Water Resources, Agriculture and Pasture: Implications of Growing Demand and Increasing Scarcity

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Water resources, agriculture and pasture: implications of growing demand and increasing scarcity

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Key points

1. Water availability for irrigation is threatened in many regions by rapidly increasing demand for nonagricultural water uses in industry, households, and the environment. The scarcity of irrigation water will not only impact crop production, but also meat production, as much of the pasture used to feed livestock is irrigated.
2. Grassland is caught between two countervailing forces: a requirement for increasing meat demand that boosts the need for additional pasture to support livestock production, and rapidly increasing water scarcity that makes pasture irrigation uneconomical.
3. The most effective means of dealing with water scarcity is likely to be conserving water in existing water uses. Improvements in the irrigation sector to increase water use efficiency must be made at the technical, managerial, and institutional levels.
4. Innovative water pricing policies that increase the prices for domestic and industrial water while preserving incomes for farmers and the rural poor will encourage water-saving innovation.

Keywords: irrigation, rainfed, policy

Introduction

The world's farmers will likely need to produce enough food to feed 8 billion people by 2025, and to do so they must have enough water to raise their crops, including pasture to feed animals for human consumption. Yet farmers are already competing with industry, domestic water users, and the environment for access to the world's finite supply of water. Irrigation, which consumes far more water than any other use, has generated enormous benefits. By helping raise farmers' yields and stabilize food production and prices, irrigation has been a key to achieving food security in many parts of the world. About 250 million hectares are irrigated worldwide today, nearly five times more than at the beginning of the 20th century. Yet inappropriate water and agricultural policies and poor irrigation management have also lowered groundwater tables, damaged soils, and reduced water quality. Moreover, growing populations with rising incomes will further increase the demand for irrigation water to meet food needs.

Other users also have important claims on water. Although the domestic and industrial sectors use far less water than agriculture, water consumption in these sectors is growing rapidly. Access to safe drinking water and sanitation is critical for health - particularly children, and the importance of reserving water for environmental purposes has only recently been recognized: during the 20th century, more than half of the world's wetlands were lost. Even as demand for water increases, groundwater is being depleted and other water ecosystems are becoming polluted and degraded, developing new sources of water is getting more costly. Will available freshwater meet the rapidly growing demands for household, industrial, and environmental needs, and still provide enough water to produce food and feed crops and sustain pasture development to produce meat for a burgeoning population? What will be the impact of these trends on water for grasslands and pasture? Given the multiple uses of water, what policy recommendations can be implemented in order to attain sustainable management of water resources in relation to its multi-faceted use globally and regionally?

This paper takes three complementary approaches to look at the relationships between water scarcity and pasture. First, an integrated global water and food modelling framework, IMPACT-WATER is applied to simulate the complex relationships among water availability and demand, food supply and demand, international food prices, and trade under three different future scenarios. Next, a set of 'soft-linked' global models used in the Millennium Ecosystem Assessment is employed to examine future changes in land use and ecosystem services to 2050. Finally, a synthesis of empirical evidence on the impact of water scarcity and increasing value of water on irrigation and water allocation is presented, to examine the impact of increasing water scarcity on irrigated pasture, and assess the implications of land use pressure and water scarcity on pasture production systems.

Analytical approach

No single model incorporates the range of interactions across crops, livestock, pasture, and water that are needed to fully address these questions. Insights are gained through three approaches: (1) a global model of water and food supply - IMPACT-WATER, that combines an extension of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) with a Water Simulation Model (WSM) to simultaneously assess food supply and demand, and water supply and demand to 2025 (Rosegrant *et al*., 2002); (2) a set of 'soft-linked' global models used in the Millennium Ecosystem Assessment to examine future changes in land use and ecosystem services to 2050. These models include IMAGE (Integrated Model to Assess the Global Environment), which has been developed to study climate change and global change issues; AIM (Asia-Pacific Integrated Model), which has a similar focus; IMPACT, which has been developed to analyse the world food situation; and WaterGAP, which examines global water supply and demand; and (3) synthesis of empirical evidence on the impact of water scarcity and increasing value of water on irrigation and water allocation.

