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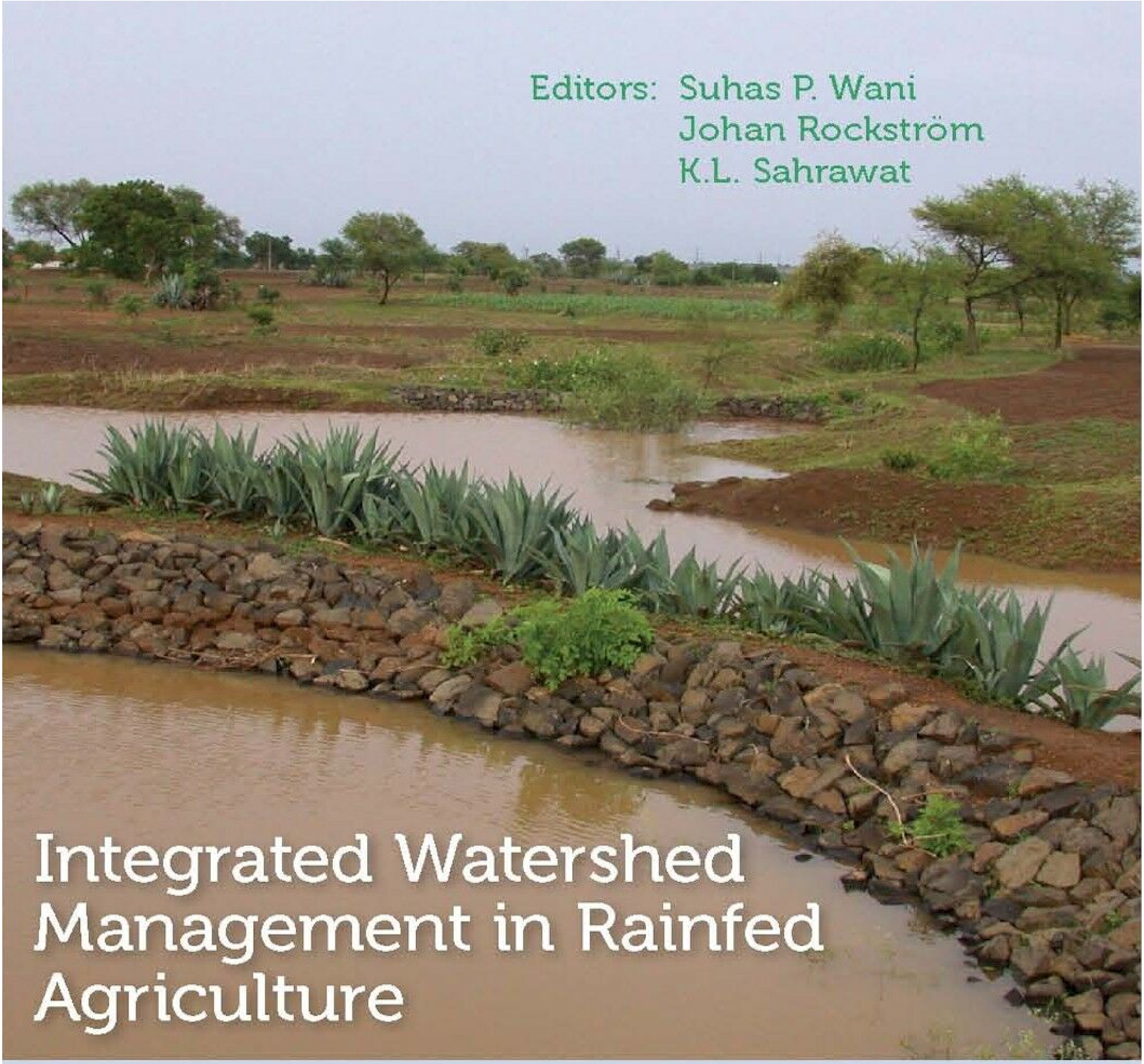

Integrated Watershed Management in Rainfed Agriculture

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A BALKEMA BOOK

Chapter 2

Watershed development as a growth engine for sustainable development of rainfed areas

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2.1 INTRODUCTION

Globally humankind is facing a great challenge of achieving food security for the ever growing population and growing per capita incomes particularly in the emerging giant economies like Brazil, Russia, India, China, and South Africa. The urgent need to decrease poverty and undernourishment while protecting the environment means delicately balancing development and sustainability resulting in increased additional pressure on the global food production system. In the foreseeable future agriculture will continue to be the backbone of economies in Africa and South Asia in spite of growing incomes and urbanization, globalization, and the declining contribution of agricultural income to gross domestic product (GDP) of the developing (in sub-Saharan Africa with 35% contribution to GDP agriculture employs 70% population) as well as emerging economies like India (with 18% contribution to GDP agriculture employs 65% population). In the past 40 years, increased crop productivity with adoption of new technologies and increased agricultural inputs along with expansion of agricultural land by about 20–25% has enabled an extraordinary progress in food security and nutrition level (FAO 2002). In 2009, more than one billion people went undernourished not because there is not enough food, but people are too poor to buy food. The percentage of hungry people in the developing world had been dropping for decades (Figure 2.1) even though the number of hungry worldwide barely dipped. The food price crises in 2008 reversed these decades of gains made in the area of food production and security (Nature 2010).

Increased food production has to come from the available and limited land and water resources which are finite. Neither the quantity of available land or water has increased since 1950, but the availability of land and water per head has declined significantly due to increase in global human population. Distribution of land and water varies differently in different countries and regions in the world and also the current population as well as expected growth which is estimated to grow rapidly in developing countries. The world is facing a severe water and land scarcity which is already complicating the national and global efforts to achieve food security in several parts. As estimated by 2025, areas where one-third of the global population resides will be facing physical and economic scarcity of water. The land expansion for agriculture is at the cost of grasslands, savannahs, and forests and land expansion for urban and infrastructure areas at the expense of agricultural land (Holmgren 2006).

