Food and Water: Analysis of potentially new themes in water management - future trends and research needs

January 2010

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Report FutureWater: 91

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1 Introduction

The German Ministry of Education and Research (BMBF) has funded several major research program on Integrated Water Resources Management and Global Change. Currently, BMBF is in the process to identify promising future research themes by analyzing the international water research and policy landscape and by taking stock of recent achievements.

Based on a preliminary assessment the following themes of high political relevance and major research needs and potential have been identified:
1. Adaptation to climate change
2. Food and water
3. Urbanization and infrastructure
4. Disasters and vulnerability to water related threats
5. Water governance (cross-cutting)
6. Ecosystem water requirements – environmental flows (cross-cutting)

This report contributes to theme 2: Food and Water

This report will cover the following main items (responsible author Peter Droogers / Nick van der Giesen):

- Trends in food demand (PD/NG)
- Rainfed agriculture (PD)
- Irrigated agriculture (NG)
- Water and fishery (NG)
- Water and livestock (PD)

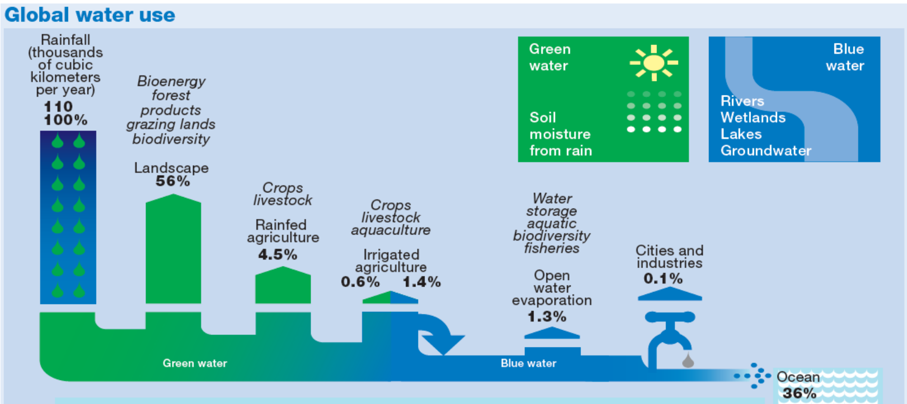

Figure 1. Global water use (source Molden, 2007)

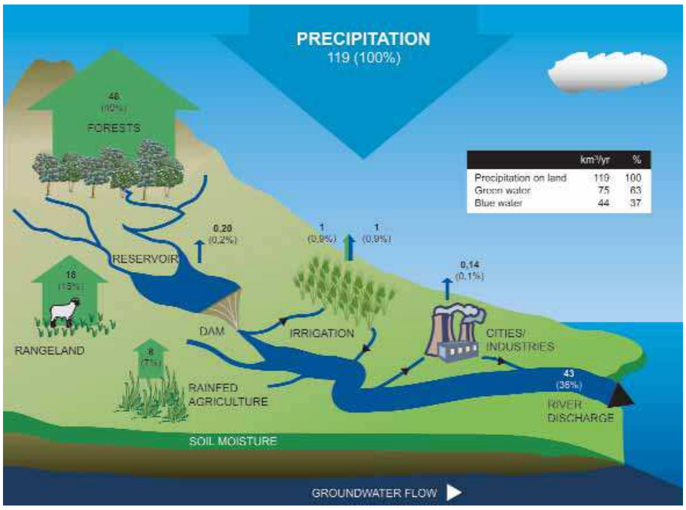

Figure 2. Global water evapotranspiration (source WWAP, 2006)

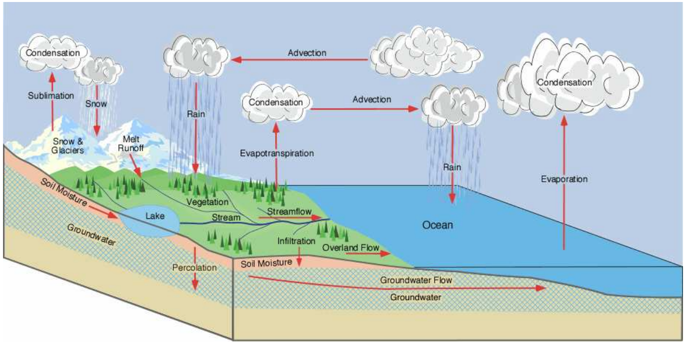

Figure 3. Hydrological cycle (source: Pidwirny, 2006)

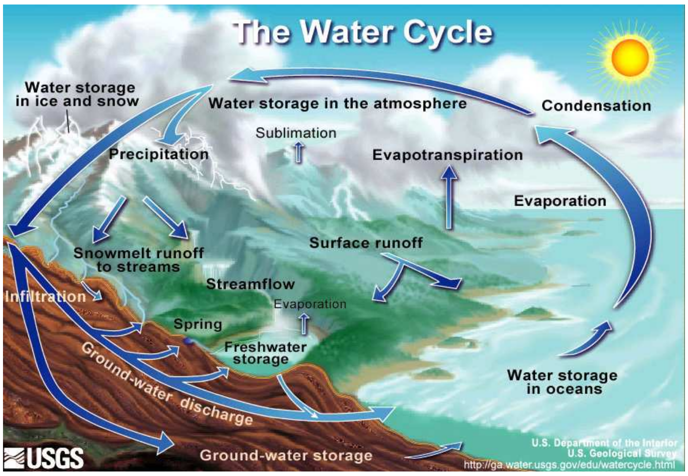

Figure 4. Hydrological cycle (source: USGS)

2 Trends in Food Demand

Various global assessment studies using an integrated approach to water and food exist. The approaches followed by these global studies can be divided into two groups. One the one hand exist studies that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often driven by food demand and food supply. Typical examples include the work of the International Food Policy Research Institute (IFPRI) in Washington.

The other group of global studies on water and food interactions is based on strong hydrological assessment. The economics are assumed of lower importance and often limited to a post-calculation of the agro-hydrological results rather than a driving force. Some typical examples include the work on the so-called AEZ (agro-ecological zones) of the The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA). A more recent approach is the so-called LPJ-MAgPIE project (Lotze-Campen et al., 2005) based on the Lund-Potsdam-Jena Dynamic Global Vegetation-Model (LPJ) and the “Management model of Agricultural Production and its Impact on the Environment” (MAgPIE) models were coupled. A prototype has been developed for Germany as well (Lotze-Campe et al., 2008).

One common weakness in both approaches is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes.

