

CPWF TOPIC 1

synthesis

Improving Rainwater Productivity

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Improving rainwater productivity: Topic 1 synthesis paper

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CPWF Topic Synthesis Papers

In the second phase of the CGIAR Challenge Program on Water and Food, activities will be organized around Basin Development Challenges and Topics. Basin Development Challenges are water and food problem areas of recognized importance in a river basin area. Topics are subject matter areas selected to support research on basin challenges. Topics play two roles: to ensure the quality of science in research on basin development challenges, and to facilitate the development of international public goods.

The process of jointly defining basin challenges and topics began with stakeholder surveys, and consultations with Basin Coordinators, Basin Focal Project teams, Phase 1 Theme Leaders, and external experts. This process culminated in a series of one-on-one interviews with key basin stakeholders from research, development and policy arenas.

In their present form, the priority Topics are as follows:

- Improving Rainwater Productivity
- Multi-purpose Water Systems
- Water Benefits Sharing for Poverty Alleviation and Conflict Resolution
- Global Drivers and Processes of Change

The four synthesis papers describe these priority Topics: their present status, how they evolved, what was learned about them in Phase 1, and the kinds of research likely to be needed on each topic in Phase 2.

These papers are not the final word, however. Basin challenges and topics will continue to be re-defined. Topics are intended to support and serve the basins: as research on basin challenges unfold, the content of individual topics may be modified. Whole new topics may emerge and other topics dropped.

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Contents

Introduction	4
Rationale	5
The potential of rainfed systems	4
Water scarcity	5
Crops and livestock	6
Issues of scale	8
Contributions from CPWF Phase 1 projects	8
Improving rainwater productivity in Africa	8
Improving sustainability and water productivity of livestock in rainfed areas	10
Improving rainwater management in salt affected areas	11
Supplementary irrigation and aerobic rice	12
Rainfed mountainous regions	12
Capacity building and participatory research	12
Remaining gaps	13
Technologies	13
Adoption, poverty and gender	13
Impacts and consequences	14
Scope	14
Sub-topics and research questions	14
CPWF niche and value added	15
References	16

Introduction

The majority of the world's rural poor people depend on rainfed crop and livestock systems for their food and incomes (Peden et al. 2007; Rockström et al. 2007). When the productivity of these systems is low, as is so often the case, food insecurity, impoverished livelihoods and land and water degradation often prevail. Over the past 50 years, expansion of land under rainfed agriculture has been a key driver of the degradation of ecosystem services (MEA 2005). Fortunately, there is great potential to increase the productivity of rainfed systems, and in ways that benefit the environment. This is true across a wide range of environments from arid and semi-arid temperate regions to the semi-arid and sub-humid tropics. Higher system productivity depends on improved rainwater management, but for the greatest benefit, improved rainwater management must be part of an integrated package of crop and livestock cultural practices.

Technical options to make better use of rainwater include use of: improved varieties (drought tolerant, salt tolerant); integrated crop, nutrient, soil and water management, including conservation agriculture (residue retention, reduced tillage, rotation of cereals and legumes); in-field water harvesting; runoff water harvesting and supplementary irrigation; cropping system approaches; improved livestock germplasm and livestock and rangeland management; and improved crop-livestock integration. These technologies must be used by very large numbers of poor farm families, however, if they are to make a substantial difference in rural food security and quality of livelihoods.

Widespread uptake of technologies often depends on the presence of enabling policies and institutional arrangements, among them: investments in dissemination strategies; improvements in access to micro-credit and input and product markets; investments in transport, market and communications infrastructure; policies that encourage collective management of common property land and water resources; and investments that benefit women – driven by a recognition that women, especially in sub-Saharan Africa, are often amongst the most poor, despite doing much if not most of the work around the farm. Furthermore, investments that benefit women (for example in terms improved income and/or decreased energy and time demands) deliver benefits back to the family, improving family welfare, nutrition, education etc.

At a larger scale, and over a longer term, the capacity to continuously improve rainwater management and farm system productivity depends on building the profes-

sional knowledge and capacity of local stakeholders (1) to develop and foster the uptake of improved management practices in smallholder farming systems, and (2) to implement integrated watershed planning (to tap the potential of small and larger-scale water harvesting interventions).

Most of the technical, policy and institutional innovations described above are not new. Even so, relatively

few farmers or communities use them. The reasons for this are not fully understood, but often include lack of awareness; technologies that are not well matched to local conditions (this can happen when technologies are developed without the participation of intended users, and the private/ public agencies that support them); poor input availability (seed of improved varieties, fertilizer, veterinary services); poor access to product markets and micro-finance; and lack of understanding of the complex linkages within farming systems, such as labor/energy constraints, weed problems, and the relatively high cost of fertilizer (Kelly 2005).

These constraints must be overcome. Best-bet technologies suited to specific production domains must be identified, methods to characterize and delineate such domains developed, awareness increased, market access improved, and investments made that benefit smallholder farmers, especially women. Technologies must be developed in partnership with intended users. Moreover, these innovations must be developed within an integrated land and water resource management framework that takes account of the impacts of upstream changes in farm system and resource management on downstream water users: other farmers, industry, urban water consumers, fishers, community and regional economies, and on environmental and ecosystem services.

Strategies to improve water productivity in agriculture ultimately must incorporate land and water management, and "green" and "blue" water resource availability and use, for agriculture and other ecosystem services. And this must be done across scales, from small fields to communities, water sheds, catchments and ultimately whole river basins.

Rationale

The potential of rainfed systems

The greatest potential to increase food production in developing countries is found in rainfed areas, where many of the world's poorest rural people live (Rosengrant et al. 2002). In fact, a full 75% of the additional food needed to feed the world's population in the coming decades could be met simply by raising the production levels of rainfed farmers with low yields up to 80% of those achieved by farmers with high yields (where land is of comparable quality). Better use of water is central to making this happen.