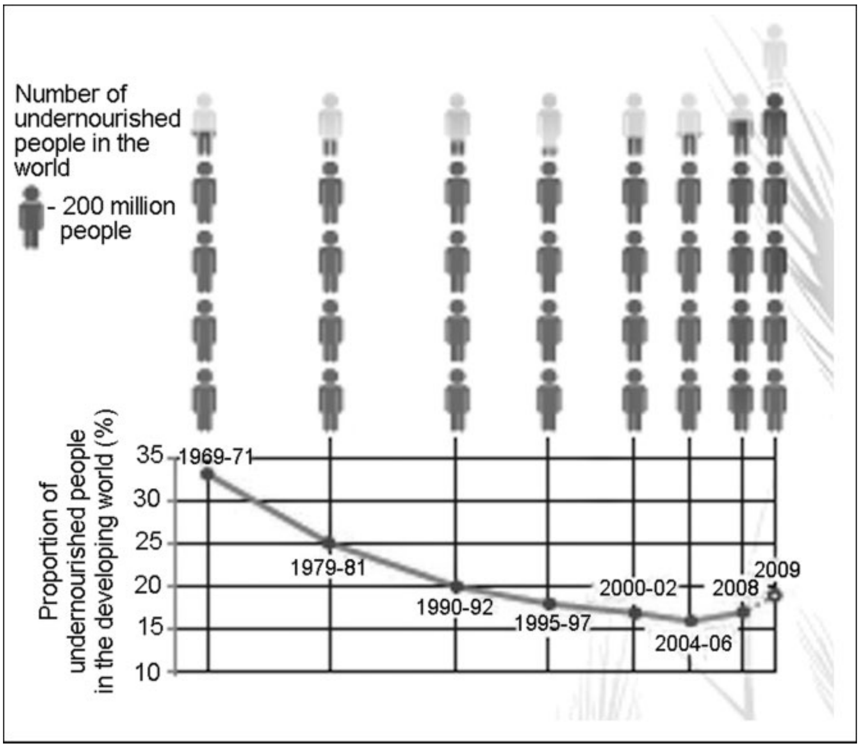

Figure 2.1 The percentage of hungry people in the developing world had been dropping for decades (bottom) even though the number of hungry worldwide barely dipped (top). But the food price crisis in 2008 reversed these decades of gains (Source: Nature 2010)

Crop land currently comprises nearly 12% (1.5 billion ha) of the world land area. In the future, crop land will not only be expanding to supply the world with food, but also to compensate for land degradation and unsustainable agricultural practices. Between 1981 and 2003 an absolute decline in net primary productivity (NPP) across 24% of the global land areas largely in southern Africa, Southeast Asia, and Southern China indicated not only the loss of farms and forests but also overall loss of 950 million tons of carbon (Bai *et al.*, 2008). The complexities of issues and multiple challenges for humankind in the 21st century such as growing population and urbanization, increasing incomes, changing diets, wastages of food, increasing land and environmental degradation, and the millennium development goal to reduce the number of poor people to half by 2015 are interlinked and call for inter-disciplinary thinking and new ways of doing agriculture. In this chapter we analyze the interlinked factors associated with food production by zooming in rainfed agriculture which covers 80% of cultivated land globally (Table 2.1) and assessing the evidence-based available options for unlocking the potential of rainfed agriculture through sustainable intensification with integrated watershed management approach.

Table 2.1 Global and continent-wise rainfed area and percentage of total arable land[a]

Continent/ Regions	*Total arable land (million ha)*	*Rainfed area (million ha)*	*% of rainfed area*
World	1551.0	1250.0	80.6
Africa	247.0	234.0	94.5
Northern Africa	28.0	21.5	77.1
Sub-Saharan Africa	218.0	211.0	96.7
Americas	391.0	342.0	87.5
North America	253.5	218.0	86
Central America and Caribbean	15.0	13.5	87.7
South America	126.0	114.0	90.8
Asia	574.0	362.0	63.1
Middle East	64.0	41.0	63.4
Central Asia	40.0	25.5	63.5
South and East Asia	502.0	328.0	65.4
Europe	295.0	272.0	92.3
Western and Central Europe	125.0	107.5	85.8
Eastern Europe	169.0	164.0	97.1
Oceania	46.5	42.5	91.4
Australia and New Zealand	46.0	42.0	91.3
Other Pacific Islands	0.57	0.56	99.3

[a] FAO (2010); FAOSTAT (2010).

2.2 A CONCEPT OF SAFE OPERATING SPACE FOR HUMANITY

The key question arising from various assessments such as the Millennium Assessment (MA), the Comprehensive Assessment on water management in agriculture, and Intergovernmental Panel on Climate Change (IPCC) is how much natural resources can be safely harnessed for human development without jeopardizing sustainability (MA 2005; IPCC 2007; Molden *et al.*, 2007).