Current uses of water

Globally, agriculture accounts for about 69% of water withdrawals - mostly for irrigation, followed by industry and energy at 23%, and domestic consumption for household, drinking water and sanitation at 8% (UN, 2003; Rosegrant *et al*., 2002; Gardner-Outlaw & Engelman, 1997). Regionally, water utilisation varies enormously. Agricultural regions such as Africa use up 88% of all water withdrawn for agriculture, domestic use accounts for 7% and industry accounts for only 5%. In contrast, in Europe, water for industry accounts for 54% of withdrawals, while agriculture's share is only 33% and domestic use is 13% (UN, 2003). In agriculture, irrigation is applied not only to crops but also to pastureland, particularly in major livestock-producing countries like US, Brazil, France, China, Australia, UK and Germany. Pastureland and crop areas take up around 37% of the earth's land area (UN, 2003) and hence compete for water withdrawal with other non-agricultural sectors.

Alternative futures for water and food

Alternative global scenarios are developed to examine how future water policies and investments will affect water use for all sectors, and water availability and food production, including business-as-usual, water crisis, and sustainable water use scenarios. IMPACT-WATER is utilised to assess these alternative futures. This model combines an extension of the IMPACT with WSM. IMPACT is a partial equilibrium model of the agricultural sector. Demand is a function of prices, income, and population growth. Growth in crop production in each country is determined by crop and input prices and the rate of productivity growth. World agricultural commodity prices are determined annually at levels that clear international markets. IMPACT generates projections for crop area; yield; production; demand for food, feed, and other uses; prices; and trade. For livestock, IMPACT projects numbers, yield, production, demand, prices, and trade. The WSM is a basin-scale model of water resource use.

The IMPACT-WATER linkage was made possible by (1) incorporating water in the crop area and yield functions of IMPACT; and (2) simultaneously determining water availability at the river basin scale, and water demand from irrigation and other uses in the WSM. IMPACT-WATER divides the world into 69 spatial units, including macro river basins in China, India, and the United States and aggregated basins for other countries and regions. Domestic and industrial water demands are estimated as a function of population, income, and water prices. Water demand in agriculture is projected - based on irrigation and livestock production growth, water prices, climate, and water use efficiency for irrigation at the basin level. Water demand is then incorporated as a variable in the crop yield and area functions for each of eight major food crops: *Triticum* spp. (wheat), *Oryza sativa* (rice), *Zea mays* (maize), other coarse grains, *Glycine* spp. (soybeans), *Solanum tuberosum* (potatoes), *Dioscorea* spp. (yams) and *Ipomea batatus* (sweet potatoes), and *Manihot esculenta* (cassava) and other roots and tubers. Water requirements for all other crops are estimated in an aggregated form.

Water availability is a stochastic variable with observable probability distributions. WSM simulates water availability for crops at the river basin scale, taking into account precipitation and runoff, water use efficiency, flow regulation through reservoir and groundwater storage, non-agricultural water demand, water supply infrastructure and withdrawal capacity, and environmental requirements at the river basin, country, and regional levels. Environmental impacts can be explored through scenario analysis of committed instream (such as recreation, hydropower generation and navigation) and environmental flows, salt leaching requirements for soil salinity control, and alternative rates of groundwater pumping. Rosegrant *et al.* (2002) provides detailed methodology for IMPACT-WATER.

The primary drivers used in the model as the building blocks of the three scenarios are:

- *Economic and demographic drivers* - population growth, rate of urbanisation, and rate of growth in GDP (gross domestic product) and GDP per capita; projected outcomes on economic and demographic drivers are held constant across scenarios;
- *Climate and hydrological parameters* - precipitation, evapotranspiration, runoff, and groundwater discharge; held constant across three scenarios;
- *Technological, management and infrastructural drivers* - river basin efficiency, reservoir storage, water withdrawal capacity, potential physical irrigated area, and crop and animal yield growth;
- *Policy drivers* - water prices, water allocation priorities among sectors, committed water flows for environmental purposes, interbasin water shares, and commodity price policy as defined by taxes and subsidies on commodities.

