. 4. Rome.

FAO. 2012b. Stability of food security in a green economy environment. FAO GEA Rio+20 Working Paper No. 3. Rome.

FAO. 2012c. Towards the future we want: end hunger and make the transition to sustainable agricultural and food systems. Rome. (available at http://www.fao.org/docrep/015/an894e/an894e00.pdf)

FAO. 2012d. Greening the economy with agriculture. Rome. (available at http://www.fao.org/docrep/015/i2745e/i2745e00.pdf)

FAO. 2012e. AGA in action. Animal Production and Health. (available at http://www.fao.org/ag/againfo/home/en/news_archive/AGA_in_action/2011_livestock_food_chains.html)

FAO. 2012f. Voluntary guidelines on the responsible governance of tenure of land, fisheries and forests in the context of national food security. (available at http://www.fao.org/docrep/016/i2801e/i2801e.pdf)

FAO. 2013. FAO Climate Smart Agriculture Sourcebook. (available at http://www.fao.org/docrep/018/i3325e/i3325e00.htm

FAO, ICLARM & IIRR. 2001. Integrated agriculture-aquaculture: a primer. FAO Fisheries technical paper No. 407. Rome.

FAO & OECD. 2012. Building resilience for adaptation to climate change in the agriculture sector. Proceedings of a joint FAO & OECD workshop. Rome. (available at http://www.fao.org/agriculture/crops/news-events-bulletins/detail/en/item/134976/)

FAO, WFP & IFAD. 2012. The state of food insecurity in the world 2012: economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. Rome.

Fellmann, T. 2012. The assessment of climate change related vulnerability in the agricultural sector: reviewing conceptual frameworks. In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Fischer, R.A., Byerlee, D. & Edmeades, G.O. 2009. Can technology deliver on the yield challenge to 2050? Background paper to the Expert Meeting on How to feed the World in 2050. Rome, FAO.

Folke, C., Carpenter, S.R., Walker, B., Scheffer, M., Chapin, T. & Rockström, J. 2010. Resilience thinking: integrating resilience, adaptability and transformability. Ecology and Society, 15(4): 20. (available at http://www.ecologyandsociety.org/vol15/iss4/art20/)

Foresight. 2011a. The future of food and farming: challenges and choices for global sustainability. Final Project Report. London, The Government Office for Science.

Foresight. 2011b. Foresight project on global food and farming futures. Synthesis Report C1: Trends in food demand and production.

Füssel, H.-M. & Klein, R.T.J. 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Climatic Change, 75(3): 301–329.

Garnett. T. 2011. Where are the best opportunities for reducing greenhouse gas emissions in the food system (including the food chain)? Food Policy, 36(1): S23–S32.

Garrity, D.P., Akinnifesi, F.K., Ajayi, O.C., Weldesemayat, S.G., Mowo, J.G., Kalinganire, A., Larwanou, M. & Bayala, J. 2010. Evergreen Agriculture: a robust approach to sustainable food security in Africa. Food Security, 2: 197–214.

Gerber, P., Vellinga, T., Opio, C., Henderson, B. & Henning, S. 2010. Greenhouse gas emissions from the dairy sector a life cycle assessment. FAO Report. Rome. (available at http://www.fao.org/docrep/012/k7930e/k7930e00.pdf).

Gibbs, H.K., Ruesch, A.S., Achard, F., Clayton, M.K., Holmgren, P., Ramankutty, N. & Foley, J.A. 2010. Tropical forests were the primary source of new agricultural land in the 1980s and 1990s. Proceedings of the National Academy of Sciences,107 (37).

Gitz, V. 2013. Usage des terres et politiques climatiques globales: la physique, l’économie et les politiques de l’usage des puits de carbone pour lutter contre le changement climatique. Presses Academiques Francophones. Saarbrucken, Germany.

Gitz, V. & Meybeck, A. 2012. Risks, vulnerabilities and resilience in a context of climate change. In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Gornall, J., Betts, R., Burke, E., Clark, R., Camp, J., Willett, K. & Wiltshire, A. 2010. Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B-Biological Sciences, 365: 2973–2989.

Grainger-Jones, E. 2011. Climate-smart smallholder agriculture: what’s different? IFAD occasional paper No.3. Rome. (available at http://www.ifad.org/pub/op/3.pdf).

Gunderson, L & Holling, C.S., eds. 2001. Panarchy: understanding transformations in human and natural systems. Island Press, Washington D.C.

Gustavsson, J., Cederberg, C., Sonesson, U., van Otterdijk, R. & Meybeck, A. 2011. Global food losses and food waste: extent, causes and prevention. Rome, FAO.

Harris, J.M., Erickson, K., Dillard, J., Morehart, M., Strickland, R., Gibbs, R., Ahearn, M., Covey, T., Bagi, F., Brown, D., McGath, C., Vogel, S., Williams, B. & Johnson, J. 2008. Agricultural income and finance outlook. AIS 86. Economic Research Service, US Department of Agriculture.

High Level Panel of Experts (HLPE). 2011. Price volatility and food security. A report by the HLPE on Food Security and Nutrition of the Committee on World Food Security. Rome.

HLPE. 2012a. Food security and climate change. A report by the HLPE on Food Security and Nutrition of the Committee on World Food Security, Rome.

HLPE. 2012b. Social protection for food security. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, Rome.

Hoffmann, I. 2010. Climate change and the characterization, breeding and conservation of animal genetic resources. Animal Genetics, 41: 32–46.

Holden, D., Hazell, P. & Pritchard, A., eds. 1991. Risk in agriculture: proceedings of the Tenth Agriculture Sector Symposium. World Bank.

Holling, C.S. 2001. Understanding the complexity of economic, ecological, and social systems. Ecosystems, 4: 390–405.

International Atomic Energy Agency (IAEA). 2017. Cambodian Researchers Use Isotopic Technique to Help Farmers Increase Yields and Revenues. (available at https://www.iaea.org/newscenter/news/cambodian-researchers-use-isotopic-technique-to-help-farmers-increase-yields-and-revenues).

IFAD. 2012b. Environment and natural resource management policy. Resilient livelihoods through the sustainable use of natural assets. (available at http://www.ifad.org/climate/policy/enrm_e.pdf).

International Fertilizer Development Center (IFDC). 2011. Fertilizer Deep Placement (FDP). (available at http://ifdc.org/getdoc/81fcf68e-c3b8-406a-a252-5148b99d8684/Fertilizer_Deep_Placement_(UDP))

INEA. 2011. Prospettive della gestione del rischio in agricoltura: riflessioni per un sistema integrato per la PAC post 2013. Roma, Quaderno, Istituto Nazionale di Economia Agraria.

Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate change 2007: impacts, adaptation and vulnerability, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linder & C.E. Hanson, eds. pp. 869-883. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Glossary II. Cambridge, Cambridge University Press.

IPCC. 2007b. Climate Change 2007: mitigation, B. Metz, O.R. Davidson, P.R. Bosch, R. Dave & L.A. Meyer, eds. Contribution of Working Group III to the Fourth Assessment Report of the IPCC. Cambridge, United Kingdom and New York, USA, Cambridge University Press.

IPCC. 2012. Managing the risks of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the IPCC. Cambridge, UK and New York, USA, Cambridge University Press. 582 pp.

Kahiluoto, H. 2012. Crop production in a northern climate. In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Karfakis, P., Knowles, M., Smulders, M. & Capaldo, J. 2011. Effects of global warming on vulnerability to food insecurity in rural Nicaragua. ESA-FAO WP series No. 11–18.

Ladha, J.K., Fisher, K.S., Hossain, M., Hobbs, P.R. & Hardy, B. Eds. 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic plains: a synthesis of NARS-IRRI partnership research. Discussion Paper No. 40. International Rice Research Institute.

Licona Manzur, C. & Rhodri, P.T. 2011. Climate resilient and environmentally sound agriculture or “climatesmart” agriculture: an information package for government authorities. Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences and Food and Agriculture Organization of the United Nations.

Lipper, L. & Neves, N. 2011. Payments for environmental services: what role in sustainable agriculture development? ESA Working Paper No. 11–20. FAO. (available at http://www.fao.org/docrep/015/an456e/an456e00.pdf).

Lobell, D., Schlenker, W. & Costa-Roberts, J. 2011. Climate trends and global crop production since 1980. Science.

Lutz, W. & Samir, K.C. 2010. Dimensions of global population projections: what do we know about future population trends and structures?, Phil. Trans. R. Soc. B, 365: 2779–2791.

