7 Can Rainfed Agriculture Feed the World? An Assessment of Potentials and Risk

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Introduction

Agriculture is practised on 12% of the total land area, hosting around 42% of the global population (FAOSTAT, 2000, 2003). Most of this area, around 80%, is under rainfed agriculture (FAOSTAT, 2005), which plays a predominant role in global food supply and water demand for food. There are large regional variations. While the majority of the agricultural land in sub-Saharan Africa is rainfed, most of the agricultural production in South Asia comes from irrigated agriculture.

Approximately 7000 km^3 of water is used annually in crop production (Rockström *et al.*, 1999; de Fraiture *et al.*, 2007; Lundqvist *et al.*, 2007), corresponding to 3000 l/person/day. The majority of this water originates from the green water resource (78%), while the remaining 22% is met by irrigation (de Fraiture *et al.*, 2007). Today, more than 1.2 billion people live in water-scarce river basins (Molden *et al.*, 2007a), and recent forecasts warn of aggravated global water scarcity unless water resources management is changed (Alcamo *et al.*, 1997; Seckler *et al.*, 1998; Seckler and Amarasinghe, 2000; Shiklomanov, 2000; Rosegrant *et al.*, 2002a, 2006; Bruinsma, 2003; Falkenmark and Rockström, 2004; SEI, 2005).

With rising incomes and growing population, food demand is expected to increase by 70–90% (de Fraiture *et al.*, 2007). Food habits change with increasing GDP (gross domestic product) to include more nutritious and more diversified diets, resulting in a shift in consumption patterns among cereal crops and away from cereals towards livestock products and high-value crops such as fruits, vegetables, sugar and edible oils; however, regional and cultural differences are large. Bioenergy is expected to add to the demand of agricultural produce, in order to increase the supply of transport fuels (i.e. biofuels) as a response to rising energy prices, geopolitics and concerns over greenhouse gas emissions. Future water requirements for bioenergy production have been estimated to range from 4000 to 12,000 km^3/year (Lundqvist *et al.*, 2007). The large uncertainty is a reflection of difficulties in estimating water productivity, which, for example, depends on how much of the biomass can be used for bioenergy production.

One of the options to respond to increased pressure on water resources is to boost low productivity through investments in water management in rainfed agriculture. There are several compelling environmental, social and economic reasons to do so. Yet, with rapidly growing and changing agricultural demand and increased climate variability due to climate change, the potential of rainfed agriculture to meet future food demand is subject to debate.

In this chapter, we examine how far rainfed agricultural production can meet future food demands in 2050. Two different productivity scenarios are compared, one pessimistic and one optimistic, using the WATERSIM model and estimates of potential yields for different agroecological zones. Moreover, the implications of these scenarios on risk minimization are illustrated.

Reasons to Upgrade Rainfed Agriculture

Large scope for poverty alleviation

Agriculture plays a key role in economic development (World Bank, 2005) and poverty reduction (Irz and Roe, 2000). For example, it has been shown that every 1% increase in agricultural yields translates into a 0.6–1.2% decrease in the absolute poor (Thirtle *et al*., 2002). In sub-Saharan Africa the majority of the poor make their living from agriculture. In this region, agriculture, which is predominantly rainfed, employs 70% of the population and accounts for 35% of GDP (World Bank, 2000). Thus, agriculture is the engine of overall economic growth and, consequently, of broad-based poverty reduction (Johnston and Mellor, 1961; World Bank, 1982; Timmer, 1988; Abdulai and Hazell, 1995; IFAD, 2001; DFID, 2002; Koning, 2002, Wani *et al*., 2008), and there are therefore strong reasons to believe that investments in low-yielding rainfed agriculture could have large impacts on poverty reduction.

Low investment costs

With rising concern over the high cost of expanding large-scale irrigation and environmental impacts of large dams, the role of upgrading rainfed agriculture is gaining increased attention. For example, irrigated cereal production in sub-Saharan Africa, characterized by high marketing and transportation costs and limited marketing opportunities, might not be able to compete with subsidized food imports from the USA and Europe. In addition, the institutional infrastructure and experience required for irrigation operation, maintenance and management are lacking. In a review of 311 case studies on watershed programmes in India focusing on rainwater management, the cost–benefit ratio was found to be 1:2.14, which can be considered relatively high (Joshi *et al*., 2005). Micro-credit schemes for water management investments in rainfed agriculture have been suggested as a core strategy for enabling small-scale farmers to invest in water management in rainfed agriculture (Wani *et al.*, 2008).