Recently, Rockström *et al.* (2009) have proposed a novel concept of a safe operating space for humanity suggesting acceptable levels of nine biophysical processes linked to the ability of the Earth system to remain in the current stable state. These describe a corridor for human development where risks of irreversible and significant damage seem tolerably low. For seven key parameters they suggested a quantifications of safe boundary levels, of which three (climate change, loss of biodiversity, and atmospheric nitrogen fixation) have already been exceeded. Agriculture is the world's second largest consumer of water after forestry. The second most important factor controlling food production globally is the soil quality which is severely affected due to growing problem of land degradation which results in crop land expansion. Over the last decade deforestation has occurred globally at a rate of about 13 million ha per year, whereas plantations have increased in few countries such as Indonesia; since 1990, Europe, South America, Southeast Asia, and Africa continue to see high rates of net forest loss (Cossalter and Pye-Smith 2003; Bringezu *et al.*, 2009; UNEP/SEI 2009). The growing need to produce more food, feed as well as biofuel for energy means increasing pressure on scarce water and land resources. These interlinked and multiple challenges suggest strongly that business as usual will not be able to achieve the goal of sustainable development. The challenge is how to enhance the water, land, and other natural resource use efficiencies to meet the goals of food, feed, energy, and water security within the safe operating space for humankind.

2.3 CURRENT STATUS OF RAINFED AGRICULTURE

Out of 1.55 billion ha arable crop land globally, 1.25 billion ha is rainfed with varying importance regionally (95% in sub-Saharan Africa, 90% in Latin America, 60% in South Asia, 65% in East Asia, and 75% in Near East and 75% in North Africa) (FAOSTAT 2010) (Table 2.1), but produces most food for poor communities in developing countries. These challenges are exacerbated by climatic variability, the risk of climate change, population growth, health pandemics (AIDS, malaria), degrading natural resource base, poor infrastructure and changing patterns of demand and production (Ryan and Spencer 2001; Wani *et al.*, 2009; Rockström *et al.*, 2010; Walker 2010). There is a correlation between poverty, hunger, and water stress (Falkenmark 1986). The UN Millennium Development Project has identified the hot-spot countries in the world suffering from the largest prevalence of malnourishment that coincide closely with the countries hosted in semi-arid and dry subhumid hydroclimates in the world (Figure 2.2), i.e., savannahs and steppe ecosystems, where rainfed agriculture is the dominating source of food, and where water constitutes a key limiting factor to crop growth (SEI 2005).

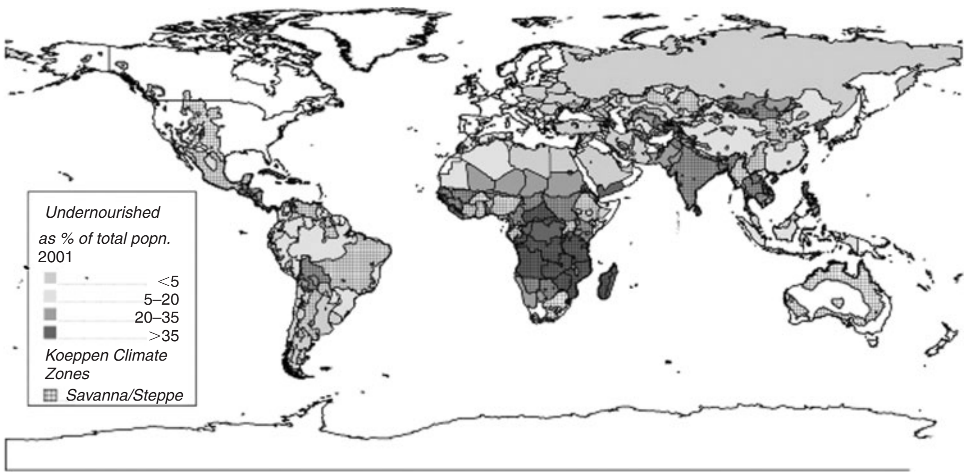

Figure 2.2 The prevalence of undernourished in developing countries (as percentage of population 2001) together with the distribution of semi-arid and dry subhumid hydroclimates in the world, i.e., savannah and steppe agroecosystems. These regions are dominated by sedentary farming subject to the world's highest rainfall variability and occurrence of dry spells and droughts (Source: SEI 2005) (See color plate section)

Even with growing urbanization, globalization, and better governance in Africa and Asia, hunger, poverty, and vulnerability of livelihoods to natural and other disasters will continue to be greatest in the rural tropical areas. The importance of rainfed sources of food weighs disproportionately on women, given that approximately 70% of the world's poor are women (WHO 2000). As most of the poor are farmers and landless laborers (Sanchez *et al.*, 2005), strategies for reducing poverty, hunger, and malnutrition should be driven primarily by the needs of the rural poor and should aim to build and diversify their livelihood sources. Substantial gains in land, water, and labor productivity as well as better management of natural resources are essential to reverse the downward spiral of poverty and environmental degradation, apart from the problems of equity, poverty, and sustainability – and hence, the need for greater investment in the semi-arid tropics (World Bank 2005; Rockström *et al.*, 2007; Wani *et al.*, 2008a, 2009).

Evidence is emerging that climate change is making the variability more intense with increased frequency of extreme events such as drought, floods, and hurricanes (IPCC 2007). A recent study assessing rainfed cereal potential under different climate change scenarios, with varying total rainfall amounts, concluded that it is difficult to estimate the exact degree of regional impact. But most scenarios resulted in losses of rainfed production potential in the most vulnerable developing countries. In these countries, the loss of production area was estimated at 10–20%, with an approximate potential of 1.3 billion people affected by 2080 (IIASA 2002). In particular, sub-Saharan Africa is estimated to lose 12% of the cultivation potential mostly projected in the Sudan-Sahelian zone, which is already subject to high climatic variability and adverse crop conditions.

2.4 VAST POTENTIAL TO INCREASE CROP YIELDS IN RAINFED AREAS

In the past 40 years, 30% of the overall grain production growth is due to expansion of agricultural areas and the remaining 70% growth originated from intensification through yield increases per unit land area. However, the regional variation is large, as is the difference between irrigated and rainfed agriculture. In developing countries rainfed grain yields are on an average 1.5 t ha^{-1} compared to 3.1 t ha^{-1} for irrigated yields (Rosegrant *et al.*, 2002), and increase in production from rainfed agriculture has mainly originated from land expansion.