MacMahon, P., Barley, D. & Holmes, L. 2011. What price resilience? Towards sustainable and secure food systems. London, The Prince's Charles Charities' International Sustainability Unit.

Mejia, D. 2008. Household metal silos: key allies in FAO's fight against hunger. FAO, Rome. (available at http://www.fao.org/fileadmin/user_upload/ags/publications/silos_E_light.pdf)

Meridian Institute. 2011. Agriculture and climate change: a scoping report. (available at http://www.climateagriculture.org/Scoping_Report.aspx)

Meybeck, A., Azzu, N., Doyle, M. & Gitz, V. 2012. Agriculture in National Adaptation Programmes of Action (NAPA). In FAO & OECD Building Resilience for Adaptation to Climate Change in the Agriculture Sector. Rome.

Ministry of Agriculture Forestry and Fisheries. 2016. Cambodia's Climate Change Priorities Action Plan for Agriculture, Forestry and Fisheries 2016-2020.

Nelson, G.C., Rosegrant, M.W., Koo., J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M. & Lee, D. 2009. Climate change impact on agriculture and costs of adaptation. International Food Policy Research Institute, Washington D.C.

Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T., Ringler, C., Msangi, S. & You, L. 2010. Food security, farming, and climate change to 2050: scenarios, results, policy options. International Food Policy Research Institute, Washington D.C. (available at www.ifpri.org/sites/default/files/publications/rr172.pdf)

Organization for Economic Co-operation and Development (OECD). 2009. Managing risk in agriculture: a holistic approach. Paris.

OECD. 2011. Joint working party on agriculture and the environment: a green growth strategy for food and agriculture. Paris.

Padgham, J. 2009. Agricultural development under a changing climate: opportunities and challenges for adaptation. Washington D.C., The World Bank.

Roy, R.N. & Misra, R.V. 2003. Economic and environmental impact of improved nitrogen management in Asian rice-farming systems. In Sustainable rice production for food security. Proceedings of the 20th Session of the

International Rice Commission. Bangkok. International Rice Commission & FAO.

Save Food Initiative. 2013. Save food solutions for a world aware of its resources. (available at http://www.savefood.org/)

Singh, U., Wilkens, P., Jahan, I., Sanabria, J. & Kovach, S. 2010. Enhanced efficiency fertilizers, 2010 19th World Congress of Soil Science. Soil Solutions for a Changing World. Brisbane, Australia. (available at http://www.iuss.org/19th%20WCSS/Symposium/pdf/1506.pdf)

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M. & de Haan, C. 2006. Livestock's long shadow. Environmental issues and options. FAO, Rome.

Tadele, T., Kanampiu, F.K., De Groote, H., Hellin, J.. Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, P.M., Shiferaw, B. & Banziger, M. 2011. The metal silo: an effective grain storage technology for reducing post-harvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. Crop Protection, 30(3): 240—245.

Thornton, P. & Cramer, L., eds. 2012. Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR's mandate. CCAFS Working Paper No. 23. CCAFS, Copenhagen, Denmark.

United Nations. 2012. The future we want. (available at http://www.uncsd2012.org/thefuturewewant.html)

United Nations Environment Programme (UNEP). 2010. Assessing the environmental impacts of consumption and production: priority products and materials, by E. Hertwich, E. van der Voet, S. Suh, A. Tukker, M. Huijbregts, P. Kazmierczyk, M. Lenzen, J. McNeely & Y. Moriguchi. A Report of the Working Group on the Environmental Impacts of Products and Materials to the International Panel for Sustainable Resource Management.

United Nations Framework Convention on Climate Change (UNFCCC). 2008. Challenges and opportunities for mitigation in the agricultural sector. Technical paper.

United Nations Framework Convention on Climate Change (UNFCCC). 2011. Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches. The Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change

United Stated of America AID (USAID). 2013. Mekong ARCC Agriculture Adaptation Report. Report prepared by IDEM for USAID.

Weber, C.L. & Scott Matthews, H. 2008. Food-miles and the relative climate impacts of food choices in the United States. Environmental Science & Technology, 42(10): 3508–3513.

World Bank. 2012. Inclusive green growth: the pathway to sustainable development. Washington D.C, The World Bank.

E ANNEXURES

ANNEX 1: AGRICULTURE ADAPTATION TECHNOLOGIES IN ECOZONES OF CAMBODIA

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
Lowland rice- based farming systems	Improved rice varieties	• Short duration • Drought/heat tolerant • Salt tolerant • Deep water/ flood tolerant rice • Improved quality seeds & seed multiplication	Tonle Sap, Delta Coast Plateaux & mountain	Individual farmer Provincial extension CARDI	SPCR Invest Project 1 – Water Resources – flood & drought SPCR Invest Project 3 – Agriculture – introduction of drought/flood tolerant crop varieties	Breeding & seed multiplication New crop/rice varieties Also applies to rice grown in upland areas Risk management strategies
	Crop management	• System of rice intensification (SRI) • Alternative wet & dry rice	Tonle Sap, Delta	Individual farmer Provincial extension CARDI	SPCR Invest Project 1 – Water Resources – strengthen capacity of communities to reduce climate risks	Extension of existing technologies from IRRI & other agencies
		• Crop diversification • Legumes • Crop rotations • Improved fallow	Tonle Sap, Delta Plateaux & mountain	Individual farmer Farmer groups Provincial extension	SPCR Invest Project 2 – Agriculture – water use efficiency	Water-logging tolerant crops & varieties Shift to dry season cropping Shifting cropping

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
						calendar – adaptation to induce system shift
		• Integrated pest management (IPM)	Tonle Sap, Delta Coast	Individual farmer Farmer groups Provincial extension CARDI	NA	Farmers Field School (FFS) Organic farming
		• Integrated nutrient management (INM)	Tonle Sap, Delta Coast Plateaux & mountain	Individual farmer Farmer groups Provincial extension CARDI	NA	Integrated nutrient management Organic Improved fertiliser use efficiency Compost making Crop legumes & rhizobia Growing nutrient use efficient crops
Lowland rice- based farming systems	Land management	• Conservation agriculture (CA) • Zero tillage • Mulching • Cover crops • Bunds • Planting pits • Soil salinity	All ecozones	Individual farmer Farmer groups Provincial extension CARDI	SPCR Invest Project 3 – Agriculture – reduce salinity & regain growing areas	CA is characterised by three principles which are linked to each other, namely: (a) continuous minimum mechanical soil disturbance; (b) permanent organic soil cover; and (c) diversified

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
		management				crop rotations in the case of annual crops or plant associations in case of perennial crops Bio-pump (main crop rice, soybean or maize, Eleusine or Cajanus Direct seeding
	Water management	• Drainage • Levelling	Tonle Sap, Delta Coast	Individual farmer Farmer groups Provincial extension	SPCR Invest Project 1 – Water Resources – flood protection SPCR Invest Project 3 – Agriculture – small scale irrigation	Drainage & land levelling are critical to efficient water use
		• Group-based water management	All ecozones	Farm Water User Groups Provincial extension	SPCR Invest Project 3 – Agriculture – small scale irrigation	WUA/Water User Group (WUG) Collective water management Water use charges
		• Drip irrigation • Sprinkler • Water lifting – tube wells, dug	Tonle Sap, Delta	Individual farmer Farmer groups Provincial	SPCR Invest Project 3 – Agriculture – small scale irrigation	Technologies for efficient application of water to plants

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
		wells etc.		extension		
		• Rainwater collection – large & small scale	All ecozones	Individual farmers & households	SPCR Invest Project 3 – Agriculture – small scale irrigation; improve rainwater harvesting	Ex-situ rainwater harvesting & water storage Water conservation
		• Crop water requirement & water use	Tonle Sap, Delta	Individual farmer Farm Water User Groups Provincial extension	SPCR Invest Project 1 – Water Resources – reduce climate risks SPCR Invest Project 2 – Agriculture – water use efficiency	Awareness of CWR is very limited even amongst MOWRAM & MAFF staff
		• Water recession management	Tonle Sap	Individual farmer CARDI	NA	Integrated crop management system for Tonle Sap to manage crop production
	Fishery systems management	• Aquaculture – fish ponds • Rice-fish/shrimp • Wild capture	Tonle Sap Delta Coast	Fishermen Fisheries groups Agri-business		Importance of integrated systems for crops (rice) & fisheries in lowland areas
Plateaux &	Sloping	• Sloping land	Plateaux &	Individual	SPCR Invest	SALT utilizes nitrogen-