An interesting synthesis paper was published recently looking at the global perspective of water and energy inputs in food production (Khan and Hanjra, 2008). The main findings in this review are repeated here:

- Loss of natural habitat on agriculturally usable land (Green et al., 2005).
- Increase in continental water storage formerly flowing to deltas, wetland and inland sinks and its impacts on greenhouse gases (Milly et al., 2003).
- Homogenization of regionally distinct environmental templates/ landscapes, due to excessive construction of dams (Poff et al., 2007), thereby altering natural dynamics in ecologically important flows on continental (Fig. 2) to global scale (Arthington et al., 2006).
- Loss or extinction of freshwater fauna populations and habitat for native fisheries, plummeting population of birds due to inadequate water flows, and loss of riverine biodiversity due to large scale hydrological changes in tropical regions (Dudgeon, 2000).
- Biodiversity loss associated with agricultural intensification (Butler et al., 2007; Kremen et al., 2002).
- Enhanced global movement of various forms of nitrogen between the living world and the soil, water, and atmosphere with serious and long-term environmental consequences for large regions of the Earth (Vitousek et al., 1997).
- Nitrate pollution of agricultural landscapes and groundwater resources, and nitrogen- and phosphorous-driven eutrophication of terrestrial, freshwater, and near-shore marine

ecosystems, causing unprecedented ecosystem simplification, loss of ecosystem services, species extinctions, outbreaks of nuisance species, shifts in the structure of food chains, and contribution to atmospheric accumulation of greenhouse gases (Correll, 1998; Tilman et al., 2001).

- Synthetic chemicals compromising symbiotic nitrogen fixation, thus increasing dependence on synthetic agrochemicals and unsustainable long-term crop yields (Fox et al., 2007).
- Soil salinity and water logging and impaired natural drainage, and associated damages to infrastructure and lost opportunities for regional growth and economic development (Khan et al., 2006; Kijne, 2006; Wichelns and Oster, 2006).
- Depletion of groundwater aquifer and reduced stream flows (Khan et al., 2008a) and associated impacts on drinking water supplies, health and rural livelihoods (Meijer et al., 2006). Displacement of population due to dam construction (Cernea, 2003), and higher incidence of vector-borne diseases in some irrigation areas and loss of human productivity (Lautze et al., 2007).
- Reduced capacity of the ecosystems to sustain food production, maintain freshwater and forest resources, purify water, regulate climate and air quality, or ameliorate infectious diseases (Foley et al., 2005).
- Global accelerated erosion from plowed agricultural fields and hill slope production – greater than 1–2 orders of magnitude than rates of soil production; and erosion under native vegetation, and long-term geological erosion (Montgomery, 2007).
- Erosion caused by human transport of larger amounts of sediment and rocks for construction and agricultural activities exceeding all other natural process operating on the surface of the planet (Wilkinson and Mcelroy, 2007).
- Surge in extreme hydrological events such as storms, droughts and floods (Illangasekare et al., 2006).
- Global, inter- and intra-state conflict over freshwater resources and potential for social instability (Yoffe et al., 2004).
- Raised threat level of global terrorism to water resources due to elevated risk to dams and reservoirs (Gleick, 2006; Mustafa, 2005).

These points mentioned by Khan and Hanjra (2008) can be considered as a starting point when identifying research priorities related to the environmental impact of agricultural production.

3 Rainfed Agriculture

3.1 Introduction

The bulk of the world's agricultural production is rainfed, not irrigated. Despite substantial increases in large-scale irrigation infrastructure over the past half century, the bulk of the world's agricultural production still comes from predominantly rainfed lands. Some 55% of the gross value of crop production is grown under rainfed agriculture on 72% of harvested land (Molden et al., 2007). Approximately 70% of the world's irrigated land is in Asia, where it accounts for almost 35% of cultivated land. Rainfed agriculture is therefore by far the most important agricultural production system in most parts of the world and a major consumer of water by evapotranspiration losses (Figure 5).

The definition whether agriculture is rainfed or irrigated is however very vague (Droogers et al., 2008). A more detailed discussion on the definition of irrigated agriculture is presented in the chapter "Irrigated Agriculture", but in the context of this chapter rainfed agriculture is defined as an agricultural production system where no water will be put artificially on the field. This means that practices as rainwater harvesting are not excluded from rainfed agriculture, as long as this water is stored in the root zone and thus available for the plant without human intervention.

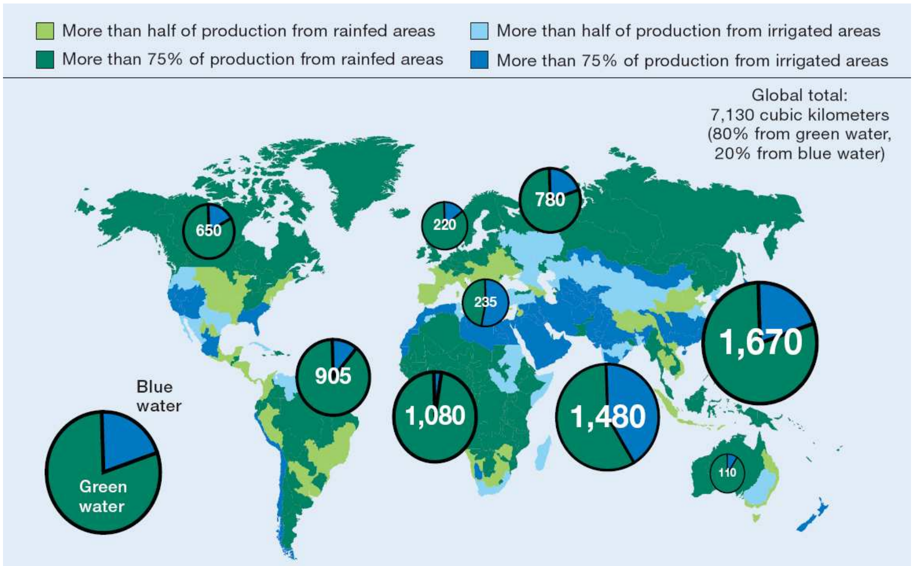

Figure 5. Food crop evapotranspiration from rain and irrigation (source Molden, 2007)

Over the last three years two comprehensive overview studies on water and food have been presented including substantial parts related to water and rainfed agriculture. The first one, Comprehensive Assessment of Water Management in Agriculture (Molden, 2007) describes in 16 chapters the state of the art of water in agriculture in general including rainfed agriculture. The researchers described their activities as

"The Comprehensive Assessment of Water Management in Agriculture critically evaluates the benefits, costs, and impacts of the past 50 years of water development, the water management challenges communities are facing today, and solutions people have developed. The results will enable better investment and management decisions in water and agriculture in the near future and over the next 50 years. The assessment is produced by a broad partnership of practitioners, researchers and policy makers."