In sub-Saharan Africa, with 99% rainfed production of main cereals such as maize, millet, and sorghum, the cultivated cereal area has doubled since 1960 while the yield per unit land has nearly been stagnant for these staple crops (FAOSTAT 2010). In South Asia, farmers shifted away from more drought tolerant low-yielding crops such as sorghum and millet, whilst wheat and maize have approximately doubled in area since 1961 (FAOSTAT 2010). During the same period, the yield per unit land for maize and wheat has more than doubled. For predominantly rainfed systems, maize yields per unit land have nearly tripled and wheat more than doubled during the same time period.

In the temperate regions, rainfed agriculture generates among the world's highest yields with relatively reliable rainfall and inherently productive soils. Even in tropical

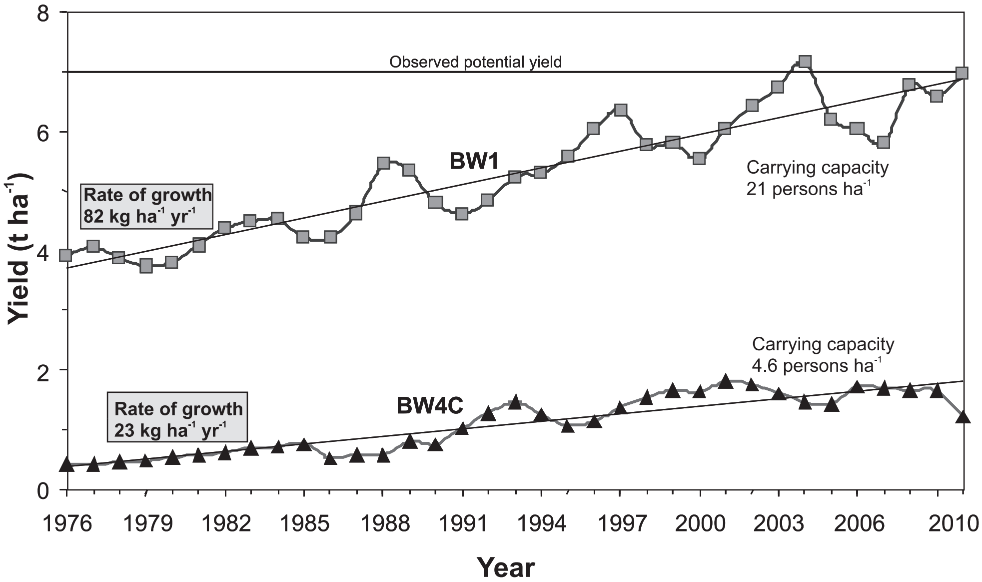

Figure 2.3 Three-year moving average of crop yields in improved (BW1) and traditional (BW4C) management systems during 1976–2009 at ICRISAT, Patancheru, India

regions, particularly in the subhumid and humid zones, agricultural yields in commercial rainfed agriculture exceed 5–6 t ha^{-1} (Rockström and Falkenmark 2000; Wani *et al.*, 2003b, 2003c) (Figure 2.3). At the same time, the dry subhumid and semi-arid regions have experienced the lowest yields and the weakest yield improvements per unit land. Here, yields oscillate between 0.5 and 2 t ha^{-1}, with an average of 1 t ha^{-1} in sub-Saharan Africa, and 1–1.5 t ha^{-1} in South Asia, Central Asia, and West Asia and North Africa (WANA) for rainfed agriculture (Rockström and Falkenmark 2000; Wani *et al.*, 2003b, 2003c, 2009, 2011; Rockström *et al.*, 2010).

Yield gap analyses carried out for Comprehensive Assessment for major rainfed crops in semi-arid regions in Asia and Africa and rainfed wheat in WANA, revealed large yield gaps with farmers' yields being a factor 2 to 4 times lower than achievable yields for major rainfed crops (Figures 2.4 and 2.5) (Agarwal 2000; Rockström *et al.*, 2007; Fisher *et al.*, 2009; Singh *et al.*, 2009; Wani *et al.*, 2011). In countries in Eastern and Southern Africa the yield gap is very large (Figure 2.5). Similarly, in many countries in West Asia, farmers' yields are threefold lower than achievable yields, while in some Asian countries the figure is closer to twofold. Historic trends present a growing yield gap between farmers' practices and farming systems that benefit from management advances (Wani *et al.*, 2003c, 2009, 2011) and vast scope exists to unlock the potential of rainfed agriculture through sustainable management of natural resources through scaling-out the experiences from the islands of success spread sporadically throughout the globe (Kijne *et al.*, 2009; Wani *et al.*, 2009).