Based on the analysis, three scenarios were illustrated: 1) BAU (business-as-usual); 2) water crisis (pessimistic); and 3) sustainable water use (optimistic). These three scenarios are further described below.

Business-as-usual

In the first scenario (business as usual) - current trends in water and food policy, management, and investment persist. International donors and national governments continue to reduce their investments in agriculture and irrigation. Governments and water users reform institutions and management in a limited and piecemeal fashion. The demand for water for non-irrigation purposes - household, industry, and livestock - will double in developing counties and increase by two-thirds in the world as a whole (Figure 1).

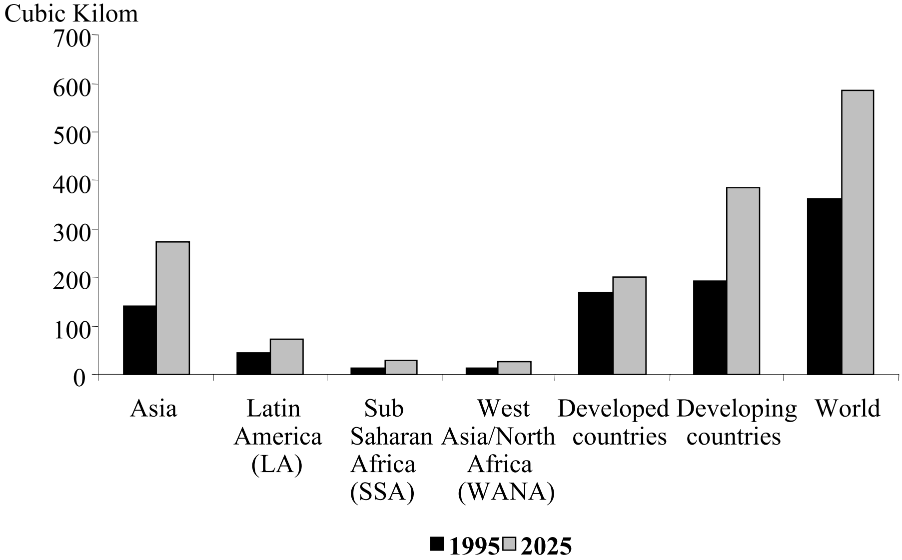

Figure 1 Total non-irrigation water consumption by region, 1995 and 2025

Industrial water use will grow much faster in developing countries than in developed countries. Domestic water demand will also grow rapidly, especially in developing countries, as a result of urbanisation and income and population growth. Farmers will consume only about 4% more irrigation water in 2025 than in 1995, unable to increase demand as rapidly as desired due to competition for water from other sectors (Figure 1). The result will be slower growth of food production and significant shifts in where the world's food is grown. In the face of water scarcity, farmers will find themselves unable to raise crop yields as quickly as in the past, and by 2025 annual irrigated cereal production will be 300 million metric tons less than it would have been with adequate water - a difference nearly as large as the US cereal crop in 2000 (Rosegrant *et al*., 2002). Faced with rising food demand and slowing production growth, developing countries will dramatically increase their reliance on food imports from 107 million tons in 1995 to 245 million tons in 2025. Some countries may finance these imports from economic growth in sectors other than agriculture, but when high food imports are the result of slow economic development, many countries may find it impossible to maintain the required imports, further worsening food security. Much of sub-Saharan Africa (SSA) and the non-oil-producing Middle Eastern and North African countries could be hit particularly hard. Competition from other users means that the share of water devoted to environmental uses will not increase.