The main message of this comprehensive assessment is that if appropriate measures, including research, will be taken, food security can be achieved under current and future conditions. The analysis resulted in eight so-called policy actions, which have implications for setting the research agenda (Molden, 2007):

- 1 Change the way we think about water and agriculture
- 2 Fight poverty by improving access to agricultural water and its use
- 3 Manage agriculture to enhance ecosystem services
- 4 Increase the productivity of water
- 5 Upgrade rainfed systems—a little water can go a long way
- 6 Adapt yesterday's irrigation to tomorrow's needs
- 7 Reform the reform process—targeting state institutions
- 8 Deal with tradeoffs and make difficult choices

Three of those points are focusing specifically on rainfed agriculture:

- **1. Change the way we think about water and agriculture**. Thinking differently about water is essential for achieving our triple goal of ensuring food security, reducing poverty, and conserving ecosystems. Instead of a narrow focus on rivers and groundwater, view rain as the ultimate source of water that can be managed. Instead of blueprint designs, craft institutions while recognizing the politically contentious nature of the reform process. And instead of isolating agriculture as a production system, view it as an integrated multiple-use system and as an agro-ecosystem, providing services and interacting with other ecosystems.
- **4. Increase the productivity of water.** Gaining more yield and value from less water can reduce future demand for water, limiting environmental degradation and easing competition for water. A 35% increase in water productivity could reduce additional crop water consumption from 80% to 20%. More food can be produced per unit of water in all types of farming systems, with livestock systems deserving attention. But this optimism should be met with caution because in areas of high productivity only small gains are possible. Larger potential exists in getting more value per unit of water, especially through integrated systems and higher value production systems and through reductions in social and environmental costs. With careful targeting, the poor can benefit from water productivity gains in crop, fishery, livestock, and mixed systems.
- **5. Upgrade rainfed systems**. 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 improving the productivity of these systems.

The second comprehensive studies on water and rainfed agriculture are undertaken by the UNESCO World Water Assessment Programme (WWAP, 2009 and WWAP, 2006) where rainfed agriculture is seen as an important factor in the world food production. The key messages as described in the World Water Development Report (WWAP, 2006) are:

- To satisfy the growing demand for food between 2000 and 2030, production of food crops in developing countries is projected to increase by 67 percent.
- As competition for water increases among different sectors, irrigated agriculture needs to be carefully examined.

- Farmers are at the centre of any process of change and need to be encouraged and guided.
- Irrigation institutions must respond to the needs of farmers, ensuring more reliable delivery of water, increasing transparency in its management and balancing efficiency and equity in access to water.
- The agriculture sector faces a complex challenge: producing more food of better quality while using less water per unit of output.
- Action is needed now to adapt agricultural and rural development policies.

The key messages of the latest report WWDR-2009 are summarized as:

- Population growth and rapid economic development have led to accelerated freshwater withdrawals.
- Trends in access to domestic water supply indicate substantial improvement in the past decade.
- Steadily increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind water use.
- The recent acceleration in the production of biofuels and the impacts of climate change bring new challenges and add to the pressures on land and water resources.
- Freshwater ecosystems provide an extensive array of vital services to support human well-being.

This latest report of the WWAP included an interesting section on “How much do we know about water uses?” The report provides the following view on this:
“Our knowledge of water use is as poor as our knowledge of water resources – perhaps poorer. Information is largely incomplete – particularly for agriculture, the largest user – and is lacking altogether for some countries. Only limited disaggregated information exists, and even this shows deficiencies of validity and homogeneity and provides extremely poor information on trends. The quality of information systems varies with each country, but there are common difficulties:

- *Statistics on the magnitude of demand and withdrawal are often estimated rather than based on data that are measured or collected from censuses. The level of uncertainty varies, but is particularly high for agriculture.*
- *Sectors of use are not defined homogeneously and are not well disaggregated.*
- *Adequate historical datasets are rare, and the dates of available statistics are not always explicit.*
- *Lack of agreed terminology leads to discrepancies in data compilation and analyses”*

Besides these two all-encompassing studies in which rainfed agriculture is an important theme, a comprehensive study focusing on rainfed agriculture exclusively was published recently: Rainfed Agriculture: Unlocking the Potential (Wani, et al., 2009). The main reason to focus on rainfed agriculture only is justified by the authors since rainfed agriculture is practiced on 80% of the world’s agricultural area and generates 60–70% of the world’s staple food (FAOSTAT, 2005).

An important question asked by many researchers is whether rainfed agriculture can feed the current and future world population (Fraiture et al., 2009). This quite straight-forward question is so-far un-answered and varies amongst researchers between a clear “yes” to a probably “no”. An important aspect in this debate is the relative roles of irrigated and rainfed agriculture. A theoretical study focusing on water resources only, indicated that the current area under rainfed agriculture could be increased by a factor three, under the conditions that all land can be converted to agriculture (Droogers et al., 2001). 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. Bruinsma (2003) foresees that the contribution to global food supply from rainfed areas will decline from 65% today to 48% in 2030, offset by productivity improvements and irrigated area expansion.

However, 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 agriculture. 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 in rainfed agriculture have been very small, mainly targeted to soil conservation rather than water harvesting (Rockström et al., 2007; Wani et al., 2009). It is also suggested that particularly in sub-Saharan Africa, irrigation investments have been a mixed success and that therefore focus should be more investments in rainfed agriculture. A study by Inocencio et al. (2006) reports a success ratio of 50% for new irrigation projects in sub-Saharan Africa.

A SCOPUS search on the keyword “rainfed” in the title for the years 2008 and 2009 indicates relevant Journals (in brackets number of articles):

- Agricultural Water Management (19)
- Field Crops Research (15)
- Indian Journal of Agricultural Sciences (13)
- Agriculture Ecosystems and Environment (8)
- Agronomy Journal (6)
- Soil and Tillage Research (5)
- Agricultural and Forest Meteorology (5)
- Journal of Agricultural Science (4)
- Journal of Plant Registrations (4)
- Nutrient Cycling in Agroecosystems (4)
- Plant and Soil (4)
- Physics and Chemistry of the Earth (3)

The main research issues regarding rainfed agriculture can be divided into the following categories and will be discussed in the next sections:

- Global scale
- Local scale
- Yield gap
- CO_2 fertilizer

3.2 Global scale

Quite a substantial number of studies have been undertaken over the last two decades related to rainfed agriculture, food and water. In fact the first global assessment on global food supply and demand was published by Thomas Robert Malthus in 1798, who famously predicted that short-term gains in living standards would inevitably be undermined as human population growth outstripped food production. However, the more recent scenario studies at the global level indicate that the potential of rainfed agriculture is large enough to meet present and future food demand through increased productivity (Molden, 2007). An optimistic rainfed scenario assumes significant progress in upgrading rainfed systems while relying on minimal increases in irrigated production, by reaching 80% of the maximum obtainable yield. This leads to an average increase of yields from 2.7 metric tons per hectare in 2000 to 4.5 in 2050 (1% annual growth). With no expansion of irrigated area, the total cropped area would have to increase by only 7%, compared with 24% from 1961 to 2000, to keep pace with rising demand for agricultural commodities. The same study indicated also that focusing only on rainfed areas carries considerable risks. If adoption rates of improved technologies are low and rainfed yield improvements do not materialize, the expansion in rainfed cropped area required to meet rising food demand would be around 53% by 2050. Globally, the land for this is available, but agriculture would then encroach on marginally suitable lands and add to environmental degradation, with more natural ecosystems converted to agriculture (Molden, 2007).

There are only few global studies focus on rainfed agriculture. An interesting example of this was presented by Rockström and Barron (2007) where they analyzed the option to increase crop yields while at the same time maintain water consumption at a constant or lower rate. Focus on increasing the so-called Water Productivity was considered as a key factor. In their research the Millennium Development Goals as established at global scale level were linked to practical management options and additional research needs as local scale. They strongly recommended that further research is required on Water Productivity of rainfed agriculture.