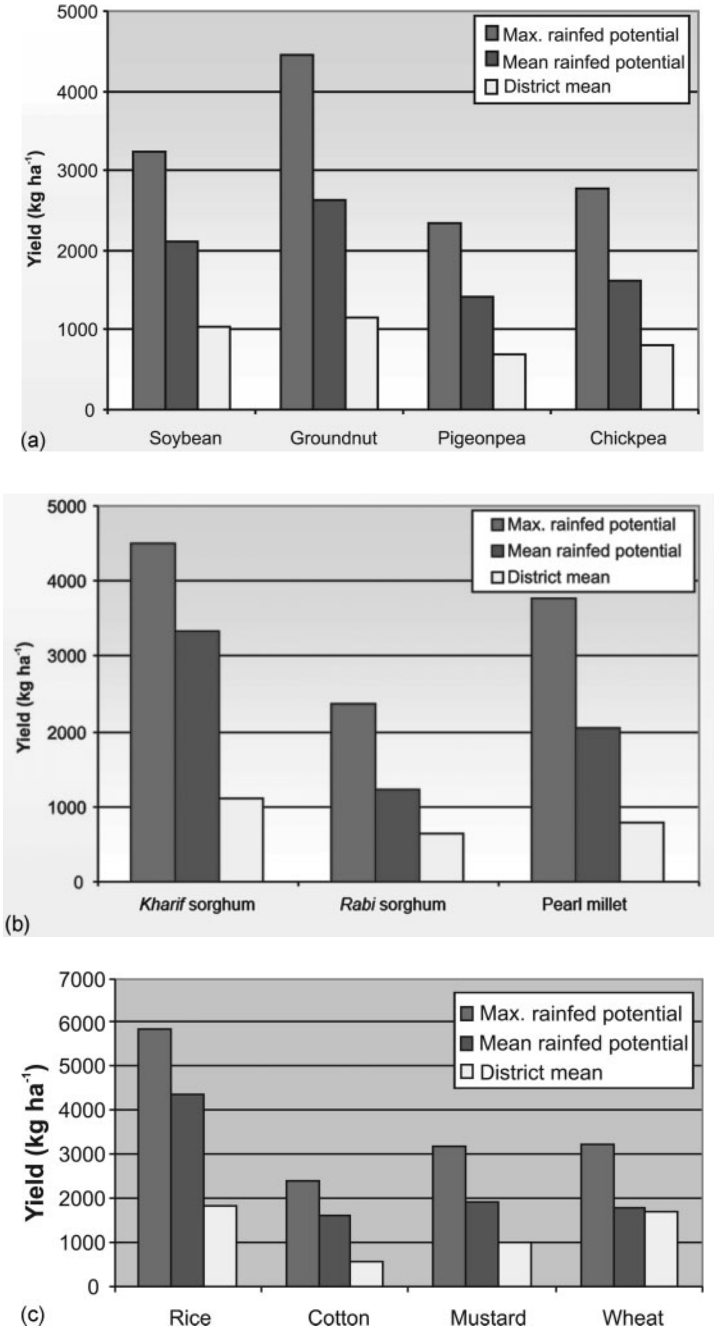

Figure 2.4 Rainfed potential yields and yield gaps of crops in India (Source: Singh *et al.*, 2009)

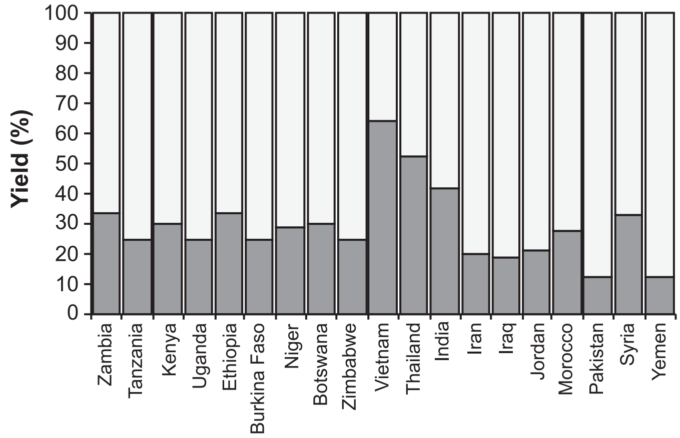

Figure 2.5 Examples of observed yield gap (for major grains) between farmers' yields and achievable yields (100% denotes achievable yield level, and columns actual observed yield levels) (Source: Rockström *et al.*, 2007)

2.5 IMPROVED WATER PRODUCTIVITY IS A KEY TO UNLOCK THE POTENTIAL OF RAINFED AGRICULTURE

An adequate human diet takes about 4000 liters of water per day to produce, which is over 90% of the daily human water requirement. If farmers continue to use the current methods for producing food then to feed the world's growing population we will need a great deal more water to keep everyone fed: another 1600 km^3yr^{-1} just to achieve the UN Millennium Development Goal of halving hunger by 2015 (SEI 2005), and another 4500 km^3yr^{-1} with current water productivity levels in agriculture to feed the world in 2050 (Falkenmark *et al.*, 2009; Rockström *et al.*, 2009) This is more than twice the current consumptive water use in irrigation, which already contributes to depleting several large rivers before they reach the ocean. It is becoming increasingly difficult, on social, economic, and environmental grounds, to supply more water to farmers.

Water scarcity is a relative concept and as explained by Rockström *et al.* (2009) current estimates of water scarcity are using the conventional approach and assessing the amount of renewable surface and groundwater per capita (i.e., so called blue water) without taking into consideration the full resource of rainfall, and notably "green water", i.e., soil moisture used in rainfed cropping and natural vegetation. As Figure 2.6a illustrates, South Asia, East Asia, and the Middle East North Africa (MENA) regions are the worst affected in terms of blue water scarcity. However, according to a recent assessment that included both green and blue water resources, the level of water scarcity changed significantly for many countries (Figure 2.6b). Large parts of China, India, and sub-Saharan Africa are conventionally water scarce but still have sufficient green and blue water to meet the water demand for food production. If green water (on current agricultural land) for food production is included, per capita water availability is doubled or tripled in countries such as Uganda, Ethiopia,