Environmental concerns related to large-scale irrigation

Diversion of water from rivers and lakes for agricultural purposes often adversely affects aquatic ecosystems (e.g. Richter *et al*., 1997; Revenga *et al*., 2000; WCD, 2000; Bunn and Arthington, 2002; MEA, 2005a,b). Negative impacts include channel erosion, declines in biodiversity, introduction of invasive alien species, reduction of water quality, habitat fragmentation and reduced protection of flood plains and other inland and coastal fisheries. On the field scale, there are two main undesirable impacts of irrigation: salinization and waterlogging (Tanji, 1990). In 1994, it was estimated that around 10% of the earth's total land surface is covered with saline soils (Szabolcs, 1994). The Goulburn Broken Catchment in Australia is one example of a region presently suffering from rising water tables due to irrigation and the removal of natural vegetation (trees), and associated problems with the threat of waterlogging and salinization, which has rendered the region extremely susceptible to chocks (Anderies *et al*., 2005). Large-scale irrigation carries environmental risks and associated costs, which works in favour of investments in rainfed agriculture.

Large yield gaps – high potential

In developing countries, rainfed grain yields are on average 1.5 t/ha, and increases in production have originated mainly from land expansion (Rosegrant *et al*., 2002b). On the other hand, in temperate regions rainfed agriculture has some of the world's highest yields, and even in tropical regions, agricultural yields in commercial rainfed agriculture exceed 5–6 t/ha (Rockström and Falkenmark, 2000; Wani *et al.*, 2003a,b). In semi-arid regions in Africa and Asia, farmers' yields are two to four times lower than achievable yields for major rainfed crops (Rockström *et al.*, 2007, Wani *et al.*, Chapter 1, this volume). Such large yield gaps indicate a high potential for investments in rainfed agriculture.

Risk minimization – opening up for further investments

Low profitability of agriculture and high risks discourage farmers from investing in land and water management. In semi-arid and dry sub-humid agroecosystems, dry spells occur almost every rainy season (Barron *et al.*, 2003). No overall estimates on losses because of drought and short dry spells are available, but yield figures show an enormous year to year variation. However, meteorological droughts, i.e. periods of inadequate rainfall to grow a crop, occur only once or twice every 10 years. Therefore, there is a large potential for investments in water management to bridge dry spells and secure harvests in most years. Furthermore, such a risk minimization is likely to have positive spin-off effects on further investments in yield-increasing inputs such as fertilizers.

Assessing the Potential for Rainfed Agriculture

Nevertheless, the potential role of rainfed agriculture in contributing to world food production is a subject of debate, and forecasts regarding the relative roles of irrigated and rainfed agriculture vary considerably. Rosegrant *et al.* (2002a) project that more than 50% of additional grain production will come from rainfed areas, particularly in developed countries, while developing countries will increase their imports of grains. The FAO (Food and Agriculture Organization of the United Nations) foresees that the contribution to global food supply from rainfed areas will decline from 65% today to 48% in 2030 (Bruinsma, 2003), offset by productivity improvements and irrigated area expansion. Referring to mixed results of past efforts to enhance productivity in rainfed areas, Seckler and Amarasinghe (2000) are less optimistic concerning the potential of rainfed areas. They foresee that only 5% of the increase in future grain production will come from rainfed agriculture, while the major part will originate from irrigated areas. Further, while numerous studies document the benefits of upgrading rainfed agriculture (Agarwal and Narain, 1999; Wani *et al.*, 2003c), upscaling successes proved challenging. Water-harvesting techniques have long been known, but adoption rates have been low due to low profitability of agriculture, lack of markets, relatively high labour costs and high risks. Yields are highly dependent on economic incentives and crop prices, and a high-yield scenario will only happen if it is profitable for individual farmers (Bruinsma, 2003).