Water crisis

If current trends in water usage, existing food policy and present investment levels were to worsen (even moderately), then the result could be a genuine water crisis. In such a scenario governments will tend to further cut their spending allocation on irrigation systems and rapidly turn over these irrigation systems to resource-poor farmers and farmer groups without the necessary reforms in water rights. Governments and international donors reduce their investments in crop breeding for rainfed agriculture in developing countries, especially for staple crops.

Total worldwide water consumption in 2025 is estimated to be 261 km^3 higher than under the business as usual scenario - a 13% increase - but much of this water will be wasted. Virtually all of the increase in demand will go to irrigation, mainly because farmers will use water less efficiently and withdraw more water to compensate for water losses. In search of adequate water supplies, farmers will extract increasing amounts of groundwater, driving down water tables and leading ultimately to the failure of key aquifers. Farmers will also tap environmental water flows, further reducing wetlands and compromising the integrity and health of aquatic ecosystems. Owing to inadequate water pricing and regulation reform, and slow adoption of improved technology, industrial water demand will be 33% higher in 2025 than under the business as usual scenario, without generating additional industrial production. The rapid increase in urban populations will quickly raise demand for domestic water, but without fundamental water pricing reforms, governments will lack the funds to extend piped water and sewage disposal to newcomers.

Naturally, such a scenario will have severe consequences for food harvests. Overall, farmers will produce 10% less cereal in 2025 than under ‘business-as-usual’ because of declines in both the amount of land cultivated and yields. This reduction is the equivalent of annually losing the entire cereal crop of India. The decline in food production will help push up food prices sharply under the water crisis scenario. The price of *Oryza sativa* will rise by 40%, *Triticum* by 80%, *Zea mays* by 120%, and other coarse grains by 85%. The ultimate result of this scenario is growing food insecurity, especially in developing countries. Per capita cereal consumption in 2025 in the developing world will actually decline compared with 1995 levels.

Sustainable water scenario

Fortunately, it is possible to envision a sustainable water scenario that would dramatically increase the amount of water allocated to environmental uses, connect all urban households to piped water, and achieve higher per capita domestic water consumption, while maintaining food production at the levels described in the ‘business-as-usual’ scenario.

Governments and international donors will increase their investments in crop research, technological change, and reform of water management to boost water productivity and the growth of crop yields in rainfed agriculture. Improved policies and increased investment in rural infrastructure will help link remote farmers to markets and reduce the risks of rainfed farming. To stimulate water conservation, the effective price of water to the agricultural sector will be gradually increased. Governments in many regions will shift water rights and management responsibilities to water users, and offer users training and support. As a result, farmers will increase their own investments in water-saving technologies. The over drafting of groundwater will be phased out as governments assign users rights to groundwater, while also toughening and better enforcing regulations. Domestic and industrial water use will also be subject to higher prices and stricter regulation. With strong societal pressure for improved environmental quality, allocations for environmental uses of water will increase, reducing pressure on wetlands.

In the ‘sustainable water scenario’ the world consumes 20% less water than under ‘business as usual’ but reaps greater benefits, especially in developing countries. These water savings will increase environmental flows by 1,030 km^3 globally, well over triple the annual flow of the Mississippi River. A key finding in this scenario is that, with higher public investment in crop breeding for rainfed areas, together with improved farm management (including increasing water harvesting, conservation tillage, and precision farming), rainfed production increases significantly. Faster growth in rainfed yields will make up for slower growth in harvested area and irrigated yields, and as a result total cereal production in 2025 is 1% greater than under ‘business-as-usual’.

Climate change, pasture and land use

Hopkins (2004) showed that grassland production is strongly influenced by climatic variability, particularly temperature and rainfall. Variation in pasture yield and production can be over 100% between different localities depending on length of growing season, rainfall distribution and soil type. Under the climate change scenarios that were developed by Hopkins (2004), grassland production is likely to be influenced by increasing temperatures and changing seasonal patterns of precipitation.