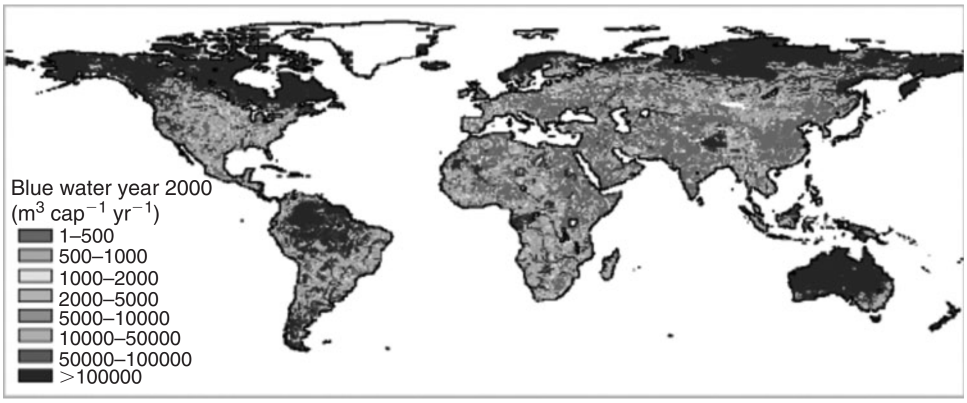

Figure 2.6a Renewable liquid freshwater (blue water) stress per capita using LPJ dynamic modeling year 2000 (after Rockström *et al.*, 2009) (See color plate section)

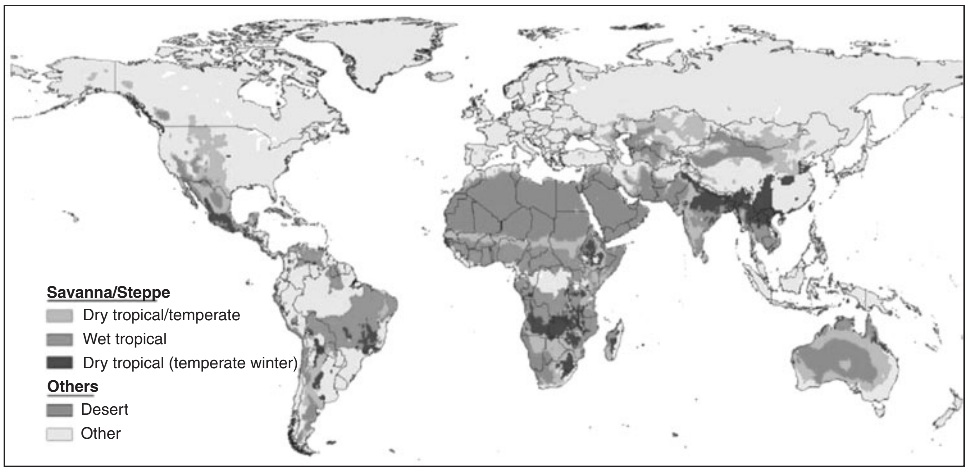

Figure 2.6b Renewable rainfall (green and blue water) stress per capita using LPJ dynamic modeling year 2000 (after Rockström *et al.*, 2009) (See color plate section)

Eritrea, Morocco, and Algeria. Moreover, low ratios of transpiration to evapotranspiration (T/ET) in countries such as Bangladesh, Pakistan, India, and China indicate high potential for increasing water productivity through vapor shift (Rockström *et al.*, 2009).

Absolute water stress is found most notably in arid and semi-arid regions with high population densities such as parts of India, China, and the MENA region. The MENA region is increasingly unable to produce the food required locally due to increasing water stress from a combination of population increase, economic development, and

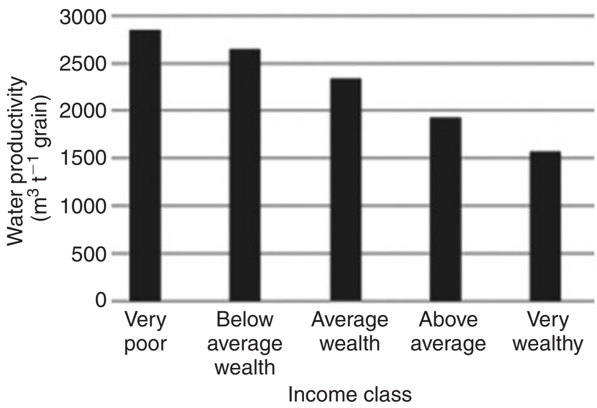

Figure 2.7 Water productivity for maize yields in smallholder farming systems in sub-Saharan Africa (based on Holmen 2004)

climate change, and will have to rely more and more on food (and virtual water) imports. For the greater part of the world the global assessment of green and blue water suggested that water stress is primarily a blue water issue, and large opportunities are still possible in the management of rainfed areas, i.e., the green water resources in the landscape (Rockström *et al.*, 2009). The current global population that has blue water stress is estimated to be 3.17 billion, expected to reach 6.5 billion in 2050. If both green and blue water are considered, the number currently experiencing absolute water stress is a fraction of this (0.27 billion), and will only marginally exceed today's blue water stressed in 2050.

Given the increasing pressures on water resources and the increasing demands for food and fiber, the world must succeed in producing more food with less water. Hence, it is essential to increase water productivity in both humid and arid regions. Some describe the goal as increasing the "crop per drop" or the "dollars per drop" produced in agriculture. Regardless of the metric, it is essential to increase the productivity of water and other inputs in agriculture. Success will generate greater agricultural output, while also enabling greater use of water in other sectors and in efforts to enhance the environment.

Water productivity can vary with household income, as farmers' yields vary as a result of local input and management styles. In a household level study of 300 farmers in eight sub-Saharan countries, the more wealthy farmers had generally higher yield levels (Holmen, 2004), and subsequently better water productivity (Figure 2.7). The differences were significant between the wealthier classes and poorest classes. More than 1,000 m^3 additional water was required per ton of maize grain produced by the poorest farmers compared to the wealthiest farmers. Data suggest that yield improvements for the purpose of poverty alleviation can also significantly improve water productivity, especially in current low yielding rainfed (green water) agriculture, in sub-Saharan Africa and parts of South Asia. Improved water use efficiency and productivity can improve food security.