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
mountain farming systems	Agriculture Land Technologies (SALT)	management • Terracing • Soil conservation • Grassland management • Watershed management	mountain Coast	farmer Farmer groups Provincial extension	Project 3 – Agriculture – land management in hilly areas – climate resilient agriculture	fixing trees as soil binder, fertilizer generator, and livestock feed source. The system also includes annual and perennial diversified food crops grown in the spaces between the hedgerows. The system can reduce soil erosion and restore moderately degraded hilly lands to a profitable farming system. Requires long term commitment & input from farmers & groups
	Agroforestry & forestry	• Rubber improvement • NTFPs • Mangrove • Boundary trees/ hedgerows • N fixing trees • Multipurpose trees	Plateaux & mountain Coast	Individual farmer Farmer groups Large scale farmers (plantations) Agri-business entities Provincial extension	SPCR Invest Project 3 – Agriculture – land management in coastal areas – climate resilient agriculture	Planting higher altitude Shading Management of NTFPs Mangrove restoration

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
Cross-cutting broad-based livelihood systems	Value chain development	• Post-harvest storage & processing	All provinces & ecozones	Individual farmer Farmer groups Private sector entities Provincial extension	SPCR Invest Project 2 – Agriculture – strengthen climate resilience of post-harvest infrastructure	Improved storage & processing (less wastage) Climate proof infrastructure for storage
		• Group management of shared infrastructure	All provinces & ecozones	Individual farmer Farmer groups Private sector entities Provincial extension	SPCR Invest Project 2 – Agriculture – strengthen infrastructure O&M	Importance of O&M of equipment & infrastructure
		• Collective marketing	All provinces & ecozones	Individual farmer Farmer groups Private sector entities	SPCR Invest Project 2 – Agriculture – strengthen infrastructure O&M	Improved, more efficient marketing & better livelihoods
		• Crop insurance	All provinces & ecozones	Individual farmer Farmer groups Private sector	SPCR Invest Project 2 – Agriculture – pilot crop insurance	Types of schemes to be determined

Category	Adaptation technology	Adaptation technology subgroup	Ecozone	Applications	SPCR project relevance	Comments
				entities	using the weather based index	
	Energy conservation	• Biogas • Energy plants • Improved stoves	All provinces & ecozones	Individual farmer Provincial extension NGOs	NA	Energy production & use
	Food security	• Seed banks • Food banks	All provinces & ecozones	Individual farmer Farmer groups Private sector entities Provincial extension	SPCR Invest Project 3 – Agriculture – introduction of drought/flood tolerant crop varieties	Closely linked to lowland rice-based farming systems, but includes all staple food crops grown in all locations
	Land/water rights	• Land/water right access	All provinces & ecozones	Individual farmer Farmer groups	NA	Key to all the above adaptation technologies is the rights of access for farm households and groups to land and water; it is therefore key to ensure that these rights are in place; government policy is important here

ANNEX 2: AGRICULTURE ADAPTATION TECHNOLOGY MULTI-CRITERIA ANALYSIS (MCA)

Table 1a: Agriculture adaptation technology scoring matrix

Adaptation category		Planning for CC and Variability				Sustainable water use and management				
Adaptation intervention Criteria	% weighting	National CC monitoring system	Seasonal inter-annual prediction	Decentralised community-run EWS	Climate insurance	Sprinkler irrigation	Drip irrigation	Solar water pump	Windmill water pump	Rainwater harvesting
1. Cost	**10%**	**0.5**	**0.5**	**0.4**	**0.5**	**0.35**	**0.35**	**0.3**	**0.3**	**0.25**
1.1 What is the cost per farmer of the initiative/practice/ device?1	50%	5	5	4	5	4	4	2	2	1
1.2 What is the cost for farmers of the initiative/ practice/device?2	50%	5	5	4	5	3	3	4	4	4
2. Economic Efficiency	**10%**	**0.1**	**0.3**	**0.2**	**0.1**	**0.4**	**0.4**	**0.2**	**0.2**	**0.2**
2.1 Will the initiative yield financial benefits substantially greater than if nothing was done?	100%	1	3	2	1	4	4	2	2	2
3. Labour	**8%**	**0.4**	**0.4**	**0.32**	**0.16**	**0.32**	**0.32**	**0.24**	**0.16**	**0.16**
3.1 Does the technology require a high investment in labour?3	100%	5	5	4	2	4	4	3	2	2
4. Flexibility/ Scalability	**10%**	**0.35**	**0.35**	**0.45**	**0.45**	**0.3**	**0.3**	**0.3**	**0.2**	**0.35**
4.1 Can the technology be easily customised for	50%	5	5	5	5	4	4	4	2	4

Adaptation category		Planning for CC and Variability				Sustainable water use and management				
Adaptation intervention		National CC monitoring system	Seasonal inter-annual prediction	Decentralised community-run EWS	Climate insurance	Sprinkler irrigation	Drip irrigation	Solar water pump	Windmill water pump	Rainwater harvesting
Criteria	% weighting									
specific landscape types, regardless of cost?										
4.2 Is the initiative/practice/ device easy to use?	50%	2	2	4	4	2	2	2	2	3
5. Activity/ technology easy to use/operate.	**10%**	**0.2**	**0.2**	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	**0.1**	**0.3**
5.1 Does the initiative require a lot of technical support?	100%	2	2	2	3	2	2	2	1	3
6. Relevance	**5%**	**0.15**	**0.15**	**0.2**	**0.25**	**0.25**	**0.25**	**0.2**	**0.2**	**0.2**
6.1 Would the technology be (more) successful if implementation were delayed five, ten or twenty years? Because of climate/ government/ knowledge/ capital/ technology/ infrastructure/ other circumstances.	100%	3	3	4	5	5	5	4	4	4
7. Equity	**5%**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.1**	**0.1**	**0.2**
7.1 Does the technology unfairly benefit some at the expense of other	100%	5	5	5	5	5	5	2	2	4

Adaptation category		Planning for CC and Variability				Sustainable water use and management				
Adaptation intervention		National CC monitoring system	Seasonal inter-annual prediction	Decentralised community-run EWS	Climate insurance	Sprinkler irrigation	Drip irrigation	Solar water pump	Windmill water pump	Rainwater harvesting
Criteria	% weighting									
regions, generations, a particular group of people (i.e. women) or particular socio-economic classes?										
8. Institutional feasibility	**5%**	**0.225**	**0.225**	**0.225**	**0.175**	**0.2**	**0.2**	**0.2**	**0.2**	**0.2**
8.1 Can it be implemented with existing institutions under existing laws?	50%	5	5	5	5	3	3	5	5	5
8.2 Does the technology support the policies of the Royal Government of Cambodia?	50%	4	4	4	2	5	5	3	3	3
9. Environmental Impact and Health and Safety	**5%**	**0.25**	**0.25**	**0.25**	**0.25**	**0.225**	**0.225**	**0.2**	**0.175**	**0.2**
9.1 Does the technology threaten any environmental resources?	50%	5	5	5	5	4	4	4	4	4
9.2 Does the technology increase or decrease the risk of disease or injury?	50%	5	5	5	5	5	5	4	3	4
10. Market oriented	**9%**	**0.18**	**0.18**	**0.27**	**0.18**	**0.36**	**0.36**	**0.18**	**0.09**	**0.18**
10.1 Is the	100%	2	2	3	2	4	4	2	1	2

Adaptation category		Planning for CC and Variability				Sustainable water use and management				
Adaptation intervention		National CC monitoring system	Seasonal inter-annual prediction	Decentralised community-run EWS	Climate insurance	Sprinkler irrigation	Drip irrigation	Solar water pump	Windmill water pump	Rainwater harvesting
Criteria	% weighting									
technology market friendly, suited to a market-based approach?										
11 Likelihood of acceptance	**8%**	**0.16**	**0.16**	**0.27**	**0.32**	**0.27**	**0.32**	**0.27**	**0.16**	**0.32**
11.1 Is the technology likely to be accepted by different communities/ types of farmers in different ecological areas?	100%	2	2	3	4	3	4	3	2	4
12. Climate Change Adaptation Impact	**15%**	**0.45**	**0.6**	**0.6**	**0.45**	**0.6**	**0.75**	**0.45**	**0.45**	**0.45**
12.1 What is the likelihood of this initiative having a climate change adaption impact?	100%	3	4	4	3	4	5	3	3	3
Total score		**3.22**	**3.57**	**3.64**	**3.39**	**3.73**	**3.93**	**2.84**	**2.34**	**3.01**

Source: Adapted from SNV (2013)

Assumptions

1 Multi-farmer benefitting technologies are project costed i.e. farmers do not (will not) invest
2 Farmer costs are for initial investment only and do not include recurring costs
3 Labour will rise when water resources are more available, but maybe offset by mechanisation
4 All major infrastructure developments adhere to environmental sustainability guidelines, as may be expected in Australia, US, etc.
5 Infrastructure investments do not include the cost of training in how to use the more available resource
6 Technologies which increase commercial production, assume higher input use. Such use follows GAP (Safe) application guidelines.