These are some of the key findings of the Comprehensive Assessment of Water Management in Agriculture (2007). This Assessment, undertaken by a broad partnership of practitioners, researchers and policy makers, provides an authoritative and "critical evaluation of the benefits, costs and impacts of water use and development, the water management challenges communities face today, and the solutions people have developed". Much of the information presented in this paper on the needs and opportunities for improving rainwater management is derived from the Assessment, and in particular from the chapters on rainfed agriculture (Rockström et al. 2007) and livestock (Peden et al. 2007).

The Comprehensive Assessment recommended eight specific policy actions. One of them, Policy Action 5, focused specifically on rainfed agriculture: *"Upgrade rainfed systems—a little water can go a long way. Rainfed agriculture is upgraded by improving soil moisture conservation and, where feasible, providing supplemental irrigation. These techniques hold underexploited potential for quickly lifting the greatest number of people out of poverty and for increasing water productivity, especially in Sub-Saharan Africa and parts of Asia. Mixed crop and livestock systems hold good potential, with the increased demand for livestock products and the scope for sustainable improvement of the productivity of these systems."*

Seventy-five per cent of the increased crop water use needed to attain the 2015 MDG hunger reduction target will have to come from rainfed agriculture (Rockström et al. 2007). Fortunately, there is high potential to increase land and water productivity in smallholder rainfed crop, livestock and crop-livestock systems through improved germplasm and management. In Africa and West Asia, yields of major rainfed crops are only 25-50% of what is achievable. In Asia, in rainfed rice growing environments prone to drought, salinity and floods, improved rice

varieties plus better management can increase on-farm yields by 50-100% (Bouman et al. 2007). Investments in rainfed agriculture can also reduce environmental degradation and maintain important ecosystem services.

Water scarcity

One reason why rainfed systems have such great potential is that rainfall is often not as scarce as is commonly thought. In the wetter semi-arid and dry sub-humid regions, total seasonal rainfall generally exceeds crop water needs. In fact, as long as appropriate levels of inputs are used, there is typically enough rainfall to double and often even quadruple yields. Low soil fertility and lack of inputs, especially nitrogen, are major constraints to increasing yield and rainwater productivity – most poor, smallholder farmers in sub-Saharan Africa do not apply fertilizer (e.g. PN1 2007; M. Fosu, S. Kabore-Sawadogo and M. M. El Hadi, pers. comm.). Even in dry semi-arid temperate areas such as Central West Asian and North Africa (CWANA), seasonal rainfall of only 300-400 mm is enough to produce as much as 4 t/ha of wheat grain because precipitation falls during the cool winter growing season and because the growing season is longer, but yields are typically less than half of this.

Yield and rainwater productivity are much lower than potential in many rainfed environments because rain often falls in a relatively small number of large events, with dry spells and droughts in between (Rockström et al. 2007). Furthermore, soil water holding capacity is often low, and many farmers grow old varieties with low drought (or other stress) tolerance and with longer than optimal duration. These factors often result in short periods of water deficit stress (or water logging!) during critical growth and grain filling stages, and/or planting later than the optimum time which also leads to terminal drought stress. Rainfall variability and the frequency of extreme events are likely to increase in the future as a result of climate change. The key challenge is to reduce water-related risks posed by extreme rainfall variability and increases in average temperature. Investments in rainwater management can help manage risk while increasing productivity.

System productivity is greatly limited by inherently poor soil, and/or human-induced soil degradation. On poorly managed land, the share of plant available water can be as low as 40-50% of rainfall. On severely degraded land, as little as 5% of total rainfall may be used productively. "Agricultural droughts" can emerge even when water itself is not scarce within the landscape. This happens when low soil fertility, poor crop and soil management, and the use of poorly-adapted varieties result in rainfall not being fully used for plant growth and grain filling.

Farmers may perceive this yield loss as being due to lack of water, thereby concluding that the risk of water-related yield loss is high. This in turn can lead to the perverse result of risk-averse farmers reducing their investment in the very inputs (such as fertilizer) that could help them avoid agricultural droughts. In this way, farmers miss opportunities to achieve higher yields. “Agricultural droughts” can also appear when farmers change cropping patterns, substituting more drought tolerant crops (e.g. millet or sorghum) with crops with less drought tolerance (e.g. maize), for example because of dietary preference. Although average system productivity may increase, risk increases and system resilience is lost.

Most hungry rural people in developing countries live in regions characterized by high rainfall variability, frequent water stress and extreme water shocks. Two-thirds to three-quarters of the rural poor live on marginal lands where land and water resources are degraded to the point they affect food security (Bossio et al. 2007). This includes 21 million hectares of saline, sodic, and saline/sodic lands in Asia, with several million hectares in the eastern Ganges Basin of India and coastal delta regions of the Ganges and Mekong Basins, home to tens of millions of food insecure, impoverished rural people. Soil and water conservation, and in-field water harvesting, form logical entry points for improved water management in rainfed agriculture (Rockström et al. 2007).

These strategies are often relatively cheap and can be applied anywhere, and should be optimised before water from external sources (supplementary irrigation) is considered. In-field water harvesting and conservation agriculture technologies need to be tailored to the local conditions (e.g. climate, cropping system, soil, socio-economic factors). For example, straw mulching can reduce soil temperature. This can have either a positive or negative effect on crop performance depending on prevailing temperatures and heat requirements for germination and growth. Straw mulch may also result in immobilization of nutrients, and changes in the incidence of pests and diseases. Additionally, farmers often favor the use of straw for feeding purposes.

Supplemental irrigation can bridge critical yield-reducing dry spells and stabilize yield (Rockström et al. 2007). Supplemental irrigation is the application of additional water to otherwise rainfed crops, to increase and stabilize yields. It can be practised without water harvesting when ground water or surface water resources are available in the rainfed areas. Water harvesting systems can also be constructed to provide a source of water for supplemental irrigation, especially in Sub Saharan Africa where most of the rainfall flows as runoff and soils gener-

ally have low water holding capacity. Rainwater-harvesting systems combine collection of runoff from watershed areas external to the cultivated land with various above and below ground methods to store it. Several studies have identified instances where supplemental irrigation systems are affordable and appropriate for household or small community investments. Some of these systems are relatively small, for example, farm ponds of 100–500 m³ (500 m³ is equivalent to 50 mm/ha), at the individual farm household level. These allow critical supplemental irrigation, enough to bridge a critical dry spell, on small areas. Others are somewhat larger, for example, micro-reservoirs of up to 10,000 m³, providing supplemental irrigation water for several households. Such systems are generally also used for off-season irrigation of small vegetable gardens.