Others counter that compared with irrigated agriculture, investments have been very small, mainly targeted to soil conservation rather than water harvesting (Rockström *et al.*, 2007; Wani *et al.*, Chapter 1, this volume). And particularly in sub-Saharan Africa, irrigation investments have been a mixed success. Inocencio *et al.* (2006) report a success ratio of 50% for new construction projects in sub-Saharan Africa.

Two scenarios

To contrast these optimistic and pessimistic views on the potential of rainfed agriculture and assess risks, the Comprehensive Assessment of Agricultural Water Management[1] developed two scenarios on the development of rainfed agriculture. The optimistic high-yield scenario assumes that prices and incentives are right and physical and institutional arrangements are in place (markets, roads, extension services and credit facilities). Low adoption rates of water-harvesting measures and supplemental irrigation are, on the other hand, assumed for the pessimistic low-yield scenario. Both scenarios are formulated based on exploitable yield gaps, using the Global Agro-Ecological Zones. The FAO and the International Institute for Applied Systems Analysis (IIASA) developed a method for assessing land suitability classes and maximum attainable yields under different input regimes using the Agro-Ecological Zones (AEZ) concept[2]. To reach maximum attainable yields, high input levels and best suitable varieties are needed, depending on the quality of land. This approach provides realistic estimates based on known techniques, without assuming major breakthroughs (Fischer *et al.*, 2002). The difference between maximum attainable and actual yield is referred to as the yield gap. The portion of the gap that can be bridged by differences in crop management is termed the 'exploitable yield gap'. Even among countries with fairly similar agroecological environments, yields differ considerably. Exploitable yield gaps are typically high in low-yield areas, as in sub-Saharan Africa (Molden *et al.*, 2007b). The high-yield scenario assumes that 80% of the gap will be bridged by the year 2050, as a result of successful institutional reform, well-functioning markets and credit systems, mechanization, improved use of fertilizers and high-yielding varieties, and rapid adoption of water-harvesting techniques. Where yields are currently low, productivity improves at a higher rate than observed historically, while in OECD (Organization for Economic Cooperation and Development) countries, where yields are already high and the exploitable gap is small, projected growth rates are relatively low. The pessimistic yield scenario assumes that only 20% of the yield gap will be bridged, owing to a slow rate of adoption of soil fertility and crop improvements, *in-situ* soil and water management, and external water-harvesting measures.

The scenarios are implemented using the WATERSIM model, a quantitative model consisting of two fully integrated modules: a food production and demand module based on a partial equilibrium framework, and a water supply and demand module based on a water balance and water accounting framework (de Fraiture, 2007). Food demand projections are based on a baseline scenario developed for the Comprehensive Assessment and are comparable to other published forecasts (FAO, 2006). In this middle-of-the-road food demand scenario, cereal demand will increase by 62% by 2050, to a large extent because of increased demand for livestock products and hence feed grains. Meat and vegetable demand will roughly double. The scenarios do not take into consideration increased demand for crops for biofuels, which at present constitute a small percentage of total food demand but may increase rapidly in future (Berndes, 2002). The scenarios assume that all additional agricultural demand is met from improved yields on existing rainfed areas and where necessary an expansion of rainfed areas.

Results: Comparing an Optimistic and Pessimistic Scenario[3]

Under the optimistic scenario all additional food demand by 2050 can be met from rainfed agriculture by improved yields combined with a modest increase in agricultural area by 7%. Rainfed cereal yields grow by 72% on a global average but more than double in low-yield areas, particularly in sub-Saharan Africa. Asia, Latin America and sub-Saharan Africa will be self-sufficient in main food crops for the most part. But the Middle East and North Africa must import food because of the lack of rain and suitable lands for rainfed agriculture. The scenario analysis shows that upgraded rainfed agriculture can produce the food required in future, but this will only happen if certain conditions are met. The required productivity increases will not occur without substantial investments in water harvesting, agricultural research, supporting institutions and rural infrastructure. In addition, crop yields will vary with economic incentives and crop prices, as farmers respond to those parameters when choosing key inputs. High yields only materialize if they are profitable for farmers (Bruinsma, 2003). Problems include the lack of domestic market infrastructure, trade barriers to international markets, high marketing costs, poor governance, institutional disincentives to profitable agriculture (taxes, corruption, lack of formal land titles) and high levels of risk discouraging farmers from investing in labour and other inputs. Without investments in supporting physical infrastructure (particularly transport) and more importantly governance and institutions, agricultural development will fail. Resources are available to improve rainfed agriculture, but the institutional structure must encourage farm-level adoption of the recommended production practices.