Table 1b: Agriculture adaptation technology scoring matrix

Adaptation category		Sustainable water use & management		Integrated soil management					
Adaptation intervention		Crop water requirement planning	Deficit irrigation	Sloping agriculture land technology	Slow-forming terraces	Conservation tillage	Integrated nutrient manag't	Compost making	Soil salinity management
Criteria	% weighting								
1. Cost	**10%**	**0.5**	**0.4**	**0.25**	**0.25**	**0.25**	**0.2**	**0.3**	**0.25**
1.1 What is the cost per farmer of the initiative/practice/ device?1	50%	5	4	2	2	2	1	2	1
1.2 What is the cost for farmers of the initiative/practice/ device?2	50%	5	4	3	3	3	3	4	4
2. Economic efficiency	**10%**	**0.5**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.2**	**0.4**
2.1 Will the initiative yield financial benefits substantially greater than if nothing was done?	100%	5	3	3	3	3	4	2	4
3. Labour	**8%**	**0.4**	**0.24**	**0.08**	**0.08**	**0.08**	**0.16**	**0.16**	**0.16**
3.1 Does the technology require a high investment in labour?3	100%	5	3	1	1	1	2	2	2
4. Flexibility/ scalability	**10%**	**0.15**	**0.15**	**0.2**	**0.2**	**0.3**	**0.35**	**0.35**	**0.15**
4.1 Can the technology be easily customised for	50%	1	1	2	2	4	5	4	1

Adaptation category		Sustainable water use & management		Integrated soil management					
Adaptation intervention		Crop water requirem ent planning	Deficit irrigation	Sloping agriculture land technology	Slow-forming terraces	Conserva tion tillage	Integrate d nutrient manag't	Comp ost makin g	Soil salinity management
Criteria	% weighting								
specific landscape types, regardless of cost?									
4.2 Is the initiative/ practice/ device easy to use?	50%	2	2	2	2	2	2	3	2
5. Activity/ technology easy to use/operate.	**10%**	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.1**
5.1 Does the initiative require a lot of technical support?	100%	1	2	1	1	1	1	2	1
6. Relevance	**5%**	**0.2**	**0.2**	**0.25**	**0.25**	**0.25**	**0.2**	**0.25**	**0.25**
6.1 Would the technology be (more) successful if implementation were delayed five, ten or twenty years? Because of climate/ government/ knowledge/ capital/ technology/ infrastructure/ other circumstances.	100%	4	4	5	5	5	4	5	5
7. Equity	**5%**	**0.05**	**0.05**	**0.1**	**0.1**	**0.15**	**0.15**	**0.1**	**0.1**
7.1 Does the technology unfairly	100%	1	1	2	2	3	3	2	2

Adaptation category		Sustainable water use & management		Integrated soil management					
Adaptation intervention		Crop water requirement planning	Deficit irrigation	Sloping agriculture land technology	Slow-forming terraces	Conservation tillage	Integrated nutrient manag't	Compost making	Soil salinity management
Criteria	% weighting								
benefit some at the expense of other regions, generations, a particular group of people (i.e. women) or particular socio-economic classes?									
8. Institutional feasibility	**5%**	**0.175**	**0.175**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.125**
8.1 Can it be implemented with existing institutions under existing laws?	50%	3	3	2	2	2	4	4	2
8.2 Does the technology support the policies of the Royal Government of Cambodia?	50%	4	4	2	2	2	4	4	3
9. Environmental Impact and Health and Safety	**5%**	**0.25**	**0.225**	**0.225**	**0.225**	**0.225**	**0.225**	**0.225**	**0.175**
9.1 Does the technology threaten any environmental resources?	50%	5	4	5	5	5	5	5	4
9.2 Does the technology increase or decrease the risk	50%	5	5	4	4	5	5	5	3

Adaptation category		Sustainable water use & management		Integrated soil management					
Adaptation intervention		Crop water requirement planning	Deficit irrigation	Sloping agriculture land technology	Slow-forming terraces	Conservation tillage	Integrated nutrient manag't	Compost making	Soil salinity management
Criteria	% weighting								
of disease or injury?									
10. Market oriented	**9%**	**0.27**	**0.27**	**0.18**	**0.18**	**0.27**	**0.45**	**0.27**	**0.18**
10.1 Is the technology market friendly, suited to a market-based approach?	100%	3	3	2	2	3	5	3	2
11 Likelihood of acceptance	**8%**	**0.16**	**0.16**	**0.16**	**0.16**	**0.32**	**0.24**	**0.24**	**0.08**
11.1 Is the technology likely to be accepted by different communities/ types of farmers in different ecological areas?	100%	2	2	2	2	4	3	3	1
12. Climate Change Adaptation Impact	**15%**	**0.6**	**0.6**	**0.75**	**0.75**	**0.75**	**0.75**	**0.6**	**0.6**
12.1 What is the likelihood of this initiative having a climate change adaption impact?	100%	4	4	5	5	5	5	4	4
Total score		**3.36**	**2.97**	**2.70**	**2.70**	**2.94**	**3.43**	**3.10**	**2.57**

Source: Adapted from SNV (2013).

Adaptation category		Sustainable water use & management		Integrated soil management					
Adaptation intervention		Crop water requirem ent planning	Deficit irrigation	Sloping agriculture land technology	Slow-forming terraces	Conserva tion tillage	Integrate d nutrient manag't	Comp ost makin g	Soil salinity management
Criteria	% weighting								

Assumptions
1 Multi-farmer benefitting technologies are project costed i.e. farmers do not (will not) invest
2 Farmer costs are for initial investment only and do not include recurring costs
3 Labour will rise when water resources are more available, but maybe offset by mechanisation
4 All major infrastructure developments adhere to environmental sustainability guidelines, as may be expected in Australia, US, etc.
5 Infrastructure investments do not include the cost of training in how to use the more available resource
6 Technologies which increase commercial production, assume higher input use. Such use follows GAP (Safe) application guidelines.

Table 1c: Agriculture adaptation technology scoring matrix

Adaptation category		Integrated soil management			Sustainable crop management					
Adaptation intervention Criteria	% weighting	Vetiver and soil stabilisation grasses	Live staking	Mulching	Crop diversification & rotations	New varieties	Ecological/ integrated pest manag't	Seed & grain storage	System of rice intensification	Alternative wetting and drying rice irrigation
1. Cost	**10%**	**0.3**	**0.3**	**0.3**	**0.4**	**0.4**	**0.3**	**0.25**	**0.35**	**0.35**
1.1 What is the cost per farmer of the initiative/ practice/ device? 1	50%	2	2	3	3	4	3	2	3	3
1.2 What is the cost for farmers of the initiative/practice/ device? 2	50%	4	4	3	5	4	3	3	4	4
2. Economic Efficiency	**10%**	**0.2**	**0.1**	**0.3**	**0.5**	**0.3**	**0.3**	**0.5**	**0.5**	**0.4**
2.1 Will the initiative yield financial benefits substantially greater than if nothing was done?	100%	2	1	3	5	3	3	5	5	4
3. Labour	**8%**	**0.08**	**0.08**	**0.16**	**0.16**	**0.24**	**0.16**	**0.16**	**0.16**	**0.16**
3.1 Does the technology require a high investment in labour?3	100%	1	1	2	2	3	2	2	2	2
4. Flexibility/ Scalability	**10%**	**0.25**	**0.25**	**0.4**	**0.35**	**0.4**	**0.4**	**0.35**	**0.25**	**0.25**
4.1 Can the technology be easily customised for specific landscape	50%	2	2	4	4	4	5	4	3	3