Investments in improved water management have a higher pay-off when investments in other production factors – soil fertility, tillage practices, and varieties – are made simultaneously. Often an enabling institutional and policy environment is required for technical change to unfold. Market access often needs to be improved, inputs made more available, or water ownership patterns clarified. By reducing risk, water harvesting and conservation may encourage farmers to increase investments in other production factors. (It is recognized that resource-poor farmers often have non-water constraints – labor shortages, nutrient deficiency, lack of knowledge, insecure land ownership, or lack of capital – that inhibit investment and keep system productivity from increasing.)

Adaptation of crop and resource management technologies to local biophysical and socio-cultural conditions has to be accompanied by institutional and behavioral transformations (Rockström et al. 2007). To date, only limited investments have been made in a systematic application of participatory methods for turning proven knowledge on management of rainfed agriculture into innovations that support smallholder farmers. Many rainfed areas have poor infrastructure because investments have been directed towards high-potential rainfed and irrigated areas. Local institutions engaged in agricultural development have limited capacity to promote rainwater management. There is limited information on available options, social and economic constraints to adoption, and lack of an enabling policy environment.

Crops and livestock

Another reason why rainfed systems have such great potential is that, even in relatively dry environments, improved livestock management can increase water productivity and enhance livelihoods and food security – especially for women, who are often actively involved in

livestock management. Systems with livestock may be divided into “livestock grazing systems” and “mixed crop-livestock systems”.

Although the area under livestock grazing systems may be relatively large (for example in sub-Saharan Africa) there are far more people – and especially, far more poor people – who manage mixed crop-livestock systems (Table 1). In areas with mixed systems, of course, not all farmers own livestock. For example, fewer than 30% of households in the South Africa portion of the Limpopo Basin were found in a recent survey to own either cattle or goats (Mpandeli et al. 2008).

In many developing regions with widespread poverty, livestock are a fundamental and essential component of rainfed systems. Livestock provide diverse goods and service such as meat, milk, blood, hides, manure, traction power and cultural values. They also serve as the preferred means of saving wealth when poor people rise out of poverty. They even define what “poverty” means: frequently, “poor people” are those without livestock. Livestock products and services are important for subsistence and for creating marketing opportunities for income generation. Livestock densities are highly correlated with human densities and agricultural intensification in developing countries. Experience shows that livestock keeping generates a major part of farmers’ incomes and serves as insurance in times of drought. Depriving people in developing countries of their animals is one of the fastest ways of driving them into poverty.

Region	Area km ² (millions)		Human population (millions)		Number of poor (millions)	
	Grazing	Mixed	Grazing	Mixed	Grazing	Mixed
East Asia	4.3	2.5	22	407	2	38
Central and South America	5.4	5.2	32	255	12	105
South Asia	0.3	1.7	19	500	5.9	223
Southeast Asia	0.2	1.4	1.4	193	0	58
Sub-Saharan Africa	8.9	6.5	62	437	33	231
West Asia/ North Africa	1.8	1.6	36	125	10	44

Table 1- Area and numbers of people and poor people with livestock grazing systems vs. crop-livestock systems by region (Source: Thornton et al. 2002)

Recent CPWF research has found that livestock in rainfed areas of developing countries use much less water than the amounts frequently reported in the literature (e.g. Goodland and Pimental 2000) and that economic

livestock water productivity in rainfed mixed crop-livestock production systems sometimes compares favorably with that observed with horticultural crops and may exceed that experienced with staple grains (Peden et al 2007). Improved livestock management also provides a mechanism for increasing agricultural water productivity (Peden et al. 2007). Four strategies for doing so include:

- Selecting animal feeding strategies that require minimal water use for producing the plants that contribute to the feed
- Enhancing animal productivity through adoption of proven animal science technologies such as nutrition, veterinary health care, appropriate breeding and genetic selection, and reducing animal stress through good husbandry
- Conserving water resources through improved grazing management, demand management of crop residues and manure to ensure that sufficient remains to maintain erosion reducing soil cover and to replenish soil fertility, and management of watering sites by restricting animal access to water resources through measures such as drinking troughs, and to riparian vegetation that helps control sedimentation and contamination
- Strategically establishing watering sites to optimally distribute livestock across landscapes so that animal demand for feed balances feed availability

Given the importance of livestock as a pathway out of poverty and as means of accumulating wealth for those emerging from poverty, there is a need to look more closely at the nexus of livestock water productivity and poverty. The Comprehensive Assessment of Water Management in Agriculture (2007) notes that poverty can be reduced by increasing agricultural water productivity. Sometimes, however, it goes the other way: reduced poverty is sometimes a precondition for increasing water productivity. Our experience with livestock suggests that water productivity increases when livestock keepers accumulate the resources that enable them to invest in the strategies described above. Consistent with the findings of the CPWF Basin Focal Projects, there is no simple correlation between water productivity and poverty. In rainfed systems, livestock make use of both privately tenured and common property land, vegetation and water resources. CPWF research suggests that livestock water productivity is higher on privately tenured land and lower on communal lands (Alemayehu et al. 2008).

One reason may be that on private land, animals travel

shorter distances to get food or water, so they have better conversion efficiencies.

In addition, livestock water productivity appears to increase when pastoralists settle into agro-pastoral livelihood strategies (Mpairwe et al. 2008). On one hand, this suggests a need to encourage a greater shift from communal to household control of common property resources. On the other hand, some of the greatest advances in agricultural and domestic water productivity may come from research and development that improve community management institutions, policy and practices.

Historically, investments in agricultural water development have often either ignored or prohibited livestock access to the benefits of the investment (Peden et al. 2006). Development officials sometimes conclude (wrongly) that livestock are “not part of agriculture” and therefore should not be factored into planning for irrigation development. However, there is growing evidence that explicit integration of the livestock sector in the planning of water resource development investments can lead to increased farm-level profitability, enhanced farm system sustainability and increased water productivity. This is true for small-scale water harvesting in rainfed systems as well as large scale irrigation development.