Rost et al. (2009) presented, what they claim, one of the first studies focusing on a spatially explicit quantification of water limitations in global crop production and the potential of different water management strategies to upgrade crop growth, under both present and projected future climate conditions. The study indicated that even the most ambitious and large-scale water management efforts on present cropland will not be sufficient to guarantee the food demands of a growing world population. This result is quite in contrast with most other studies (Molden, 2007; WWDR, 2006; WWDR, 2009; Rosegrant et al., 2009). A nice overview of these global assessments studies was published in Science by Rosegrant and Cline (2003).

3.3 Local scale

Researches on rainfed agriculture on smaller scales are focusing often limited to field scale issues only and to specific crops. The intermediate scale, like basins or watershed, is by enlarge ignored. Typical examples can be obtained by a search in recent scientific literature (using SCOPUS), on the keyword “rainfed”. The following 10 titles of the most recent research papers are:

- Modelling the fate of nitrogen following pig slurry application on a tropical cropped acid soil on the island of Réunion (France)

- Response of lowland rice to agronomic management under different hydrological regimes in an inland valley of Ivory Coast
- Runoff water harvesting for dry spell mitigation for cowpea in the savannah belt of Nigeria
- Carbon losses by tillage under semi-arid Mediterranean rainfed agriculture (SW Spain)
- Role of temperature, moisture and Trichoderma species on the survival of Fusarium oxysporum ciceri in the rainfed areas of Pakistan
- Estimating the potential of rainfed agriculture in India: Prospects for water productivity improvements
- Nitrogen in Rainfed and Irrigated Cropping Systems in the Mediterranean Region
- Soil texture, climate and management effects on plant growth, grain yield and water use by rainfed maize-wheat cropping system: Field and simulation study
- Frequency of occurrence of various drought types and its impact on performance of photoperiod-sensitive and insensitive rice genotypes in rainfed lowland conditions in Cambodia
- Influence of conservation tillage on soil physicochemical properties in a tropical rainfed agricultural system of northeast India

Regarding the regional and local focus it is clear that most research on rainfed agriculture is focused on arid and semi-arid areas, while ignoring by enlarge the humid regions. However, there is a growing notice that water shortage is an important topic in humid regions as well. The 2003 Europe Heat Wave for example resulted in a fodder deficit varied from 30% (Germany, Austria and Spain) to 40% (Italy) and 60% in France and the fall in cereal production in EU reached more than 23 million tonnes (MT) as compared to 2002 (UNEP, 2003). Agricultural losses were estimated at 5 billion Euros across the then 15-member EU (http://www.euronews.net).

3.4 Yield gap

An important issue in research in rainfed agriculture is the so-called yield-gap (Molden, 2007; Fermont et al., 2009; Aggarwal et al., 2008). Yield gap is in general defined as “the difference of actual yield and yield obtained under optimum management practices”. However, some researchers take a somewhat more restricted eco-system oriented definition as “yields determined by the land-based natural resources” (Bindraban, 2000). The latter one assumes that no additional fertilizer or irrigation will be applied. The first definition is more accepted and will be used here.

Yield gap studies can be divided into two categories. The first category takes the actual obtained maximum yields on well-managed fields in a region as the basis. These fields are often experimental fields or farmer fields who manage to obtain highest yields in a region (Kalra et al., 2007; Fermont, 2009). Another approach is to assess the maximum yields in a particular region for a particular crop using simulation models (Bhatia et al., 2008; Abeledo et al., 2008).

Most of the studies conclude that closing, or reducing, this yield gap might be the best option to ensure food security for a growing population under water limited conditions. Although most of the yield gap studies are very local, FAO (1996) analyzed the yield gap at a global scale (Figure 6). This study is quite outdated and it is necessary to renew the analysis taking into account more recent data sets, analysis and tools.

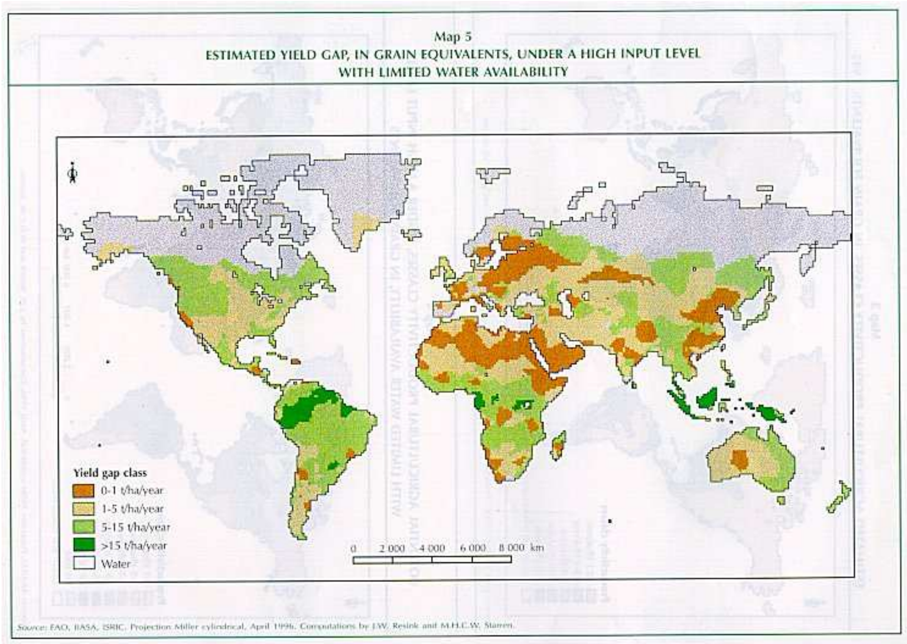

Figure 6. Global yield gap estimates (FAO, 1996)

3.5 CO_2 fertilization

An important aspect in the potential of rainfed (and irrigated) agriculture is the impact of enhanced CO_2 levels on plant growth and water consumption. An interesting review, although somewhat outdated, of this CO_2 fertilization is presented by Bazzaz and Sombroek (1996). They mention that the rise in atmospheric carbon dioxide (CO_2) concentration from about 280 ppm before the industrial revolution to about 360 ppm currently is well documented (e.g., Baker and Enoch, 1983; Keeling et al., 1995). The consensus of many studies of the effects of elevated CO_2 on plants is that the CO_2 fertilization effect is real (see Kimball, 1983; Allen, 1990; Rozema et al., 1993). However, the CO_2 fertilization effect may not be manifested under conditions where some other growth factor is severely limiting, such as low temperature (Long, 1991).