Adaptation category		Integrated soil management			Sustainable crop management					
Adaptation intervention		Vetiver and soil stabilisation grasses	Live staking	Mulching	Crop diversification & rotations	New varieties	Ecological/ integrated pest managʼt	Seed & grain storage	System of rice intensification	Alternative wetting and drying rice irrigation
Criteria	% weighting									
types, regardless of cost?										
4.2 Is the initiative/ practice/ device easy to use?	50%	3	3	4	3	4	3	3	2	2
5. Activity/ technology easy to use/operate.	**10%**	**0.2**	**0.3**	**0.2**	**0.2**	**0.3**	**0.1**	**0.2**	**0.2**	**0.2**
5.1 Does the initiative require a lot of technical support?	100%	2	3	2	2	3	1	2	2	2
6. Relevance	**5%**	**0.2**	**0.25**	**0.25**	**0.25**	**0.15**	**0.2**	**0.25**	**0.25**	**0.25**
6.1 Would the technology be (more) successful if implementation were delayed five, ten or twenty years? Because of climate/ government/ knowledge/ capital/ technology/ infrastructure/ other circumstances.	100%	4	5	5	5	3	4	5	5	5
7. Equity	**5%**	**0.15**	**0.15**	**0.2**	**0.15**	**0.25**	**0.2**	**0.2**	**0.15**	**0.15**
7.1 Does the technology unfairly benefit some at the expense of other	100%	3	3	4	3	5	4	4	3	3

Adaptation category		Integrated soil management			Sustainable crop management					
Adaptation intervention		Vetiver and soil stabilisation grasses	Live staking	Mulching	Crop diversification & rotations	New varieties	Ecological/ integrated pest manag't	Seed & grain storage	System of rice intensification	Alternative wetting and drying rice irrigation
Criteria	% weighting									
regions, generations, a particular group of people (i.e. women) or particular socio-economic classes?										
8. Institutional feasibility	**5%**	**0.15**	**0.15**	**0.2**	**0.25**	**0.225**	**0.225**	**0.25**	**0.225**	**0.175**
8.1 Can it be implemented with existing institutions under existing laws?	50%	3	3	4	5	5	4	5	5	4
8.2 Does the technology support the policies of the Royal Government of Cambodia?	50%	3	3	4	5	4	5	5	4	3
9. Environmental Impact and Health and Safety	**5%**	**0.225**	**0.175**	**0.2**	**0.225**	**0.2**	**0.25**	**0.225**	**0.25**	**0.25**
9.1 Does the technology threaten any environmental resources?	50%	5	4	4	4	4	5	4	5	5
9.2 Does the technology increase or decrease the risk of disease or injury?	50%	4	3	4	5	4	5	5	5	5
10. Market oriented	**9%**	**0.09**	**0.09**	**0.18**	**0.36**	**0.36**	**0.27**	**0.45**	**0.27**	**0.27**
10.1 Is the	100%	1	1	2	4	4	3	5	3	3

Adaptation category		Integrated soil management			Sustainable crop management					
Adaptation intervention		Vetiver and soil stabilisation grasses	Live staking	Mulching	Crop diversification & rotations	New varieties	Ecological/ integrated pest manag't	Seed & grain storage	System of rice intensification	Alternative wetting and drying rice irrigation
Criteria	% weighting									
technology market friendly, suited to a market-based approach?										
11 Likelihood of acceptance	**8%**	**0.08**	**0.08**	**0.32**	**0.32**	**0.32**	**0.32**	**0.32**	**0.16**	**0.16**
11.1 Is the technology likely to be accepted by different communities/ types of farmers in different ecological areas?	100%	1	1	4	4	4	4	4	2	2
12. Climate Change Adaptation Impact	**15%**	**0.6**	**0.6**	**0.6**	**0.75**	**0.75**	**0.75**	**0.6**	**0.3**	**0.45**
12.1 What is the likelihood of this initiative having a climate change adaption impact?	100%	4	4	4	5	5	5	4	2	3
Total score		**2.53**	**2.53**	**3.31**	**3.92**	**3.90**	**3.48**	**3.76**	**3.07**	**3.07**

Source: Adapted from SNV (2013).

Assumptions

1 Multi-farmer benefitting technologies are project costed i.e. farmers do not (will not) invest
2 Farmer costs are for initial investment only and do not include recurring costs
3 Labour will rise when water resources are more available, but maybe offset by mechanisation
4 All major infrastructure developments adhere to environmental sustainability guidelines, as may be expected in Australia, US, etc.
5 Infrastructure investments do not include the cost of training in how to use the more available resource
6 Technologies which increase commercial production, assume higher input use. Such use follows GAP (Safe) application guidelines.

Table 1d: Agriculture adaptation technology scoring matrix

Adaptation category		Sustainable farming and livelihood systems			Capacity building and stakeholder organisation					Water resource development
Adaptation intervention		Integrated rice-fish systems	Mixed farming systems	Agro-forestry	Community based agricultural extension	Farmers field schools	Forestry user groups	Water user associations	Community based seed systems	Canal & pumping intervention
Criteria	**% weighting**									
1. Cost	**10%**	**0.3**	**0.3**	**0.25**	**0.4**	**0.35**	**0.4**	**0.3**	**0.3**	**0.35**
1.1 What is the cost per farmer of the initiative/ practice/device?1	50%	2	2	2	4	3	4	3	3	4
1.2 What is the cost for farmers of the initiative/practice/ device?2	50%	4	4	3	4	4	4	3	3	3
2. Economic Efficiency	**10%**	**0.2**	**0.3**	**0.2**	**0.2**	**0.2**	**0.4**	**0.4**	**0.4**	**0.4**
2.1 Will the initiative yield financial benefits substantially greater than if nothing was done?	100%	2	3	2	2	2	4	4	4	4
3. Labour	**8%**	**0.16**	**0.16**	**0.08**	**0.4**	**0.24**	**0.24**	**0.16**	**0.16**	**0.16**
3.1 Does the technology require a high investment in labour?3	100%	2	2	1	5	3	3	2	2	2
4. Flexibility/ Scalability	**10%**	**0.35**	**0.35**	**0.3**	**0.35**	**0.3**	**0.2**	**0.2**	**0.3**	**0.3**
4.1 Can the technology be easily	50%	4	4	3	5	4	2	2	4	2

Adaptation category		Sustainable farming and livelihood systems			Capacity building and stakeholder organisation					Water resource development
Adaptation intervention		Integrated rice-fish systems	Mixed farming systems	Agro-forestry	Community based agricultural extension	Farmers field schools	Forestry user groups	Water user associations	Community based seed systems	Canal & pumping intervention
Criteria	**% weighting**									
customised for specific landscape types, regardless of cost?										
4.2 Is the initiative/practice/device easy to use?	50%	3	3	3	2	2	2	2	2	4
5. Activity/technology easy to use/operate.	**10%**	**0.3**	**0.3**	**0.3**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**
5.1 Does the initiative require a lot of technical support?	100%	3	3	3	1	1	1	1	1	1
6. Relevance	**5%**	**0.25**	**0.25**	**0.25**	**0.25**	**0.2**	**0.25**	**0.25**	**0.25**	**0.25**
6.1 Would the technology be (more) successful if implementation were delayed five, ten or twenty years? Because of climate/ government/ knowledge/ capital/ technology/ infrastructure/ other circumstances.	100%	5	5	5	5	4	5	5	5	5

Adaptation category		Sustainable farming and livelihood systems			Capacity building and stakeholder organisation					Water resource development
Adaptation intervention		Integrated rice-fish systems	Mixed farming systems	Agro-forestry	Community based agricultural extension	Farmers field schools	Forestry user groups	Water user associations	Community based seed systems	Canal & pumping intervention
Criteria	**% weighting**									
7. Equity	**5%**	**0.2**	**0.15**	**0.1**	**0.25**	**0.2**	**0.2**	**0.1**	**0.1**	**0.1**
7.1 Does the technology unfairly benefit some at the expense of other regions, generations, a particular group of people (i.e. women) or particular socio-economic classes?	100%	4	3	2	5	4	4	2	2	2
8. Institutional feasibility	**5%**	**0.225**	**0.2**	**0.15**	**0.25**	**0.25**	**0.25**	**0.2**	**0.225**	**0.25**
8.1 Can it be implemented with existing institutions under existing laws?	50%	5	4	3	5	5	5	4	5	5
8.2 Does the technology support the policies of the Royal Government of Cambodia?	50%	4	4	3	5	5	5	4	4	5
9. Environmental Impact and Health and Safety	**5%**	**0.25**	**0.2**	**0.225**	**0.25**	**0.25**	**0.25**	**0.25**	**0.225**	**0.2**
9.1 Does the technology threaten any environmental	50%	5	4	5	5	5	5	5	5	4