Issues of scale

Improving rainwater management requires consideration of cross-scale interactions. Runoff, lateral sub-surface flows and deep drainage may be affected by increased water harvesting and increased crop transpiration. Water quality may be affected by changes in crop and livestock management practices. Sometimes, the people who most benefit from upstream adoption of resource conserving technologies are downstream water users. The integration of livestock into cropping introduces additional issues of scale: unlike crops, livestock are mobile and their movements often take advantage of spatial and seasonal variability in water and feed availability. Equity questions are ubiquitous and unavoidable: it is essential to understand who wins and who loses when land and water management practices change. “Who loses” can, of course, also mean the environment. Scale issues can include interactions across landscapes, regions and countries.

Water resources planning at the river basin scale is important. However, such planning usually does not place adequate emphasis on water management in rainfed agriculture, which overwhelmingly occurs at the catchment scale, on farms of less than 5 ha (Rockström et al. 2007), and on grazing lands subject to community based management. A focus on integrated land and water resources management is as important at the catchment

level as it is at the basin scale.

A new approach to agricultural water policy is needed that views rainfall as the freshwater resource and that considers both green and blue water for livelihood options at the appropriate scale for local communities (Comprehensive Assessment for Water Management in Agriculture 2007). Water resources management is normally governed under ministries for water affairs and focuses on developing and allocating water for large-scale irrigation, drinking water and hydropower. Ministries of agriculture have tended to give priority to erosion control over water management in general. Ministries of livestock have focused on animal drinking water. Redirection of water governance and management toward upgrading rainfed agriculture as a key strategy for reducing poverty and increasing agricultural production is needed. Policy, governance and market strategies, at watershed to regional to national scales, are needed. Such a broader policy and improved governance environment should ensure high levels of participation in decision making by all stakeholder groups.

Contributions from Phase 1 Projects

Improving Rainwater Productivity in Africa

IMPROVING PRODUCTIVITY OF RAINFED CROPPING SYSTEMS IN THE SEMI-ARID TROPICS OF AFRICA

Several CPWF Phase 1 projects (PN1, 2, 5, 6, and 17) have demonstrated the potential for increasing crop yields and water productivity in smallholder rainfed farming systems in Africa. These projects, implemented in the Limpopo, Nile and Volta basins, have shown that yields and water productivity can be doubled by combining simple, low cost ways to capture and conserve rainfall with improved varieties and nutrient management practices (Love et al. 2006; Mupangwa et al. 2006, 2007, 2008; Cooper et al. 2008; Fosu et al. 2008; Sawadogo-Kabore et al. 2008; Twomlow et al. 2008). Supplementary irrigation has also shown promise.

Adoption of these technologies, however, has been limited. Reasons for low adoption were examined in comprehensive baseline surveys conducted in the Limpopo basin by two CPWF projects (PN1 and PN17) (PN1 2007). Major reasons included:

- Low levels of awareness among farmers and extension workers regarding the existence or benefits of improved technologies
- Poor input availability (seed of improved varieties, fertilizer, veterinary services)
- Poor access to product markets, grain storage facilities, and micro-finance
- Lack of capacity of NARES to overcome these constraints.

It is also recognized that there is a lack of information on which technologies are most suited to specific production and socio-economic situations, and during the course of several projects, the lack of capacity of the NARES to determine the optimum technologies for different situations became very apparent.

Having identified constraints to adoption, CPWF Phase 1 projects in collaboration with other donor funded projects have also worked to overcome them. PN1 showed that farmers are more likely to try fertilizer if it is supplied in small, more affordable packages. It has persuaded two fertilizer companies in the Limpopo basin to make fertilizer available in such packages (Dimes, 2008; Simpungwe et al. 2008). PN5 showed in preliminary trials in Burkina Faso that warrantage storage/microfinancing systems result in net financial benefits and greater food security for farmers (Sawadogo-Kabore et al. 2008). This has led to a plan for warrantage systems to be set up in ten new communities in Burkina Faso, with support from a new donor, and guided by the findings of the PN5 team (S. Sawadogo-Kabore, pers. comm.). PN2 has achieved community and Ministry support for community based seed production systems, to supply seed of locally adapted improved germplasm. This has already been fully implemented in one village.

PN17 has taken a broader approach to rainwater management (Love et al. 2008). This project works on a range of innovations at multiple scales: soil/water/nutrient management research at the field level; hydrogeological studies at sub-catchment and catchment levels; climate analysis at the basin level; and analysis of institutional needs for good water governance at all levels. It seeks to help improve the livelihoods of poor smallholder farmers through an Integrated Water Resource Management (IWRM) framework that enables farmers to better cope with dry spells and droughts through improved use of water flows and better risk management. This includes investigating the potential of small reservoir and alluvial aquifer systems of non-perennial rivers to support

supplemental irrigation in southern Zimbabwe (de Hamer et al. 2008), and identifying the challenge of combining the lessons learned from integrated natural resources management (INRM) at the farmer field scale with IWRM at a range of scales from small catchments to the whole Limpopo Basin (Twomlow et al. 2008).

IMPROVING WATER PRODUCTIVITY OF RAINFED CROPPING SYSTEMS IN SEMI-ARID TEMPERATE ENVIRONMENTS OF CENTRAL AND WEST ASIA

In the rainfed areas of the Karkeh River Basin, constraints to improved productivity in addition to low cropping season rainfall and its poor distribution include low soil fertility, low soil water holding capacity, and the use of old varieties and traditional cultural practices. PN8 and PN24 addressed these water productivity problems by assessing the natural resources, especially rainfall and surface and ground water resources, identifying constraints to production, and developing options for improved productivity (Farahani et al. 2008).