2.6 WATER ALONE CANNOT DO IT

Successful efforts to increase crop yields through improved management practices other than water help in bridging the yield gaps by increasing water use efficiency. Hence, it provides good opportunities to examine other critical constraints which are holding back the potential of increasing crop yields. Soil health is severely affected due to land degradation and is in need of urgent attention. Often, soil fertility is the limiting factor to increased yields in rainfed agriculture (Stoorvogel and Smaling 1990; Rego *et al.*, 2005). Soil degradation, through nutrient depletion and loss of organic matter, causes serious yield decline closely related to water determinants, as it affects water availability for crops, due to poor rainfall infiltration, and plant water uptake, due to weak roots. Nutrient mining is a serious problem in small-holder rainfed agriculture. In sub-Saharan Africa soil nutrient mining is particularly severe. It is estimated that approximately 85% of African farm land in 2002–04 experienced a loss of more than 30 kg ha^{-1} of nutrients (nitrogen, phosphorus, and potassium) per year (IFDC 2006). There is a need to manage soil fertility through integrated fertility management options through optimum use of biological, organic, and chemical sources of required nutrients.

On-farm diagnostic work of the International Crops Research Institue for the Semi-Arid Tropics (ICRISAT) in different community watersheds in different states of India as well as in Southern China, North Vietnam, and Northeast Thailand showed severe mining of soils for essential plant nutrients including secondary and micronutrients along with macronutrients (Rego *et al.*, 2007; Sahrawat *et al.*, 2007). Evidence from on-farm participatory trials in different rainfed areas in India clearly indicated that investments in soil fertility improvement directly improved water management resulting in increased rainwater productivity and crop yields by 70 to 120% when both micronutrients and adequate nitrogen and phosphorus were applied (Rego *et al.*, 2005; Sahrawat *et al.*, 2007; Srinivasarao *et al.*, 2010). Similarly, integrated land, nutrient, and water management options as well as use of improved cultivars in semi-arid regions increased significantly rainwater productivity (Wani *et al.*, 2003a, 2011; Sreedevi and Wani 2009). Gains in rainwater use efficiency with improved land, nutrient, and water management options were far higher in low rainfall years (Figure 2.8).

In addition, soil organic matter, an important driving force for supporting biological activity and crop productivity in soil, is very much in short supply particularly in tropical countries (Lee and Wani 1989; Syers *et al.*, 1996; Katyal and Rattan 2003). Management practices that augment soil organic matter and maintain at a threshold level are needed. Improved agricultural management practices in the tropics such as intercropping with legumes, application of balanced plant nutrients, suitable land and water management and use of stress-tolerant high-yielding cultivars improved soil organic carbon content and also increased crop productivity (Lee and Wani 1989; Wani *et al.*, 1995, 2003b, 2005, 2007; ICRISAT 2005; Gowda *et al.*, 2009; Srinivasarao *et al.*, 2009). Good quality organic materials in fields using farm bunds and degraded common lands in the villages could be produced by growing nitrogen-fixing shrubs and trees to generate nitrogen-rich loppings. Also, large quantities of farm residues and other organic wastes could be converted into valuable source of plant nutrients and organic matter through vermicomposting (Nagavallemma *et al.*, 2005; Sreedevi *et al.*, 2007; Wani *et al.*, 2008b; Sreedevi and Wani 2009).

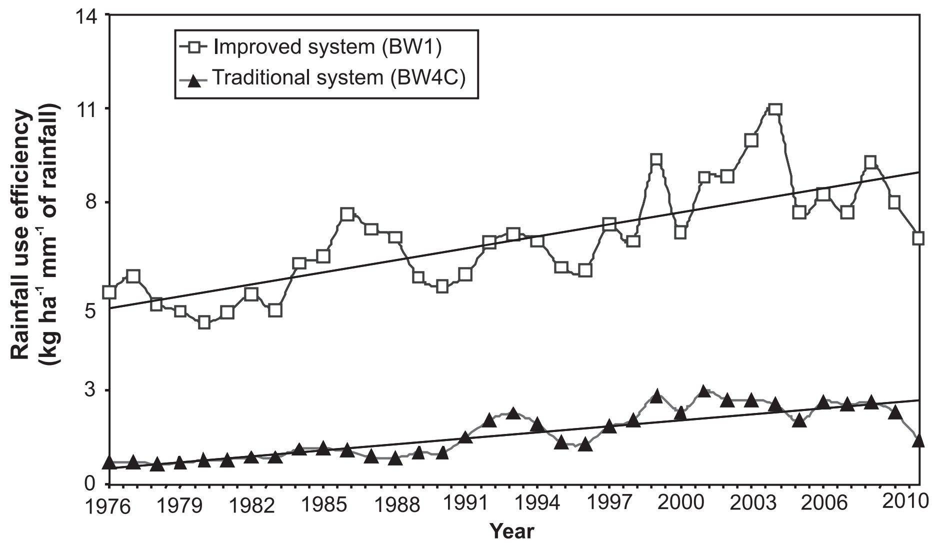

Figure 2.8 Increased rainwater use efficiency in low rainfall years at ICRISAT, Patancheru, India

2.7 INTEGRATED WATERSHED MANAGEMENT IS KEY FOR SUSTAINABLE MANAGEMENT OF LAND AND WATER RESOURCES AND IMPROVED LIVELIHOODS

Of the 100,000 km^3 of water that falls on the land each year, 65% becomes green water, i.e., water contained in the root zone of the soil and 35% results in blue water, i.e., runoff water into lakes, rivers, reservoirs, and aquifers. Integrated watershed management provides a good opportunity to manage land and water resources in an integrated manner for sustainable livelihoods while protecting the environment (Wani *et al.*, 2002, 2008a, 2009, 2011). Both green and blue water is generated in the landscape and integrated water resource management is the key for sustainable development and management of water at small catchment scale that is recommended for enhancing the efficiency of water in rainfed areas (Wani *et al.*, 2002, 2009, 2011; Molden *et al.*, 2007; Rockström *et al.*, 2007, 2010). Rockström *et al.* (2009) have indicated that green water dominates food production as consumptive use of green water is four times larger than that of blue water (fresh water in rivers, lakes, reservoirs, and aquifers).