Interesting is that a recent study from the International Food Policy Research Institute (Nelson et al., 2009). In their executive summary it was stated that *"Calorie availability in 2050 will not only be lower than in the no–climate-change scenario—it will actually decline relative to 2000 levels throughout the developing world"*. However, this conclusion is based on changes in rainfall and temperature only, ignoring the effect of CO_2 fertilization. This is interesting as it is well agreed that changes in CO_2 levels are considered as the most certain compared to other changes. The study results indicated that if CO_2 fertilization will be included in the analysis daily per capita calorie availability will increase in developing countries by 5.7%

On crop scale a substantial number of researches have been undertaken to analyze the impact of CO_2 fertilization on yields (http://www.co2science.org/). A typical example based on 222 published papers is presented in Figure 7 for one particular crop. There is however a huge knowledge gap as what the impact might be on crop water consumption. Atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption and hence slower soil moisture depletion, or the combination of both. Morgan et al. (2004) concluded, based on a substantial number of research, that the central question is as to what degree CO_2 enrichment experiments produce direct CO_2 (photosynthesis-driven) responses vs. indirect, water-driven responses, The latter ones being tightly coupled to climatic co-variables like temperature and humidity.

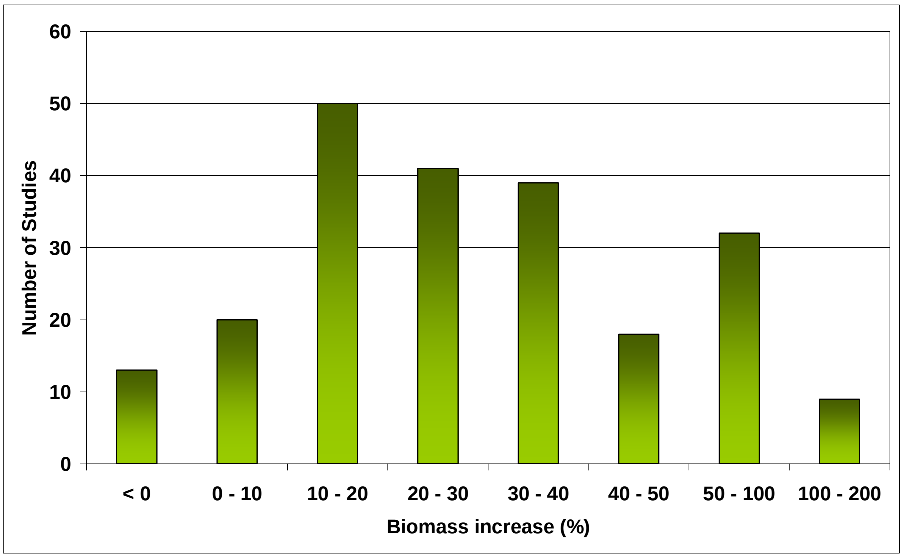

Figure 7. Percent biomass increases for 300 ppm increases in CO_2 concentration for wheat, based on 222 publications. (Source: http://www.co2science.org)

3.6 Research Issues

Based on the previous sections the most important research issues regarding Water and Rainfed Agriculture are summarized here

3.6.1 Global opportunities rainfed agriculture

There is still a scientific debate on the potential of rainfed agriculture to feed the world in the future. Some research suggests that this potential is sufficient to feed the expected 9 billion world population while other studies indicate severe food shortages. These differences are often a reflection of different assumptions, often in terms of limiting factors in rainfed production, in the analysis. Research is therefore needed with a clear focus and appropriate definitions on these limitations. Analysis should therefore start with the full potential of rainfed agriculture, assuming no limitations at all. Stepwise, limitations would be added on this potential such as: water, land, investments, farmer knowledge, climate change etc.

3.6.2 Local scale

Research issues on water and rainfed agriculture are so-far mainly oriented towards arid and semi-arid areas with a focus on rainwater harvesting. There is a clear need for studies that will include the following four integrated components: (i) humid areas, (ii) expand the very local focus to more generic conclusions, (iii) impact of rainwater harvesting on downstream water users, and (iv)water productivity.

3.6.3 Yield gap

Closing the yield gap is seen as an important aspect to increase food production and reduce water consumption by crops. Two promising and unexplored research themes can be identified. First, yield gap research is in many cases very local, crop specific and more descriptive. There is a clear need to upgrade yield gap studies at a higher conceptual level based on fundamental deductive analyses. A second research need is yield gap analyses at larger scale levels (regions) with a strong emphasis on water issues including impact on other water users in the region.

3.6.4 CO_2 fertilization

It is clear that atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption or (3) the combination of both. Studies are very much needed that will provide an answer on the contribution of CO_2 fertilization on water consumption of crops.

4 Irrigated Agriculture

[To be included: Nick van der Giesen]

4.1 Area under irrigation

Irrigated agriculture is on a global scale responsible for somewhere between 30 and 45% of the total food production (Molden et al., 2007). The exact figure is unknown as this depends by enlarge on the definition of irrigated. A commonly used definition is “Area equipped for irrigation” (FAO-AQUASTAT), which can be substantially different from reality. Moreover, there seems to be a tendency, especially in the developed world, as a result of the negative image of irrigation, to frequently use terms like rainfall harvesting and supplemental irrigation rather than irrigation. This is clearly illustrated through the following definitions from Oweis et al. 1999:

- “Water harvesting (WH) is defined as the process of concentrating rainfall as runoff from a larger area for use in a smaller target area.”
- “Supplemental irrigation (SI) is defined as the application of a limited amount of water to the crop when rainfall fails to provide sufficient water for plant growth to increase and stabilize yields.”

Without any doubt, these two descriptions would have been defined as “full irrigation” a decade ago. Another example of this problem with definitions is that according to FAO statistics the percentage of agricultural land under irrigation[1] in the Netherlands is 37 percent, while this figure for Germany is 4% and for Belgium 2% (FAO-Aquastat, Country factsheets). The likely cause is that some limited sprinkling of fields during dry summers is possibly counted as irrigation in the Netherlands and not in Germany and Belgium.

Cai et al. (2007) made a strong case that separating irrigated and rainfed agricultural data is required in order to calculate economic performance of irrigated/rainfed agriculture and irrigation water consumption from irrigated lands. They have developed and tested a method to separate harvested area and yield for irrigated crops from rainfed crops in a region, given gross harvested area and yield, and climatic, agronomic and economic data for crops. The method is based on the principle of general maximum entropy, which combines incomplete data, empirical knowledge and a priori information to derive desired information.

The first shortcoming is that estimates are based on official figures, rather than actual areas. Deviations in the official statistics can differ from the real irrigated areas due to several reasons. It is very common that only water users who pay for their water are registered as irrigators. A study in Turkey revealed for example that the officially reported irrigated areas were only 58% of the actual irrigated areas on a basin scale, while at irrigation system level figures range from 50% to 86% (GDRS/IWMI, 2000). The main reason for this was that farmers not paying for water, such as those using groundwater and ‘illegal’ extractions, were ignored in the statistics. Recently, Bastiaanssen et al. (2001) showed that for Pakistan the difference between official irrigated areas and actual irrigated areas could be more than 100% at canal command area level.

A second problem is the definition of irrigation.

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[1] Official definition is “total area equipped for irrigation as percentage of cultivated area”

A third aspect, related to the definition problem, is the time period for which fields are actually irrigated. From a water resources point of view it is essential to know the period when fields are really irrigated. However, most figures present this as simply “irrigated”—with no reference to time.

5 Water and Fishery

[To be included: Nick van der Giesen]

6 Water and Livestock

6.1 Background

The term livestock refers to “animals kept or raised for use or pleasure; especially**:** farm animals kept for use and profit” (Webster dictionary). In this report only the restricted use of the term livestock “farm animals kept for use and profit” will be discussed.