The most important opportunities for increasing yield and water productivity included supplemental irrigation (SI) combined with improved cultural practices (Tavakoli et al. 2008). Use of a single supplementary irrigation (50 mm) to bring forward the start of the growing season by 2-4 weeks roughly doubled yields of wheat and barley by giving enough time for good crop stand establishment before the onset of winter frosts. While full supplementary irrigation to satisfy crop water requirements gave maximum yield, it required more irrigation water, and water productivity was maximized with a single irrigation ("deficit" irrigation). Applying one irrigation (100 mm) in spring also increased wheat grain yield by about one-third, but with much lower irrigation water productivity (0.9 kg/m³) than for a single irrigation prior to sowing (3.4 kg/m³). Combining supplementary irrigation with improved varieties that are more responsive to irrigation and nitrogen more than doubles yield and water productivity.

However the costs and environmental impacts of practising supplementary irrigation on winter rainfed crops also need to be considered. Where irrigation schemes already exist for summer full irrigation (when there is no rainfall), the same irrigation schemes can be used for supplementary irrigation of winter crops, with no additional cost except operations. However, in other areas water resources need to be developed and irrigation systems need to be installed. The large increases in productivity associated with supplementary irrigation may justify the capital cost required in many places, however, in KRB and other basins in the dry areas, it is common to overuse ground water encouraged by high profits. At the same time, there is

good potential for water harvesting using small reservoirs for storage at the farm or the community levels, but the downstream impacts need to be considered. PN8 studied the consequences of implementing the full potential of supplementary irrigation in KRB upper catchments and found that downstream flow may be reduced by about 15% as a result (Hessari et al. 2008). The reallocation of water resources to be used in rainfed agriculture is among the important policy issues to be tackled. Optimizing the return for water may be the logical criterion, but water rights and historic water use are among the issues in the reallocation process. As water becomes scarcer this reallocation becomes more important to achieve the maximum productivity.

PN24 also evaluated a range of approaches for increasing the productivity of fully rainfed systems in the upper KRB. The use of *Azotobacter* and *Azospirillum* inoculants increased cereal yields and household income (by \$2.2 k per year) (Milani and Anthofer 2008). This technology is cheap, easy to apply, does not change major parts of the farming and cropping system and was quickly adopted by farmers. Therefore, this technology can serve as a strategic component for farmers to increase livelihood resilience in KRB and similar areas. PN24 also showed that improved chickpea and lentil cultivars gave substantial increases in yield and water productivity in the upper KRB (Sabaghpour et al. 2008). Improved chickpea germplasm also opened up the possibility of autumn planting, with significantly higher yields than for spring planting.

Improving Sustainability and Water Productivity of Livestock in Rainfed Areas

Prior to CPWF Phase 1, remarkably little attention had been given to the explicit integration of livestock into river basin management. (There is some scattered literature on the impacts of livestock on wetlands, and the consequences of grazing intensity on soil erosion and run-off.) When livestock managers think about water at all, they usually think in terms of drinking water. They rarely take account of other ways in which livestock may use water resources, or the effects of livestock on the quantity and quality of water available to others.

CPWF Phase 1 project PN37 formalized the concept of livestock water productivity (LWP) (Peden et al. 2007) and applied it in three ways: case studies of LWP in the temperate rainfed mixed crop-livestock production systems of the Ethiopian Blue Nile highlands (Alemahehu et al. 2008; Amede et al. 2008; Gebreselassie et al. 2008; Haileslassie et al. 2008; Peden et al. 2008); research on rainfed grazing and agro-pastoral areas of Sudan and

Uganda; and spatial analyses of livestock and water management in the whole Nile River basin (van Breugel et al. 2008). Several key findings emerged:

In the Blue Nile highlands, LWP was found to compare favorably with water productivity in horticulture and often exceeded water productivity in grain production. LWP was found to be much higher than is commonly reported in the popular literature (a literature often quite critical of the livestock sector). This is largely based on the fact that domestic animals in this region are fed crop residues and byproducts. Residue production requires little additional water beyond what is used by crops in the normal process of producing grain: it is not possible to produce grain without also producing residues. In estimating LWP, it is essential to recognize that livestock have multiple uses for their owners, including securing an asset base. Because most cattle are kept for farm power, the water cost of keeping bovines is primarily an "input" into crop production and beef can be thought of as byproduct of livestock keeping.

Rainfed mixed crop-livestock systems are usually a mosaic of privately tenured land used for crops and homesteads, with communal grazing lands and water sources. PN37 research found that LWP on private lands, especially when managed by relatively wealthy farmers, is higher than that in communal lands, or on private lands managed by poorer farmers. Research by this project also found instances where LWP is higher than crop water productivity (Peden et al. 2007; Haileslassie et al. 2008;). The implications are that policies are needed to encourage private tenure, or to improve collective management of common property natural resources, and that measures are needed to alleviate poverty so that farmers have greater opportunity to invest in interventions that increase water productivity and crop and animal production.

Relatively arid rainfed grazing areas of Sudan and more humid pastures in Uganda were found by PN37 to experience severe land and water degradation. In both places, however, significant opportunities to increase LWP were identified (Faki et al. 2008; Mpairwe et al. 2008). In Central Sudan, despite significant investments in recent years, animal demand for drinking water greatly exceeds supply. Consequently, livestock tend to concentrate in small areas, suffer stress because of long trekking distances to watering sites, and are exposed to relatively high risks from water-borne diseases. Large areas in these countries (and in the Nile Basin in general) actually have surplus feed resources to which animals do not have access. One intervention option is to invest in new strategically distributed watering sites

while simultaneously limiting stocking rates to levels that avoid degradation of the water and adjacent pasture and riparian vegetation. Such a strategy can greatly increase rainwater productivity in the Nile while promoting environmental sustainability.

In Uganda, past investments in water harvesting (valley tanks) encourage overgrazing. Accompanied by excessive charcoal production, overgrazing has led to a nearly complete loss of palatable and nutritious pasture grasses, encroachment of shrubs of little value and a ravaging plague of termites that impede pasture recovery. PN37 researchers developed a technology to control termites, restore pastures, reduce soil erosion and help prevent siltation of valley tanks while improving the quality of the water within them. Effective community participation in the management of the common property pasture and water resources is helping to restore agricultural productivity, improve environmental quality including domestic drinking water, and improve livelihoods.