Evidence from water balance analyses on farmers' fields around the world shows that only a small fraction, less than 30% of rainfall, is used as productive green water flow (plant transpiration) supporting plant growth (Rockström 2003). In arid areas, typically as little as 10% of the rainfall is consumed as productive green water flow (transpiration) and 90% flows as non-productive evaporation flow, i.e., no or very limited blue water generation (Oweis and Hachum 2001). In temperate arid regions, such as WANA, a large portion of the rainfall is generally consumed in the farmers' fields as productive green water flow (45–55%) that resulted in higher yield levels (3–4 $t\,ha^{-1}$ as compared to 1–2 $t\,ha^{-1}$) and 25–35% of the rainfall flows as non-productive green water flow, and remaining 15–20% generate blue water flow. These indicate a large scope of opportunity. Low agricultural yields in rainfed agriculture, often blamed as rainfall deficits, are in fact caused by other factors than rainfall.

This suggests great scope and opportunity for improvement of green water productivity, as it entails shifting non-productive evaporation to productive transpiration, with no downstream water trade-off. This vapor shift (or transfer) through improved management options is a particular opportunity in arid, semi-arid, and dry subhumid regions (Rockström *et al.*, 2007).

Field measurements of rainfed grain yields and actual green water flows indicate that by doubling yields from 1 to 2 $t\,ha^{-1}$ in semi-arid tropical agroecosystems, green water productivity may improve from approximately 3500 $m^3\,t^{-1}$ to less than 2000 $m^3\,t^{-1}$. This is a result of the dynamic nature of water productivity improvements when moving from very low yields to higher yields. At low yields, crop water uptake is low and evaporative losses are high, as the leaf area coverage of the soil is low. This results in high losses of rainwater as evaporation from soil. When yield levels increase, shading of soil improves.

Business as usual to manage rainfed agriculture as subsistence agriculture with low resource use efficiency cannot sustain the economic growth and needed food security. There is an urgent need to develop a new paradigm for upgrading rainfed agriculture. The conventional sectoral approach to water management produced low water use efficiencies resulting in increased demand for water to produce food. We need to have a holistic approach based on converging all the necessary aspects of natural resource conservation, their efficient use, production functions, and income enhancement avenues through value chain and enabling policies and much needed investments in rainfed areas (Wani *et al.*, 2003c, 2009; Rockström *et al.*, 2007).

Furthermore, the current focus on water resource planning at the river basin scale is not appropriate for water management in rainfed agriculture, which overwhelmingly occurs on farms of $<$5 ha at the scale of small catchments, below the river basin scale. Therefore, focus should be to manage water at the catchment scale (or small tributary scale of a river basin), opening for much needed investments in water resource management also in rainfed agriculture (Rockström *et al.*, 2007).

Evidence collected during the Comprehensive Assessment of water for food and water for life revealed that business as usual in global agriculture would not be able to meet the goal of food security and reducing poverty. If the situation continued it will lead to crises in many parts of the world (Molden *et al.*, 2007). However, the world's available land and water resources can satisfy future demands by taking the following steps:

- Upgrade rainfed agriculture by investing more in rainfed agriculture to enhance agricultural productivity (rainfed scenario).
- Discard the artificial divide between rainfed and irrigated agriculture and adopt integrated water resource management approach for enhancing resource efficiency and agricultural productivity.
- Invest in irrigation for expanding irrigation where scope exists and improving efficiency of the existing irrigation systems (irrigation scenario).

- Conduct agricultural trade within and between countries (trade scenario).
- Reduce gross food demand by influencing diets and reducing postharvest losses, including industrial and household waste.

To upgrade rainfed agriculture in the developing countries, community based participatory and integrated watershed management approaches are recommended and are found effective through a number of islands of success in Asia and Africa (Wani *et al.*, 2002, 2003a, 2008b; Rockström *et al.*, 2007). In the rainfed areas of the tropics, water scarcity and growing land degradation cannot be tackled through farm-level interventions alone and community-based management of natural resources for enhancing productivity and improving rural livelihoods are urgently needed (Wani *et al.*, 2003a, 2009; Rockström *et al.*, 2007). A holistic approach is needed that integrates all the necessary aspects of natural resource conservation, their efficient use, production functions, and income enhancement avenues through value chain and enabling policies and much needed investments in rainfed areas. A major research and development challenge to upgrade rainfed agriculture is to integrated knowledge systems amongst different stakeholders and scientific disciplines by coming out of disciplinary compartments and translate available blue prints into operational plans and implement them (Wani *et al.*, 2003a, 2006, 2009; Rockström *et al.*, 2007). We know what to do but the challenge is how to do it.

The community-based management of natural resources calls for new approaches (technical, institutional, and social), which are knowledge-intensive and need strong capacity building measures for all the stakeholders including policy makers, researchers, development agents, and farmers. The small and marginal farmers are deprived of new knowledge and materials produced by the researchers. There is a disconnect between the farmers and the researchers as the extension systems in most developing countries are not functioning to the desired level. There is an urgent need for a holistic approach to address issues of rainfed agriculture to achieve food security and alleviate poverty to meet the Millennium Development Goals.

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