Livestock have always made a major contribution to the welfare of human societies by providing food, shelter, fuel, fertilizer and other products and services. They are a renewable resource, and utilize another renewable resource, plants, to produce these products and services. In addition, the manure produced by the animals helps improve soil fertility and, thus, aids the plants. In some regions the manure is not utilized as a fertilizer but is dried as a source of fuel.

Food is, by far, the most important contribution of agricultural animal, although they rank well behind plants in total quantity of food supplied. Plants supply over 80 percent of the total calories consumed in the world. Animals are a more important source of protein than they are of calories, supplying one-third of the protein consumed in the world. Meat, milk and fish are about equal sources of animal protein, supplying, respectively, 35%, 34% and 27% of the world supply of total protein (OSU, 2009).

Although livestock are less important in terms of calorie provider, in terms of impact on land livestock play a dominant role. According to FAOstat (2009), almost 70% of the agricultural lands are in use as permanent meadows and pastures (Table 1). This figure various substantial between countries and continents, ranging from 38% for Europe to 79% for Africa (Figure 8).

Given this dominancy of livestock in terms of land use, livestock is definitely an important factor related to water. A very good introduction on water and livestock for human development is given by Peden et al., (2007), with a strong focus on the developing world.

The link of water and livestock is in many researches considered as the actual amount of water drunk by animals. These so-called direct water requirements of livestock vary substantially between different animals. Typical numbers are 2 to 10 liter per day per sheep, 25 to 100 liters per day per cow, and 40 to 50 liter per day per horse (Markwick 2002). Moreover, livestock in general cannot withstand long periods without water with the exception of camels. The camel has a legendary reputation to withstand relatively long periods of water deprivation under hot conditions even up to 17 days (Fillali & Shaw 2004). In water resources projects in Africa the notion of including livestock drinking water requirements is often ignored in project leading to potential or actual conflicts over water in rural communities (Gleitsmann et al. 2007).

A very rough first estimate of this direct water consumption can be made by multiplying the estimated water requirements by the total number of stock (Table 2). The figures show that this amount is approximately 100 MCM per day on a global scale. Compared to global human drinking water needs of 12 MCM per day (assuming 2 l/p/d), the drinking water requirement of livestock at global scale is relatively high. However, total urban water requirements, including sanitation needs, are about 600 MCM per day (assuming 100 l/p/d) and are thus substantially higher than drinking water needs for livestock. However, quite some of these total urban water requirements are drained and can be reused.

Besides these global figures, the regional distribution of livestock drinking water requirements and regional water availability can be far out of balance. Especially if the temporal timescale will be added on top of this, drinking water for livestock can be very problematic. Studies on the relationships between number of livestock and water availability show always, not very surprisingly, a strong correlation (e.g. Bergstrom and Skarpe, 1999).

An important aspect of livestock and water requirements is that in many farming systems animals are vital parts for survival. The predominant farming system in most semi-arid watersheds in Asia and Africa is the ‘mixed crop-livestock farming system’ under rainfed conditions (Puskur et al. 2004). Especially in the more water stressed regions, the competition of human and animal for drinking water can be severe and might result in killing part of the livestock of a household. A typical example was given by (Sen & Chander 2003) for Rajasthan, India, for the drought in 2002. In three years time villages had just one-fifth of the livestock they had three years ago, and the price of buffaloes had come down from INR 15,000 (approximately US$320) to only INR 800 (approximately US$17).

The real issue in livestock water requirements is actually the production of fodder required to feed animals. This is comparable to humans where the drinking water requirements only are limited to a few liters a day and the water required to produce food is in the order of 3000 to 5000 liters per person per day. However, it is impossible to find accurate data on these total water requirements of livestock. Much popular and environmental literature considers livestock production to be among the greatest threats to sustainable water use over the coming decades (Peden et al., 2007). The large volumes of water necessary to produce human food from livestock are the major concern. For example, the Times of India (2004) reported that one liter of milk requires 3,000 liters of water, and attributes to rapid declines in groundwater levels. Goodland and Pimental (2000) and Nierenberg (2005) state that producing 1 kilogram (kg) of grainfed beef requires about 100,000 liters of water, while producing 1 kg of potatoes takes only 500 liters. However, SIWI and others (2005) estimate that grainfed beef uses only 15,000 liters of water. Thus, while there is little agreement on the precise amount of water needed for grainfed beef production, the literature does agree that it takes much more water to produce 1 kg of grainfed beef than 1 kg of crops (Chapagain and Hoekstra 2003; Hoekstra and Hung 2003).

A different view is presented by some lobbyist. For example, the website “www.BeefFrom PastureToPlate.org” claims that meat production is not wasteful to water:
“The activist myth goes something like this: meat production uses outrageous amounts of water, feed and land that should be used for something else. The truth is it takes 2.6 pounds (~ 1.2 kg) of grain and 435 gallons (~ 1600 liters) of water to produce a pound (~0.45 kg) of beef in the United States. The reality is that 85 percent of the nation’s grazing lands are not suitable for farming. It is important that we use land that is too rough, too high, too dry, too wet and largely inaccessible to graze livestock to produce food for the world’s population. Cattle eat forages that humans cannot consume and convert them into a nutrient-dense food.”

Interesting is that most global water studies ignore the amount of water required to produce fodder (Zimmer and Renault 2003). In some cases it is specifically mentioned that this water consumption is not included (Zimmer and Renault, 2003), while in most cases it is just ignored at all. There are three reasons for this: (i) ignorance, (ii) difficulty to quantify this value, and (iii) the usefulness of this number. In the context of virtual water, and thus the potential implication of using fodder-water to fulfill other demands, there are conceptual problems. The potential water savings imbedded in imported food will only materialize locally, if the decrease in food production frees up local water resources that can be made available for other uses. This is however not always the case. Some water used for crops and food products cannot be substituted with another use of water, as for instance in the case of cattle which feed on natural rainfed pasture. Livestock in many relative dry regions are taking advantage of a huge territory where little rain can still produce food or fodder, but would otherwise be lost for production. Any attempt to reduce water consumption will not be relevant as the water could never be used for another purpose nor is any other production possible given the limited rains (Renault, 2002).

Water and livestock research in the developing world is often related to water quality and especially to groundwater pollution by nutrients, with a focus on nitrogen. In the European context various resolutions are important including (EC, 2009):

- Nitrates Report - COM(2007)120
- Annexes to the Nitrates Report - SEC(2007)339
- Directive 91/676/EEC on nitrates from agricultural sources
- Report COM(2002)407
- Eutrophication and health

The European Community has been taking measures concerned with nitrogen pollution in waters for over twenty years. Whilst the initial directives concerned themselves mainly with water for human consumption, more recent directives, such as those on nitrates from agricultural sources and urban waste water treatment have placed increased emphasis on the environmental effects of excess nitrogen, in particular eutrophication. These recent directives are currently in the process of implementation.