The environmental and social costs of a failed 'rainfed strategy' can be substantial, as the pessimistic yield scenario shows. If high yields do not materialize and only 20% of the yield gap is bridged, the rainfed area will need to be expanded by 400 million ha to meet food demand by 2050, an increase of 53% compared with 2000. Globally this land is available, particularly in sub-Saharan Africa and Latin America, but such a large expansion might occur at the expense of forests and natural lands, or lead to soil degradation problems if rainfed agriculture is expanded into marginal areas. Countries without potential to expand rainfed areas – due to either lack of suitable land or unreliable rainfall – must increase food imports. In the pessimistic yield scenario, the Middle East and North Africa will import more than two-thirds of their agricultural needs. Owing to lack of suitable land South and East Asia will become major importers of maize and other grains, importing between 30 and 50% of their domestic demand. Latin America, OECD countries and Eastern Europe, having potential to expand land in agriculture, will increase their exports. Globally, food trade will increase from 14% of total agricultural production today to 22% in 2050. There is a risk that poor countries may not be able to afford food imports, and household-level food insecurity and inequity might worsen.

Future food production under the optimistic and pessimistic rainfed scenarios will lead to substantial increases in soil water consumption. Improved water management is a prerequisite for the yield improvements in the high-yield scenario. With higher yields, transpiration by crops must increase to produce enough biomass and economic yield. Part of the increased evapotranspiration might be offset by higher water productivity, by improving the harvest index, by reducing losses from soil evaporation, or by increasing transpiration while reducing evaporation. When yields are low, the scope to improve water productivity is high. But if yields are high, additional water is required to achieve even higher yields (Molden *et al.*, 2007b). In the optimistic rainfed yield scenario, total evapotranspiration on cropland increases by 30%, from 7130 to 9280 km^3. While the global average cereal yield improves by 72%, crop water productivity improves by 35%. In the pessimistic yield scenario, global cereal yields improve by 20% and water productivity by 10%, while soil water depletion increases by 60% to 8960 km^3, an additional 4300 km^3 compared with 2000. Increases in soil water depletion of that order of magnitude will have impacts on river flows and groundwater recharge, causing issues regarding downstream water users and those relying on groundwater resources.

Reducing risks

Relying on rainfed agriculture poses substantial risks to farmers because of high temporal and spatial variations. Harvests are always at risk because of frequent short dry spells during the growing season, which reduce the volume of yields (Barron *et al.*, 2003). They also have an indirect impact on cultivation, as farmers are less likely to invest in inputs and land management due to the high risk of crop failure. Many water-harvesting techniques are useful to bridge short dry spells but longer dry spells may lead to total crop failure. To get an indication of risks we ran the optimistic and pessimistic scenarios for four different river basins in India over 30 years and counted the number of years in which yields were reduced due to water stress by at least 20% and 40%, respectively. The WATERSIM model uses the linear crop yield reduction function developed by the FAO[4]. To differentiate between different climate zones we used the aridity index (AI), defined as precipitation divided by potential evapotranspiration. Areas with an AI of more than 0.65 are classified as humid. In semi-humid and semi-arid areas the AI falls in the range 0.65–0.4 and 0.2–0.4, respectively. Where the AI is smaller than 0.2, the area is arid. The optimistic scenario, in which enabling conditions for water-harvesting measures are met, assumes that the amount of rainwater falling on the field that can be beneficially used by plants (i.e. effective precipitation as defined by the FAO[5]) is augmented by 30%. Measures to enhance effective precipitation include *in-situ* soil and water management techniques such as conservation agriculture, bunds, terracing, contour cultivation, furrows and land levelling. *Ex-situ* water-harvesting measures for supplemental irrigation consist of surface microdams, subsurface tanks and farm ponds. The pessimistic scenario, in which adoption rates of these measures are low (due to low profitability and lack of market access), assumes an enhancement of effective precipitation of only 10%.