Adaptation category		Sustainable farming and livelihood systems			Capacity building and stakeholder organisation					Water resource development
Adaptation intervention		Integrated rice-fish systems	Mixed farming systems	Agro-forestry	Community based agricultural extension	Farmers field schools	Forestry user groups	Water user associations	Community based seed systems	Canal & pumping intervention
Criteria	**% weighting**									
resources? 9.2 Does the technology increase or decrease the risk of disease or injury?	50%	5	4	4	5	5	5	5	4	4
10. Market oriented	**9%**	**0.36**	**0.45**	**0.27**	**0.18**	**0.09**	**0.36**	**0.27**	**0.45**	**0.36**
10.1 Is the technology market friendly, suited to a market-based approach?	100%	4	5	3	2	1	4	3	5	4
11 Likelihood of acceptance	**8%**	**0.32**	**0.32**	**0.24**	**0.4**	**0.4**	**0.16**	**0.16**	**0.32**	**0.4**
11.1 Is the technology likely to be accepted by different communities/ types of farmers in different ecological areas?	100%	4	4	3	5	5	2	2	4	5
12. Climate Change Adaptation Impact	**15%**	**0.3**	**0.6**	**0.45**	**0.3**	**0.3**	**0.75**	**0.75**	**0.45**	**0.75**
12.1 What is the likelihood of this initiative having a climate change adaption impact?	100%	2	4	3	2	2	5	5	3	5

Adaptation category		Sustainable farming and livelihood systems			Capacity building and stakeholder organisation					Water resource development
Adaptation intervention		Integrated rice-fish systems	Mixed farming systems	Agro-forestry	Community based agricultural extension	Farmers field schools	Forestry user groups	Water user associations	Community based seed systems	Canal & pumping intervention
Criteria	**% weighting**									
Total score		**3.22**	**3.58**	**2.82**	**3.33**	**2.88**	**3.56**	**3.14**	**3.28**	**3.62**

Source: Adapted from SNV (2013).

Assumptions

1 Multi-farmer benefitting technologies are project costed i.e. farmers do not (will not) invest
2 Farmer costs are for initial investment only and do not include recurring costs
3 Labour will rise when water resources are more available, but maybe offset by mechanisation
4 All major infrastructure developments adhere to environmental sustainability guidelines, as may be expected in Australia, US, etc.
5 Infrastructure investments do not include the cost of training in how to use the more available resource
6 Technologies which increase commercial production, assume higher input use. Such use follows GAP (Safe) application guidelines.

ANNEX 3: COLLABORATIVE RESEARCH AND DEVELOPMENT OF ADAPTATION TECHNOLOGIES

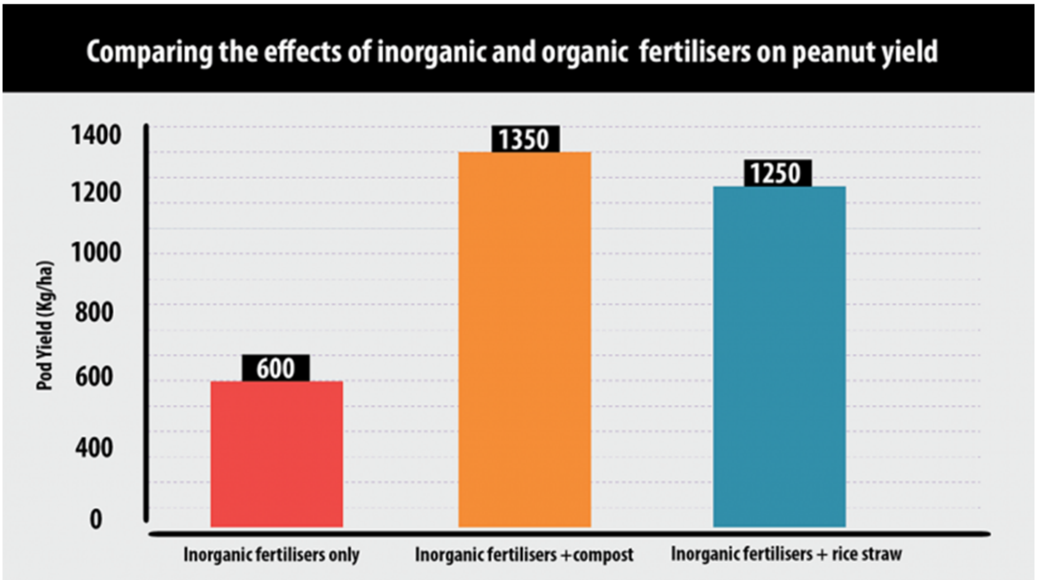
Note: the information below is sourced from IAEA (2017), with certain sections abstracted.

Cambodia's agricultural researchers have found that poor farmers who cannot afford to buy enough fertilizer can achieve high yields by using more manure and compost and planting alternative crops between rice-growing seasons. These findings are the result of research supported by the IAEA and FAO, using nuclear-related techniques to measure fertilizer and water uptake by rice and other crops. Cambodia is among a growing number of countries using such techniques to increase crop yields, optimize fertilizer use and evaluate varieties of rice, cereals and vegetables for their efficiency in making the best use of fertilizers. These adaptation technologies have important implications for climate change.

1. Blending organic and inorganic

Experiments conducted by scientists at CARDI found that replacing half of the recommended amount of chemical fertilizer with organic materials (when inorganic fertilizer is either not accessible or too expensive) actually increases rice yields. This has various benefits: farmers save money on chemical fertilizer, and at the same time they can achieve higher yields.

In the case of peanuts (a legume cash crop), replacing half of the chemical fertilizers with a mix of cattle manure and rice straw more than doubled yields (see graph below). For rice, the use of a reduced amount of chemical fertilizer with organic manure led to yields comparable to the use of chemical fertilizers only.



As an example, Borey Thai, a farmer with 1.5 hectares of land in Kampong Speu province south of Phnom Penh, replaced half of the chemical fertilizer with a mix of manure and farmyard waste in this year's growing season. As a result, she saved a third of the money she used to spend on fertilizer. "It is much cheaper, but is more work," she said. "But what matters is that I can use the savings to renovate my house." She expects her yield to be around 20% higher this year compared to the previous year, thanks to the use of mixed fertilizer.

One challenge her neighbours face, she added, is to find good quality manure. "If we could find more manure, more of us would switch to organic."

2. Alternative crops

MAFF researchers found that growing non-rice crops between rice-growing seasons is another way for farmers to increase their income. Historically, farmers have used their fields only during the rainy season to grow rice, with lands left idle during the dry season.

Researchers have found that conditions during the dry season are optimal for other crops, particularly legumes such as beans and lentils. "These would not only provide farmers with additional income, but legumes add nitrogen from the atmosphere to the soil and, in addition, decomposing bean plants also increase the quality of the soil, leading to higher rice yields in the following rice season," as stated by Phirum from MAFF. Researchers used the nitrogen-15 isotopic technique to study the amount of fertilizer absorbed by the plants from the soil, fixed from the atmosphere, in addition to quantifying the efficiency of fertilizer applied.

The research teams received various forms of support under the IAEA's technical cooperation programme. They learned the use of nuclear-related and other techniques in workshops and through participation in fellowships in neighbouring countries. They received equipment and materials to conduct the experiments, and advice from experts at the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture in interpreting the results.

A researcher experimenting with rice, using stable nitrogen-15 ($_{15}N$) to monitor the nitrogen uptake by the plants. (Photo: CARDI)

3. Labelled nitrogen isotope

Nitrogen plays an important role in plant growth and photosynthesis, the process through which plants convert energy from sunlight into chemical energy. Nitrogen is often added to soil in the form of fertilizer. By using fertilizers labelled with nitrogen-15 ($_{15}N$) stable isotopes — an atom with an extra neutron compared with 'normal' nitrogen — scientists can track the pathway and determine how effectively the crops are taking up the fertilizer. The technique helps to determine the optimal amount of fertilizer to use. Isotopic techniques have an important role to play, particularly for farmers working on poorer soil. Isotopes are also used in nuclear techniques in agricultural water management.

ANNEX 4: APPROACHES FOR ASSESSING COSTS AND BENEFITS OF ADAPTATION OPTIONS

Overview of Methodological Issues

The IPCC AR4 defines adaptation costs as "the costs of planning, preparing for, facilitating, and implementing adaptation measures, including transition costs," and defines benefits as "the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures". To arrive at an estimate of the benefits of adaptation options relative to a baseline scenario, the projected climate change impacts and the costs of the different options must be examined. Adaptation measures will usually not completely negate the negative impacts of climate change, so the cost of residual damage that remains after implementation of the adaptation option must also be taken into account. After comparing the options, those with the highest estimated net benefits are selected for implementation. The literature on the costs and benefits of adaptation options raises a number of methodological issues, which can be grouped under the broad themes of uncertainty, valuation and equity, as shown in Figure 1.