At a larger scale, it was found that livestock migration can help increase effectiveness of rainfed agriculture. Crop residues and byproducts from both irrigated and rainfed croplands can provide feed reserves that enable livestock keepers to sustain their animals during dry periods but enable them to utilize pasture during better times. In Central Sudan, the feeds produced from the irrigated systems of the Nile allow herders from Darfur and Kordofan to sustain animal production, their primary livelihood in these extensive rainfed areas of the Nile.

Improving Rainwater Management in Salt Affected Areas

The CPWF Phase 1 projects discussed above have demonstrated the potential for increasing crop yields, crop water productivity and LWP in smallholder rainfed farming systems in sub-Saharan Africa and CWANA. In a similar vein, projects PN7 and PN10 have identified important opportunities to increase system productivity and improve incomes and livelihoods in rainfed salt-affected lands in the eastern Gangetic plains, and the Ganges and Mekong deltas (Mondal et al. 2006; Mahata et al. 2008; Singh et al. 2008; Salam et al. 2008; Ismail et al. 2008a,b; Ram et al. 2008). These opportunities are based on the use of salt-tolerant varieties, cost-effective approaches to resource management and land reclamation, crop intensification and diversification, diversification to a range of crop-aquaculture systems, and innovative water management practices using scarce fresh water resources for supplementary irrigation.

When salt-tolerant varieties are used on salt-affected soils, the results are often dramatic. Such varieties can make the difference between no yield and yields of

2-4 t/ha. PN7 has established an effective network for exchange of genetic material, salt tolerance nurseries for evaluation across salt-affected environments, and a database of the performance of this material. The project has developed rapid screening methods for salt tolerance, and a marker-assisted selection system for rice which will greatly speed up breeding efforts to incorporate salinity tolerance into locally adapted high yielding varieties for different salt-affected locations. Varietal requirements vary greatly between regions and between localities within regions depending on soils, climate, local agronomic and grain quality preferences, and other socio-economic factors. Salt tolerance has already been incorporated into several modern varieties, including one from Bangladesh (Salam et al., 2007), using conventional breeding. Good progress has also been made in the screening and identification of varieties of a range of salt tolerant non-rice food and feed crops which can be grown in rotation with rice.

Research by PN7 has found that the biggest gains are made where salt tolerant rice varieties are grown in combination with soil amelioration. Most farmers with saline/sodic soils in target areas cannot afford the high cost of the gypsum needed to ameliorate their soil. A range of low cost reclamation methods was developed by NARES partners in the past. PN7 has begun scaling out these technologies by introducing them to farmers during participatory varietal selection trials with salt tolerant varieties.

In salt-affected coastal delta regions, it is normally possible to grow only one crop (rice) per year, during the rainy season. Dry season cropping is impeded by a lack of fresh water for irrigation and the higher levels of soil salinity that are characteristic of the dry season. PN10 is exploring ways to grow a dry season rice crop using groundwater and/or river water, including low-salinity river water stored in old river channels ("reservoirs") in the polders. PN10 investigated the effect of groundwater pumping during the dry season on groundwater pressure levels and salinity, because of questions about sustainability of groundwater use due to the risk of salinization of the aquifer (Mondal et al. 2008). They found that the suitability of groundwater for dry season irrigation is rather site specific, and thus its use for irrigation warrants careful studies. Using field and modeling studies,

PN10 has also developed a methodology to determine the optimum planting date for dry season rice to maximize production with the limited amount of fresh water that can be stored in the reservoirs, and to predict the area that can be cropped in this (Sharifullah et al. 2008).

PN10 is also developing a system for establishing a rice

crop prior to the main rainy season crop, through the use of short duration salt tolerant varieties (provided by PN7), direct seeding (to advance establishment) and use of groundwater to establish the crop. Research by PN10 on integrated resource management has led to the development of a range of more diverse, resilient and profitable rice-based systems for small farmers including wet season rice grown in rotation with dry season shrimp (produced using brackish water), and the production of fish and or fresh water prawn in rice fields (Alam et al. 2008).

Supplementary Irrigation and Aerobic Rice

Irrigated rice provides 75% of the world's rice production, and consumes 24-30% of the world's developed fresh water resources (Bouman et al. 2006). However in the future more rice must be produced using less water, due to increasing competition for water, and reduced rainfall in water harvesting catchments and/or in farmers' fields as a result of climate change. Most irrigated rice is transplanted into puddled soil which remains flooded until shortly before harvested, resulting in very high water use. The aerobic rice system makes it possible to convert conventional flooded, irrigated rice production systems into non-puddled, direct seeded rainfed systems that use just a few supplementary irrigations.

PN16 undertook strategic research to develop sustainable aerobic rice systems for water-scarce irrigated and rainfed environments in Asia (Bouman et al. 2008). In the Yellow River Basin of China, with a temperate climate, the project demonstrated that aerobic rice yields of 6 t ha⁻¹ are attainable with 0 to 3 supplementary irrigations and using only about half of the total water input (irrigation plus rain) needed for puddled transplanted rice. The profitability of aerobic rice was on average comparable with that of other food crops such as maize and soybean.

Compared to China, the development of sustainable aerobic rice systems is at an early stage in the sub-tropics and tropics. In the Ganges Basin, PN16 identified rice varieties that can be grown in aerobic conditions, producing 4-4.5 t ha⁻¹ and using 30-40% less input water than lowland rice at the same yield level. In the Philippines, attainable yields from aerobic rice ranged from 2.9 to 3.8 t ha⁻¹ in the dry season, and from 3.9 to 4.5 t ha⁻¹ in the wet season. A risk of yield reduction from soil-borne pests (such as nematodes) and/or nutrient disorders was identified at a few sites. The project also identified the potential for aerobic rice systems to increase yield and rainwater productivity in the favorable rainfed uplands of the Mekong Basin. Preliminary extrapolation domain analysis suggested large areas where aerobic rice systems could be grown, especially in large parts of the

Ganges and Mekong Basins.