Water and livestock is also related to the EU Common Agricultural Policy and the wish to integrate environmental concerns as well. The relationship between agriculture and the environment is not static. Agriculture has intensified and intensification in turn has increased pressure on the environment. The European Commission is particular interested in developing a system under the overall term of "sustainable agriculture". This calls for management of natural resources in a way which ensures that their benefits are also available for the future. The agriculture sector performs its tasks with a view to the protection, preservation and improvement in the quality of water, air and soil, in the abundance of bio-diversity and in preservation and enrichment of the EU's landscape.

There is however a big debate within Europe on how to implement these policies and what the scientific base is (Sonneveld and Bouma, 2003). Especially the national implementation of these directives and the spatial diversification on these regulations is an unexplored area (Bouma and Droogers, 2007).

It is clear that European policies are an important driver to science directions and funding. Total FP7 funding is 51 Billion Euros over 7 year, of which Food, Agriculture and Fisheries, and Environment receive about 12%.

6.2 Research Issues

Based on the previous section the most important research issues regarding Water and Livestock are summarized here:

6.2.1 *Livestock and water productivity*

The concept of water productivity has gained quite some attention over the last years, but is still largely unexplored in the context of livestock. This livestock water productivity does include all water use so direct drinking as well as water required to produce feed. Obviously, this item is mainly relevant in areas where water is scarce. The following research activities are relevant:

- Global scale assessment of livestock water productivity with strong emphasis on spatial and temporal resolution.
- Assessment of the possibility of alternative use of livestock water consumption in semi-arid regions

6.2.2 *Livestock and water quality*

Especially in the developed world livestock is seen as an important polluter of water. Policies are defined and strict regulations are being implemented. However there is a debate whether these regulations take into account local specific conditions. Based on this chapter the following two research areas are relevant in the broad context of livestock and water quality:

- Impact of livestock on water quality is a completely unexplored area in the developing world. Research might identify potential problems which might lead to policies before severe damage will take place.
- Regional distributed research on the impact of livestock on water quality.

Table 1. Distribution of land between arable and pastures (FAOstat, 2009).

	Total land million ha	Agriculture % of total land	Arable	Permanent crops	Permanent pastures
			===== % of agricultural lands ====		
Africa	2964	39	19	2	79
Northern America	1867	26	45	2	53
Central America	245	52	24	4	72
South America	1760	33	19	2	78
Asia	3094	54	30	4	66
Europe	2207	21	59	3	38
Australia and New Zealand	795	55	10	0	90
World	**12932**	**38**	**29**	**3**	**69**

Table 2. Number of animals on a world scale (FAOstat, 2009) and estimated drinking requirements.

Animals	Stocks (millions)	Drinking (l/d/stock)	Total (million m3 / day)
Chickens	17863	0.2	4
Cattle	1357	50.0	68
Ducks	1096	1.0	1
Sheep	1087	5.0	5
Pigs	918	5.0	5
Goats	830	5.0	4
Turkeys	473	1.0	0
Geese and guinea fowls	343	1.0	0
Buffaloes	177	50.0	9

Beehives	64	0.0	0
Horses	59	40.0	2
Asses	42	10.0	0
Camels	24	10.0	0
Other Rodents	17	10.0	0
Mules	12	10.0	0
Other Camelids	7	10.0	0
Animals Live Nes	6	0.0	0

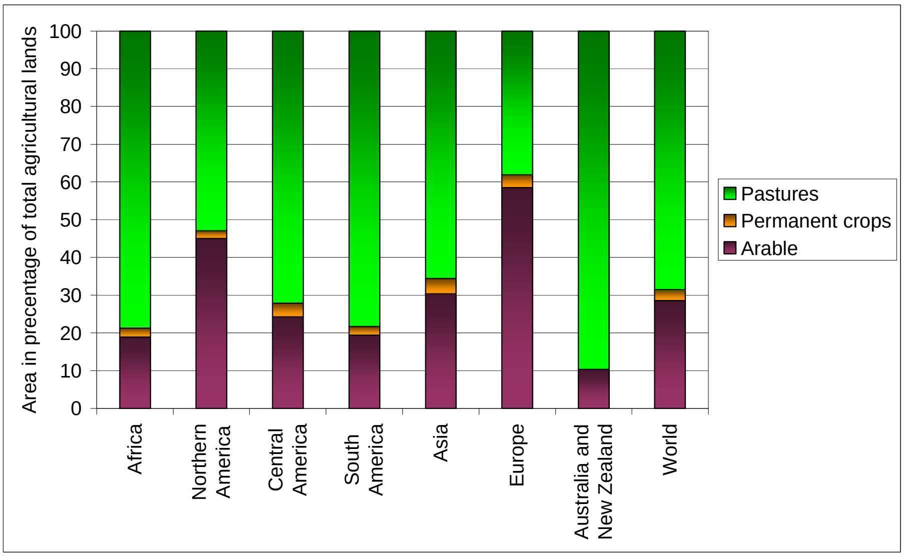

Figure 8. Land under pasture, permanent crops and arable expressed as percentage of total agricultural lands.

7 Synoptic overview of research issues

1. Trends in food demand

Food production will have to increase by 1-2% per year for the next generation in order to keep up with food demand. Increase in food demand is caused by a combination of population growth and changes in consumption patterns, especially an increase in animal-based protein in our diets (Liu & Savenije, 2008). The production of biofuels may, until the advent of so-called third generation biofuels, put extra stress on grain and sugar production. The spike in food prices in 2008 (see Figure 9) has dampened but food prices are still 70% higher than they were five years ago. It has been known for a long time that the supply elasticity of food is low. World trade without dramatic productivity rises can, therefore, only be a limited solution.

There are many direct links between food production and water. In this report, we distinguish four areas:

1. Rainfed agriculture
2. Irrigated agriculture
3. Fresh water and fishery
4. Water and livestock

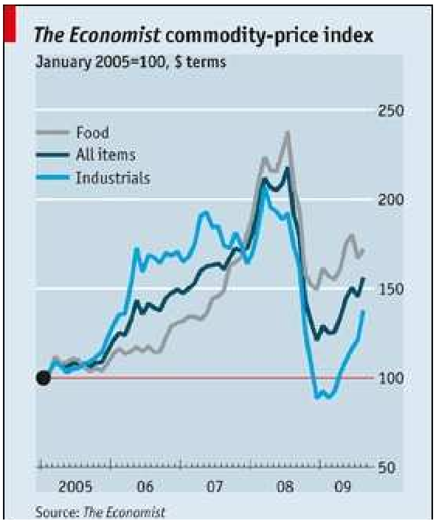

Figure 9. Commodity price development.

Research issue 1.1

Global analysis of food production and its dependency on water

Various global assessment studies using an integrated approach to water and food exist. The approaches followed by these global studies can be divided into two groups. One the one hand exist studies that have a strong embedding in the economic science where physical (hydrological) processes are to a large extent ignored. In these studies water-food issues are represented by simplified parametric equations and the main driving forces are considered to be the economic ones. These economics are often driven by food demand and food supply.