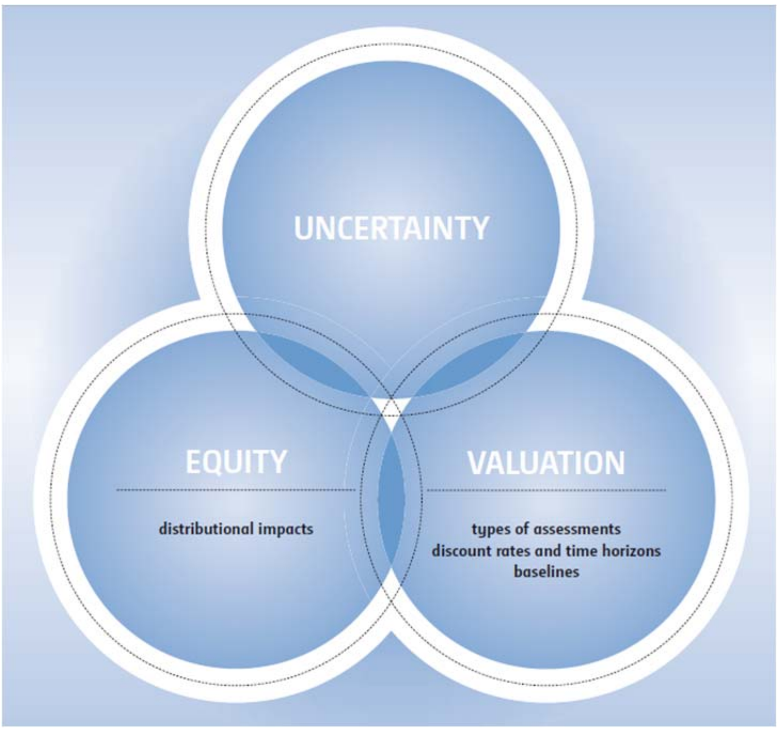


Figure 1. *Main methodological themes concerning costs and benefits of adaptation*

Uncertainty

Uncertainty surrounding future climate change impacts and future socio-economic development constrains the identification of optimal adaptation options. Even under a specific scenario of future emissions, the range of possible impacts is large. It is important to note though that uncertainties will decline over time as more climatic and socio-economic data becomes available. Adaptation measures should therefore be designed in a flexible manner so that adaptation options can be adjusted or reversed as new information becomes available. This is particularly important for adaptation options that have long-term implications, or for measures that will have a long life span, such as infrastructure. Another aspect of uncertainty relates to data/measurement uncertainty, which can be addressed through having an adequate sample size and measurement approach so that results are robust enough for decision making.

Valuation

Assessing the costs and benefits of adaptation options can be undertaken narrowly through *financial assessments* or more comprehensively through *economic assessments*. Financial assessments are usually undertaken within the budgetary framework of the adaptation option under consideration and consider financial costs and benefits only. In contrast, economic assessments consider the wider costs and benefits to the national economy as a whole. In addition, social and environmental costs and benefits may also be assessed (e.g. impacts on availability of jobs, institutional capacity or ecosystem services).

When assessing the costs and benefits of adaptation options, it is important to not only consider market costs and benefits, i.e. costs and benefits that can be easily quantified in monetary terms because they can be traded in markets (e.g. agriculture, fisheries and forestry), but also non-market costs and benefits, i.e. those costs and benefits that are difficult to quantify in monetary terms because they are not traded on markets (e.g. human health and ecosystem services).

Definition of a *baseline* is one of the most important, but also one of the most difficult aspects of estimating the costs and benefits of adaptation options. The baseline should define what would happen to the main variables in the absence of climate change. Significant challenges exist because adaptation assessments must look ahead into the future and analyses must predict levels of development and social changes up to 2030 and beyond. When drawing the baseline, it is important to remember that outcomes may vary and not all plans will always be fully implemented. Given the number of uncertainties, some researchers have proposed the use of multiple baselines when estimating the costs and benefits of adaptation and evaluating adaptation options.

Discount rates are commonly used to estimate the present values of the costs and benefits of the adaptation options under consideration because the costs of an option occur earlier in time than the benefits of such an option. Present values are very sensitive to the choice of the discount rate and to any assumption about the consistency of the discount rate over time. There is considerable disagreement among economists about the rate (or rates) at which these future costs and benefits should be discounted. Some studies apply existing discount rates relevant to the country or organization under consideration.

Many studies undertake sensitivity analyses to test to what extent the result of the assessment is affected by changes in key variables such as the discount rate. Applying a range of discount rates allows planners to test the validity of results and ensure that the discount rate is not chosen close to a tipping point that reverses the decision, in which case further analysis is applied.

The *time-horizon* of the evaluation is directly linked to the discount rate. The horizon depends on the lifespan of the options under consideration. For example, the lifespan of infrastructure projects (e.g. dams and roads) ranges from 50 to 70 years. So, when assessing these options, the totality of costs, including investment and maintenance costs, benefits and expected impacts of climate change over the entire period should be taken into account. In contrast, plans for adapting to health impacts can take a short- to medium-term view (5 to 20 years), which can later be extended to cover longer periods if necessary.

Equity

As pointed out by the IPCC AR4, climate change impacts disproportionately affect vulnerable populations, many of whom are poor. It is therefore important for adaptation planners not only to consider net benefits but also to consider the distribution of the costs and benefits of adaptation options. The distributional aspect of net benefits can be addressed in a number of ways. One is to give weights to different costs and benefits according to who receives the benefits and who bears the cost, for example doubling the benefits for poor people, and halving that for the rich. The difficulty with applying weights is that, in practice, there is a subjective aspect to choosing where the thresholds should lie and what the weighting coefficients should be. An alternative and more popular approach is to present the distributional impacts of adaptation options alongside the aggregate costs and benefits and let the decision be taken by the policymakers.

Choosing an Approach to Assess the Costs and Benefits of Adaptation Options

Once adaptation planners have identified possible adaptation options, have agreed upon decision criteria, and have considered the different methodological aspects, they can then choose between a number of approaches to assess the costs and benefits of each option. Figure 2 below provides a schematic of the possible approaches that can be applied and that are elaborated below.

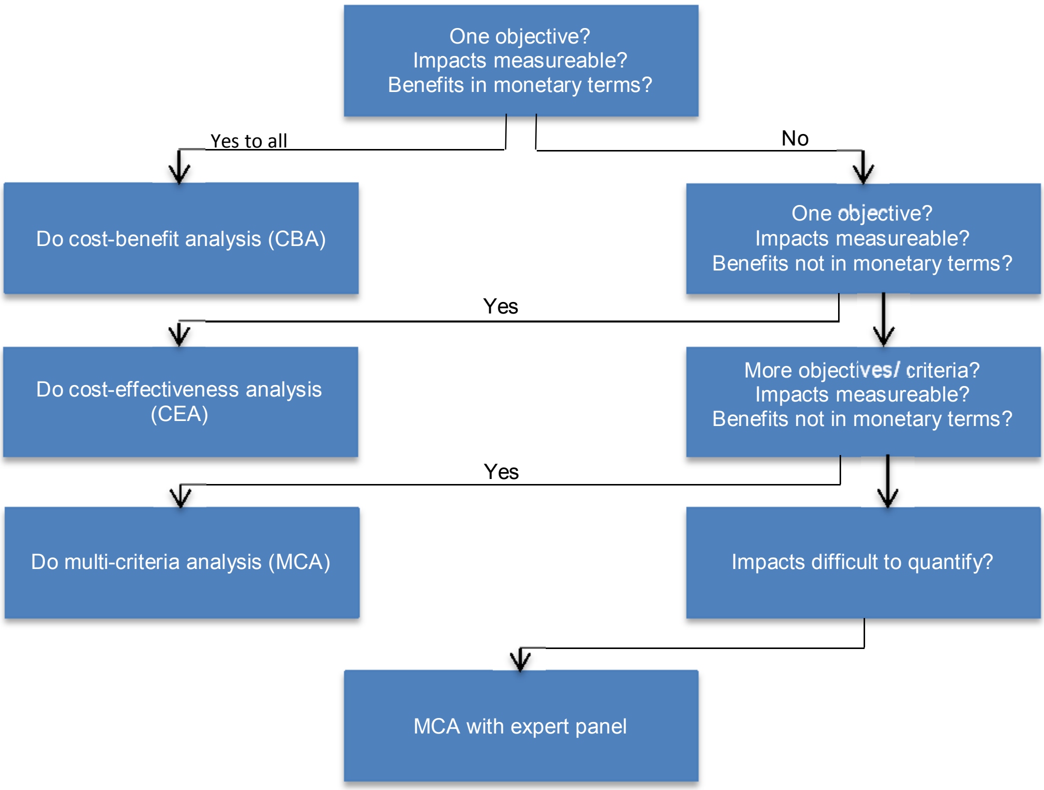


Figure 2. Decision tree of possible approaches for assessing the costs and benefits of adaptation options

Source: Adapted from Boyd R and Hunt A. 2004. Costing the Impacts of Climate Change in the UK: Overview Guidelines. UK Climate Impacts Programme Technical Report.