Rainfed Mountainous Regions

Slash and burn agriculture is commonly practised on steep slopes in mountainous regions of the tropics and sub-tropics, including Central America and the Andes, and in upper catchments in the Mekong. The use of slash and burn typically leads to erosion, loss of soil fertility, reduced system productivity, and pollution of streams. In some areas, new land management technologies have emerged, often based on the principles of conservation agriculture. One of the more successful of these is the Quesungual Slash and Mulch Agroforestry System (QSMAS). Project PN15 is characterizing the biophysical and socioeconomic factors underlying successful adoption of QSMAS. They have quantified the systems' many production benefits including reduced runoff and soil erosion, increased water availability and higher crop productivity (Castro et al. 2008). Many environmental benefits have also been identified, including increased carbon sequestration, reduced greenhouse gas emissions, and lower levels of downstream water pollution (turbidity). In upper catchments of the Mekong in Laos, PN11 is in the process of developing an understanding of the hydrological relationship between land management on the steep slopes and water availability in the lower slopes and valley floors for paddy rice production (Ritzmer et al. 2008). The project has also shown that there is good potential to increase rice production in the water-short upper rice terraces through the introduction of aerobic rice. A preliminary reconnaissance visit by a PN15 project scientist to the upper catchment sites of PN11 in Laos and Vietnam suggested that QSMAS may have potential in these regions.

Capacity Building and Participatory Research

CPWF Phase 1 projects also help build the capacity of NARES to undertake the kinds of research described above. Capacity-building (CB) is largely on-the-job, often includes post-graduate studies, and sometimes focuses on cutting edge methods for the analysis of impact pathways and social networks (Douthwaite et al. 2008), and the use of these methods to foster scaling out and up of improved technologies and input/output marketing opportunities. CB on impact pathways is conducted in collaboration with CPWF Basin Focal Project teams. CB also includes training and hands-on experience in participatory crop and agricultural systems research, a key component in all CPWF Phase 1 projects on rainfed farming. Participatory approaches are most developed in PN2 in Eritrea, where all stakeholders (farmers, extension, local government, researchers, and Ministry representatives) are involved in research review and planning, implementation, technology evaluation, selection of

germplasm, and project evaluation. An exciting outcome is the empowerment of farmers to demand research (M. Maatougui, pers. comm.). An ideal outcome would be stable funding from the NARES to exploit the improved capacity of the farmers, extensionists and researchers to undertake the targeted research identified and desired by them.

Remaining gaps

Technologies

Soil cover and conservation agriculture: A key issue in managing rainfed agriculture is how to maintain adequate levels of vegetative soil cover, using plant species that benefit both people and agroecosystems. Such soil cover reduces evaporation, runoff and erosion, increases infiltration, and maximizes the opportunity for transpiration, the key water depletion pathway that enhances agricultural water productivity. In this respect, there is great need to integrate the concepts of LWP and crop water productivity. Because of land scarcity, and a high demand for vegetative production for human food, animal feed and fuel, often there is little organic matter returned to the soil. Furthermore, burning of crop residues and fallow vegetation is not uncommon. This loss of organic matter can reduce water holding capacity and soil fertility and undermine future production potential. Technologies and policies are needed that help increase crop biomass production, and encourage the conservation of vegetative soil cover in croplands, grazing lands and riparian areas. And so, the circle turns once more, again coming around to integration of water, nutrient, crop and livestock management.

Supplementary irrigation for Africa: It is well-known that supplementary irrigation at critical stages can dramatically increase crop yield and water productivity. Several projects (for example, those supported by FAO and IFAD) have successfully analyzed and mapped the potential for supplementary irrigation in the rainfed croplands of sub-Saharan Africa. The potential for supplementary irrigation in other areas needs to be mapped.

The question is how to exploit that potential – important questions include the optimum timing of supplementary irrigation, and how to maximize the potential benefits through optimization of the cropping system (crops/varieties, agronomy, inputs (especially fertilizer) and soil and residue management). The downstream consequences of extensive adoption of supplementary irrigation also needs to be researched.

Aerobic rice in Asia: Aerobic rice offers the potential

to substitute supplementary irrigation for full irrigation in rice production in the many rice-growing regions where water (or energy) scarcity for irrigation is an increasing problem, and a bigger constraint to production than land scarcity. Aerobic rice systems can increase the effective use of rainfall and greatly reduce irrigation water (and energy) use in vast areas of the Ganges Basin, especially in the central and western portions. However the technology is still in an early stage of development.

Further work is needed on how to manage aerobic rice in the context of sustainable cropping systems approaches which include the possibility of capitalizing on the potential benefits of conservation agriculture. While irrigation and energy savings from widespread adoption of the technology are likely to be very large, net water savings and impacts on the rate of groundwater decline are unknown at present and need to be quantified for different situations. The large target domain identified by preliminary extrapolation domain analysis needs to be tested and refined to better determine the potential areas and impacts of widespread adoption (water, energy, food security, groundwater pollution) in the Ganges.

Adoption, poverty and gender

Domains and targeting – CPWF Phase 1 projects made good progress in evaluating integrated crop-water-nutrient technologies for improved food security and livelihoods in rainfed regions. Nonetheless, there remains much to be done if these technologies are to benefit large numbers of farmers over large areas. The key question is how to accelerate widespread adaptation and adoption of known technologies. Part of the answer will lie in finding a better match between best-bet technologies and specific production domains or situations, defined in terms of both agro-ecological and socio-economic conditions and major limitations to productivity. Participatory approaches will help achieve this. Faster adoption is particularly urgent for rainfed cropping in Africa, for the upper landscapes of the Mekong, and for inland and coastal salt affected areas of the Ganges.

Policies, institutions, markets and adoption: An important constraint to adoption of improved technologies is lack of access to input and output markets and micro-finance. One option is the warrantage system, which enables farmers (or producer organizations) to mortgage their cereals at harvest time to secure a loan, and provides clean, safe storage, and which may be linked with a co-operative input shop. Other options may feature revolving funds, loan guarantees, or vouchers. Currently, it is unclear how well such systems serve farmers, and women farmers in particular, nor the extent to which the availability of such systems leads to increased adoption

of improved technologies for increasing land and water productivity. Furthermore, there have been no systematic studies to understand the socio-economic, cultural, institutional and political environments under which such systems are successful, and how to adapt them to different environments.