In the humid basin, cereal yields do not suffer from water stress except in a few dry years (Table 7.1). By contrast, in the arid and semi-arid basins, yield reduction of at least 20% due to water stress occurs in 50–67% of the years. By enhancing the amount of rainfall that can be beneficially used by 30%, the number of years that yield reduction occurs in semi-arid areas can be drastically reduced, to one-third of the time. In the arid basin, where rainfall is low compared with potential evapotranspiration, enhancing effective precipitation has a relatively modest effect on risk reduction. The results show that from a biophysical point of view, with appropriate measures, risk of yield reduction due to water stress can be mitigated. This will improve yields by mitigating water stress and by creating a favourable environment for farmers to invest in yield-enhancing inputs.

Conclusion: Upgrading Rainfed Agriculture Offers Good Potential to Meet Future Food Demand

There are compelling reasons to invest in upgrading rainfed agriculture. Many rural poor depend on rainfed agriculture rather than irrigated agriculture. Targeting the poor implies focusing on smallholders in rainfed areas. Investment costs per ha to upgrade rainfed areas tend to be relatively low and, particularly in sub-Saharan Africa, where most rural poor live in rainfed areas, more poor persons are lifted out of poverty by focusing investment to rainfed areas rather than irrigated agriculture. Realizing the potential of existing rainfed areas reduces the need for new large-scale irrigation development. On the other hand, improving rainfed production through water harvesting and supplemental irrigation also requires infrastructure and is likely to affect surface water and groundwater resources downstream.

Current yields in many rainfed settings are low, suggesting that there is good potential to improve harvests and output per unit of rainwater. In an optimistic yield-growth scenario, in which 80% of the gap between actual and obtainable yields is bridged, 85% of projected food demand by 2050 can be met by improving productivity of existing lands. An expansion of rainfed land by 7% is needed to meet all additional food demand.

But relying largely on rainfed agriculture is also risky. Water-harvesting techniques are useful in bridging short dry spells, but longer dry spells can lead to crop failure. Because of this risk, many farmers are reluctant to use fertilizers, pesticides and labour in rainfed settings. Cost of failure is higher, for the individual farmer who loses his/her income and for society. In a pessimistic yield-growth scenario, where technology adoption rates are low, rainfed areas expand up to 60%, leading potentially to encroachment of marginal lands, natural areas and forests. Risks to the individual farmers can be mitigated by appropriate measures in rainwater harvesting, increasing the amount of rainwater that can be beneficially used by crops (i.e. effective precipitation). For example, in the semi-arid basin, risk of yield reduction due to water stress was reduced from 57 to 33% by augmenting effective precipitation by 30%. With the right incentives and measures to mitigate risks to individual farmers, water management in rainfed agriculture holds a large potential to increase food production and reduce poverty while maintaining ecosystem services.

Table 7.1. Percentage of years in which yield reduction due to water stress occurs in cereals excluding rice[a].

Description	Humid (Ganges Basin)		Semi-humid (Cauvery Basin)		Semi-arid (Krishna Basin)		Arid (Indus Basin)	
Yield reduction	> 20%	> 40%	> 20%	> 40%	> 20%	> 40%	> 20%	> 40%
Pessimistic[b]	0%	0%	37%	7%	57%	27%	67%	20%
Optimistic[c]	3%	0%	13%	3%	33%	7%	50%	10%

[a]Source: WATERSIM model simulation. Data: precipitation over 1961–1990 (CRU_TS 2.0); evapotranspiration 1961–1990 Water Gap 1.0; [b]Scenario: 10% enhancement of effective precipitation; [c]Scenario: 30% enhancement of effective precipitation.

Notes

[1] http://www.iwmi.cgiar.org/Assessment/ and synthesis book by Molden (2007).

[2] http://www.iiasa.ac.at/Research/LUC/GAEZ/index.htm?sb=6

[3] Details of the scenarios analysis and results are given in de Fraiture *et al*. (2007).

[4] Yield reduction = ky.ETa/ETp; see Doorenbos and Kassam (1979) with ky = crop factor; ETa = actual evapotranspiration; and ETp = potential evapotranspiration.

[5] http://www.fao.org/docrep/S2022E/s2022e00.htm

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