Cost-Benefit Analysis

Cost-benefit analysis (CBA) is often used to assess adaptation options when efficiency is the only decision making criteria. A CBA involves calculating and comparing all of the costs and benefits, which are expressed in monetary terms. The comparison of expected costs and benefits can help to inform decision makers about the likely efficiency of an adaptation investment. CBA provides a basis for prioritising possible adaptation measures. The benefit of this approach is that it compares diverse impacts using a single metric. However, it is important to be explicit about how the costs and benefits are distributed, in addition to their aggregate values. In addition, it can be challenging to include reliable estimates of things that are valuable but not valued in markets: for example, the costs and benefits often associated with issues such as environmental goods and services and social or cultural values. This can mean that non-market costs and benefits are excluded, and consequently the results of the analysis are misleading.

Strengths and weaknesses of CBA

CBAs are appealing because it is possible to compare and/or aggregate many different categories of benefits or costs into a single value. A limitation of CBA is that it requires all benefits to be measured and expressed in monetary terms and that there is a particular emphasis on efficiency. CBA does not address those equity considerations related to the distribution of the costs and benefits of adaptation options across stakeholder groups, for example, by not including whether those who benefit from the policy can afford to pay for it. The argument that projects or policies with the best BCR are socially desirable rests on the assumption that those who gain can in principle compensate those negatively impacted by a project or policy, and still be better off. However, whether such compensation actually takes place is dependent upon the design of the adaptation policy. Another complexity of CBA is that it must monetize categories of costs and benefits that are experienced at different times. This entails the need for discounting costs and benefits incurred in the future to compute their present value, but doing so requires choosing a discount rate with the difficulties discussed above.

Cost−Effectiveness Analysis

Cost-effectiveness analysis (CEA) is used to find the least costly adaptation option or options for meeting selected physical targets. Given that CEA is performed when the objectives of the adaptation measures have been identified and the remaining task is to find the lowest-cost option for meeting these objectives, it does not evaluate whether the measure is justified (e.g. by generating a certain benefit-cost ratio or IRR). CEA is applied in assessing adaptation options in areas where adaptation benefits are difficult to express in monetary terms, including human health, freshwater systems, extreme weather events, and biodiversity and ecosystem services; but where costs can be quantified. For example, given the necessity for water, the aim of an assessment is not to find alternative adaptation options that might yield higher adaptation benefits, but to find those options that ensure sustainable water quality and quantity for vulnerable communities.

Strengths and weaknesses of CEA

CEA is a useful alternative to CBA in areas where benefits cannot be quantified monetarily to compare alternative adaptation options with a view to identifying the option which can reach a well-defined objective in the most cost effective way. However, CEA is often not used as a standalone tool for decision support as the benefits are defined in one single dimension only (e.g. cost-effectiveness). Other dimensions such as equity, feasibility or co-benefits are not considered in the primary analysis but could be considered during the selection process of the chosen options.

Multi-Criteria Analysis

Multi-criteria analysis (MCA) allows assessment of different adaptation options against a number of criteria. Each criterion is given a weighting. Using this weighting, an overall score for each adaptation option is obtained. The adaptation option with the highest score is selected. MCA offers an alternative for the assessment of adaptation options when only partial data is available, when cultural and ecological considerations are difficult to quantify and when the monetary benefit or effectiveness are only two of many criteria. MCA essentially involves defining a framework to integrate different decision criteria in a quantitative analysis without assigning monetary values to all factors. MCA was the method of choice for least developed countries (LDCs) in preparing their national adaptation programmes of action (NAPAs). The robustness of an MCA result depends on the (un)certainty of the information regarding the selected criteria, the relative priorities given to various criteria (the weights or scores) and the extent to which the weights are commonly agreed upon by stakeholders. Sensitivity analysis can be used to check the robustness of the result for changes in scores and/or weights and weaknesses of MCA.

Strengths and weaknesses of MCA

MCA helps to structure the challenge of selecting an adaptation option by outlining the various objectives of a programme and the criteria to measure those objectives in a transparent manner. MCA can accommodate quantitative as well as qualitative information and helps to communicate the strengths and weaknesses of each adaptation option. In addition, MCA allows for direct stakeholder engagement by allowing the beneficiaries of the adaptation options to be involved in choosing them, which is crucial for creating ownership and subsequent implementation of the adaptation measures. Difficulties associated with MCA include assigning weights, especially if the number of criteria is large and the criteria are very different in character, and standardizing scores, which leads to losing some information that could be valuable in later stages. Explicit statement of the weight assigned to each criterion can enhance public debate. Since it is not always easy to reach agreement among stakeholders on criteria and their relative importance, it is advisable to conduct a sensitivity analysis to determine if the ranking is sufficiently robust to withstand scrutiny.

Best Practices and Lessons Learned

Adaptation planners should consider the strengths and weaknesses of the various approaches for assessing adaptation options vis-à-vis their objectives and circumstances. In some situations, a number of approaches could be applied in a complementary fashion. Regardless of which assessment approach the adaptation planner chooses, each should be:

Practical, i.e. approaches have to be appropriate for a given cultural and socio-economic setting and take into account data constraints. For example, if the benefits cannot be quantified monetarily it is not advisable to undertake a CBA;

Relevant, i.e. results should be presented in a timely manner and in a format that is compatible with existing decision making. For example, if public policy options are usually assessed using CBA, assessing adaptation options using CEA may be less acceptable;

Robust, i.e. approaches should be transparent and consistent within and across sectors regarding the underlying climatic and socio-economic assumptions, expert judgments and uncertainties such as discount rates and be explicit about inherent uncertainties;

Comprehensive, i.e. approaches should assess a wide range of options, including inaction, action outside sectoral boundaries and co-benefits; and

Proportional, i.e. the depth of the selected approach should be driven by the decisions to be made and not by the aim for the perfect decision.

Many best practices and lessons learned have been illuminated throughout this paper. Adaptation planners should:

Assess the costs and benefits of adaptation options following solid impact and vulnerability assessments;

Consider short and long-term adaptation options in the broader development and planning context, and should identify a holistic adaptation portfolio rather than stand-alone adaptation interventions;

Take into account distributional effects, i.e. the assessment needs to consider which sectors, groups or communities will bear the cost and which will enjoy the benefits of the adaptation option under consideration;

Undertake sensitivity analyses, including variation of the discount rates, to investigate the robustness of the results;

Adopt, where possible, multiple approaches for assessing adaptation options, as linking these together would provide a greater evidence base. It can be almost impossible to see how one single approach could capture the complexities of the methodological underpinnings, the diversity of circumstances in which adaptation takes place and the variety of objectives with which adaptation is undertaken;

Involve stakeholders in the assessment through surveys or workshops in order to create ownership and increase the chance of implementing selected adaptation options;

Embed the assessment of adaptation options into the broader planning process and create vehicles or processes to ensure that results are integrated into national, subnational or sectoral policies; and

Undertake evaluations following the implementation of selected adaptation option to assess whether the initial costing was higher or lower than the real costs and to assess the range of direct to more indirect benefits.

Conclusions

Assessing the costs and benefits of different policy options is not unique to adaptation actions. Governments, businesses and communities have applied assessment approaches such as CBA, CEA and MCA, along with other tools to support their decision making and allocate scarce funds. Issues related to uncertainty, valuation and equity have often necessitated adjusting those approaches to the adaptation context. The value of such assessments goes beyond attempting to quantify the costs and benefits. They can stimulate debate among stakeholders on the overall objective of adaptation and underlying climate-related and socioeconomic assumptions and value judgments as well as assist in creating ownership and responsibility for implementation. Given the increasing need for adaptation, assessments of the costs and benefits of adaptation options should support decisions rather than be seen as a prerequisite or reason to delay implementing urgent adaptation measures. Assessing the costs and benefits does not end when adaptation measures are implemented. Costs and benefits should be monitored and evaluated during and after implementation. Monitoring and evaluation results should feed back into the adaptation policy process with a view to generating and applying new information and knowledge to continuously improve adaptation planning and implementation.

More information

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