Water management and gender - A big gap seems to remain within the CPWF in relation to the impact of water management on gender relations. There is a need to first reveal the role (often predominant) of women in most productive systems. We have seen in PN#37 that women greatly benefit, if they can improve milk and poultry production but they may suffer if the focus is on beef production.

Impacts and consequences

Widespread adoption of technologies to increase land and water productivity of rainfed cropping systems may have major “downstream” impacts and consequences which may be positive or negative for downstream ecosystems and communities. Widespread adoption may affect patterns and quality of surface runoff and deep drainage to groundwater, with possible consequences for downstream water uses, including surface and groundwater dependent ecosystems. The complexity of hydrological fluxes from the local to the river basin scale are not well understood, but this understanding is needed to understand the impacts of widescale adoption of technologies that increase transpiration and reduce deep drainage and runoff. Methodologies for assessing downstream impacts of upstream technical change need to be developed and a range of case studies implemented. IWRM approaches need to be developed and applied to identify optimal solutions – or at least, to highlight trade-offs between upstream and downstream costs and benefits under different uptake scenarios.

In areas prone to salinization, where groundwater is fresh and available (as in some salt-affected coastal delta regions), the consequences of heavy groundwater pumping needs to be assessed, and the risk of salt intrusion in freshwater aquifers examined.

Where livestock are important components of farming systems, there is a need to integrate livestock management, crop management, land and water use practices, and resource degradation into one integrated framework. PN37’s LWP framework is a start.

Scope

During the second phase of the CPWF, research on Topic 1, “Improving rainwater productivity” will pursue the broad range of issues described above. This research is relevant to all six Phase 2 benchmark basins. Rainwater harvesting (in-field and supplementary irrigation) and integrated land and water management are particularly relevant to the Limpopo, Nile and Volta basins. Rainwater management in rainfed mountainous regions will most relevant in the Mekong and Andes system of basins, with the potential to transfer much of the biophysical and socio-economic understanding and approaches from the Andes to the Mekong. Research on land and water management in salt-affected areas, and tapping the potential of aerobic rice, are most relevant to the Ganges and Mekong basins. Increasing livestock water productivity is relevant to all basins, although less so in the Mekong. The downstream, cross-scale consequences of land and water management for water users, including the environment, and gender issues in land and water management, need to be examined in all basins.

Sub-topics and research questions

Through research on Topic 1, the CPWF will seek to develop technical, institutional and policy options aimed at increasing land and water productivity and raising the profitability of rainfed cropping, livestock and mixed crop-livestock systems. It will do this in ways that are mindful of downstream, cross-scale consequences. Building on earlier findings of the CPWF and its allies and partners, research will focus on the following sub-topics and research areas. The research questions will be refined and prioritised for each Basin based on further discussions with basin stakeholders.

Development and application of systematic approaches and tools to identify and adapt technical options for increasing land and water productivity of rainfed crop and livestock systems in different agroecological and socio-economic situations or domains

- What are the best integrated cropping system options for different agroecological and socioeconomic situations, taking account of climate and market risk, farm household assets, and other farmers’ circumstances? Integrated cropping system options may feature:

- Rainwater harvesting (in-field, runoff for supplementary irrigation) combined with improved germplasm and crop and resource management practices to optimize the benefits from rainfall. This specifically includes conservation agriculture approaches for water conservation, soil fertility improvement, and reduced erosion and sedimentation of downstream water bodies.
 - Integration of crops and livestock or crops and fish
 - Water harvesting for multiple uses (crops, livestock, domestic, fish) (Topic 2)
- What are the best ways to tap the potential of supplementary irrigation? This specifically features the use of surface runoff and/or run-off recharged groundwater from small farm ponds, community micro-reservoirs, or sand/gravel aquifers.
 - What are the key elements for sustainable aerobic rice systems for sub-tropical climates, and where? These systems are essentially rainfed, with some supplementary irrigation.
 - How can better use be made of rainwater and scarce freshwater resources to increase land and water productivity in inland and coastal salt-affected areas?
 - What are the best livestock management strategies that maintain vegetative cover, protect riparian vegetation from uncontrolled grazing, and increase livestock productivity?
 - What are the best ways to define and delineate technology domains? This should include development of methodologies to improve local adaptation of technologies
Development and application of strategies for engaging, informing and influencing key stakeholders and policy makers to accelerate widespread adoption of technologies
 - How can key stakeholders be engaged and influenced to achieve the policy and institutional changes needed to accelerate widespread adoption of suitable technologies? These may involve investment in extension and infrastructure for capacity building at farmer, extensionist and agricultural researcher levels, development of input and output markets, and improved access to microcredit for the rural poor.

Development and application of approaches and tools to

assess the impacts, including cross-scale and downstream consequences, of wide scale adoption of new technical options

- What is the likely impact of widespread adoption of increased rainwater use by crops, and of improved rangeland management, on downstream water users, including ecosystems? What is the effect of increased rainwater harvesting on local hydrological fluxes, and how do local changes combine and alter water resource availability at larger scales?

CPWF niche and value added

CPWF is well-positioned to make significant progress in these key research areas in the Limpopo, Volta, Nile, Ganges, Mekong and Andean Basins because all of this work builds on the significant achievements of phase 1 projects – for example, in terms of building multidisciplinary research teams, involvement of key partners (research, stakeholder participants, out scaling and up scaling partners), experience and research achievements.

The research on increasing rainwater productivity in the new phase can also benefit from the research in the 1st phase in the Karkeh and Yellow River Basins, especially in relation to research findings in relation to conservation agriculture and supplementary irrigation. Also linkages could help out scaling the results more broadly beyond the six phase 2 basins.

However new partners and approaches need to be added to increase the capability of undertaking work across spatial scales, such as assessing the potential for rainwater harvesting for supplementary irrigation, and analyzing the impacts of widespread adoption of technologies on downstream water users, and on food security, farmers and society as a whole).

A unique feature of CPWF is its development of methodologies for analyzing impact pathways and networks, and identifying influential stakeholders who are key to promoting up scaling and out scaling. Building on this work will be key to achieving widespread adoption of improved technologies for improving rainwater management.

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