One common weakness is the focus on average conditions. There are hardly any global studies that include the natural year-to-year variation in the analysis, while it is expected that the impact of climate change will alter not only the mean but will have a significant increase on extremes. There is need for a global model that maps future food productivity with sufficient realistic detail. The dependence on water for each production type needs to be analyzed.

Research issue 1.2

Role of trade and virtual water

Richer countries have not been self-sufficient in their food supply for a very long time. Especially the poor in the world have suffered from recent food price increases. The possibility for densely populated poor countries to increase their food production is not a given. The question then becomes where the extra food needed can be grown and if trade can ensure delivery to those who need it most. The water needed to produce these commodities is called "virtual water" and many studies have been undertaken that map the virtual water content of goods and map global flows (Hoekstra & Chapagain, 2008). A global optimization of food production from a water perspective would be an important next step towards good water governance.

2 Rainfed agriculture

The most important research issues regarding Water and Rainfed Agriculture based on the evaluations as described in Chapter 3 are:

Research issue 2.1

Global opportunities rainfed agriculture

There is still a scientific debate on the potential of rainfed agriculture to feed the world in the future. Some research suggests that this potential is sufficient to feed the expected 9 billion world population while other studies indicate severe food shortages. These differences are often a reflection of different assumptions, often in terms of limiting factors in rainfed production, in the analysis. Research is therefore needed with a clear focus and appropriate definitions on these limitations. Analysis should therefore start with the full potential of rainfed agriculture, assuming no limitations at all. Stepwise, limitations would be added on this potential such as: water, land, investments, farmer knowledge, climate change etc.

Research issue 2.2

Local scale

Research issues on water and rainfed agriculture are so-far mainly oriented towards arid and semi-arid areas with a focus on rainwater harvesting. There is a clear need for studies that will include the following four integrated components: (i) humid areas, (ii) expand the very local focus to more generic conclusions, (iii) impact of rainwater harvesting on downstream water users, and (iv)water productivity.

Research issue 2.3

Yield gap

Closing the yield gap is seen as an important aspect to increase food production and reduce water consumption by crops. Two promising and unexplored research themes can be identified. First, yield gap research is in many cases very local, crop specific and more descriptive. There is a clear need to upgrade yield gap studies at a higher conceptual level based on fundamental deductive analyses. A second research need is yield gap analyses at larger scale levels (regions) with a strong emphasis on water issues including impact on other water users in the region.

Research issue 2.4

CO_2 fertilization

It is clear that atmospheric CO_2 enrichment may stimulate plant growth directly through (1) enhanced photosynthesis or indirectly, through (2) reduced plant water consumption or (3) the combination of both. Studies are very much needed that will provide an answer on the contribution of CO_2 fertilization on water consumption of crops.

3 Irrigated agriculture

Increased food production can potentially be achieved by different routes but the role that irrigation needs to play is important to understand. Based on the evaluations described in Chapter 4, the following research issues can be identified.

Research issue 3.1

Global opportunities irrigated agriculture

The 2008 spike in food prices coincided with the end of a period of approximately twenty years during which there was almost no growth in irrigated area. This increase in food process has prompted the World Bank to resume investments in irrigation development. It is probably unlikely that the needed increase in food production can be achieved without significant increases in irrigated agriculture. An obvious and important question then becomes where in the world such development can and/or should take place.

Less densely populated areas (Americas, sub-Saharan Africa, Central Asia) would seem to be the most obvious candidates but each region has important drawbacks. In North America, irrigated agriculture seems to have peaked and further expansion there is unlikely due to declining groundwater tables (Ogallala aquifer) and environmental flow requirements. Expansion of (irrigated) agriculture in South America may come at the cost of important losses in bio-diversity rich ecosystems. Central Asia has seen a decline in irrigation development since the breaking up of the Soviet Union and does not have a good environmental track record either. Africa, and especially the savanna zones, may be the most promising from a physical point of view but earlier attempts have stranded in issues of poor governance and low returns on investments. A quantitative analysis of potential irrigation development and associated drawbacks would be a first step towards a better understanding of the food and water issue.

Research issue 3.2

Stressors on irrigated agriculture

Throughout the world, we see examples of a decline in irrigated areas due to unsustainable practices within, and external pressures from without irrigated agriculture. Depletion of groundwater is perhaps the most urgent stressor. Both the Indo-Gangetic and North China plains show water tables declining at alarming rates. Large scale trans-basin water transfers are seen as possible solutions but it is doubtful such measures can be much more than partial fixes. Decline in water and soil quality through accumulation of salts and agro-chemicals is a second important stressor. Thirdly, in many densely populated areas in the world, such as the rice growing areas of Asia, irrigated agriculture declines due to urban expansion. Finally, the competition for water from other sectors increases further, not only due to urban and industrial development, but also because of the higher value put on environmental water uses. The West of the United States is a clear example. The gravity of all different stressors and their development over time and space would be an important research theme.

Research issue 3.3

New technologies for irrigated agriculture

Irrigation is about as old as sedentary agriculture and no miracle technologies are to be expected. Still, the efficiency of irrigated agriculture can be greatly enhanced by supporting technologies. Genetically Manipulated Organisms may be helpful to reduce water demands but early results for GMO maize have been somewhat disappointing, showing only relatively small increases in production under water stressed growing conditions. In arid areas, water re-use will continue to increase but research on better water and soil treatment methods remains needed. Precision agriculture, from plant to parcel scale, will increase water productivity and reduce environmental stress through better control on accumulation of agro-chemical and salt. Remote sensing and ubiquitous sensing will be important technologies to improve irrigation efficiencies.

4 Fresh water and fishery

Research issue 4.1

Value of fresh water fisheries, especially in developing countries

The value of fresh water fish has for a long time been neglected. For most inhabitants of developing countries, however, fish is the main source of animal protein. An early example that showed the importance of fisheries was provided by Ringler (2001) for the Mekong River. All alternative water uses in the Mekong, including hydropower, had lower economic returns than the present fisheries. The global importance of fresh water fisheries, and their effects on diets of people in developing countries, is not yet clear. Over the past decades, many developing projects have tried to improve fish production. Scientific analysis at regional to global scales, including yield gaps, is still needed.

5 Water and livestock

The most important research issues regarding Water and Livestock as emerging from the analysis in Chapter 6 are:

Research issue 5.1

Livestock and water productivity

The concept of water productivity has gained quite some attention over the last years, but is still largely unexplored in the context of livestock. This livestock water productivity does include all water use so direct drinking as well as water required to produce feed. Obviously, this item is mainly relevant in areas where water is scarce. The following research activities are relevant:

- Global scale assessment of livestock water productivity with strong emphasis on spatial and temporal resolution.
- Assessment of the possibility of alternative use of livestock water consumption in semi-arid regions

Research issue 5.2

Livestock and water quality

Especially in the developed world livestock is seen as an important polluter of water. Policies are defined and strict regulations are being implemented. However there is a debate whether these regulations take into account local specific conditions. Based on this chapter the following two research areas are relevant in the broad context of livestock and water quality:

- Impact of livestock on water quality is a completely unexplored area in the developing world. Research might identify potential problems which might lead to policies before severe damage will take place.
- Spatially distributed research on the impact of livestock on water quality.

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