The impact of climate change on pasture and other land use is also examined by the Millennium Ecosystem Assessment (MA), an international effort to provide scientific information to policymakers and the public on the effect of ecosystem change on human well being, and to offer options for dealing with those changes. As noted above, the MA scenarios were analysed using several global models; greater consistency between the calculations of the different models was achieved by ‘soft-linking’ the models, in the sense that output files from one model were used as inputs to other models. The scenarios were implemented by:

- *specifying a consistent set of model inputs* based on the scenario storylines;
- ‘s*oft-linking’ the models* by using the output from one model as input to another;
- *compiling and analysing model outputs* about changes in future ecosystem services and implications for human well-being.

As a part of the MA, a Global Scenarios group assessed plausible scenarios for land use on a global scale, using the ‘soft-linked’ models mentioned above, and incorporating the impact of climate change on land use and production.

These scenarios account for the impact of climate change, and represent plausible alternative futures of the world. They explore the outcomes of increased globalisation versus increased regionalisation on the one hand, and increased economic growth versus increased emphasis on local adaptive management of ecosystems and their services on the other hand. Both the Global Orchestration (GO) and Techno Garden (TG) scenarios focus on increased globalisation, with GO emphasizing economic growth and public goods provision, while TG strives for greener technologies. The Order from Strength (OS) scenario has a regionalised approach focusing on national security and self-sustenance, whereas the Adapting Mosaic (AM) scenario focuses on local adaptation and flexible governance. The GO scenario assumes low population growth, high income growth, high investments in human and physical capital, medium to high levels of development in technology, rapid irrigation efficiency and yield improvements, high meat demand, full trade liberalization, and medium to low controls on environmental pollution.

Under the TG scenario, assumptions include medium to low population growth, income growth slightly lower than GO, high investments in human, physical and natural capital, medium to high levels of development in technology and irrigation efficiency, medium meat demand, full trade liberalization, and substantial controls on environmental pollution.

The OS scenario assumes high population growth, low to medium income growth, medium to low investments in human, physical, or natural capital, low levels of development in technology, irrigation efficiency and yield improvements, high meat demand in developed countries and low demand in developing countries, increased protectionism, and little control on environmental pollution.

Finally, the AM scenario assumes relatively high population growth, low but improving income growth, medium but increasing investments, medium increasing levels of development in technology, irrigation efficiency and yield improvements, low meat demand, no irrigated area expansion, current levels of protection, and medium but improving environmental pollution controls. The scenarios are distinct from earlier global scenario exercises through their focus on alternative pathways for sustaining ecosystem services. While the GO and OS scenarios are cast as taking a reactive approach to environmental issues, the TG and AM scenarios are formulated as being proactive, embracing environmental issues (Millennium Ecosystem Assessment, 2005).

Land use change, pastures and deforestation

In the first decades of the scenario period, all scenarios show an ongoing expansion of agricultural land (including pasture and cropland) in developing countries replacing current forests, while agricultural land actually declines in the OECD (Organization for Economic Cooperation and Development) and FSU (Former Soviet Union) regions. Differences among the scenarios remain somewhat limited due to counteracting forces embedded in the drivers (for example, low population growth coupled with high economic growth).

Deforestation is fastest under the OS scenario. The rate of loss of undisturbed forests actually increases from the historic rate of 0.4% to 0.6% per year, fuelled among other factors by rapid population growth and the largest expansion in agricultural area among the four scenarios (Figure 2). Crop and pasture area continues to grow rapidly in the developing regions. Under the GO scenario, deforestation continues at historic rates, while it slows somewhat under the AM and TG scenarios.

Under the GO scenario, agricultural area expands as a result of rapid income growth and stronger preferences for meat. In the developed countries, there is no net global increase of pastureland as low-input extensive grazing systems, are replaced by more intensive forms of grazing, but pastureland grows significantly in developing countries. Undisturbed forests disappear at near current global rates. About 50% of forests in SSA disappear between 2000 and 2050.

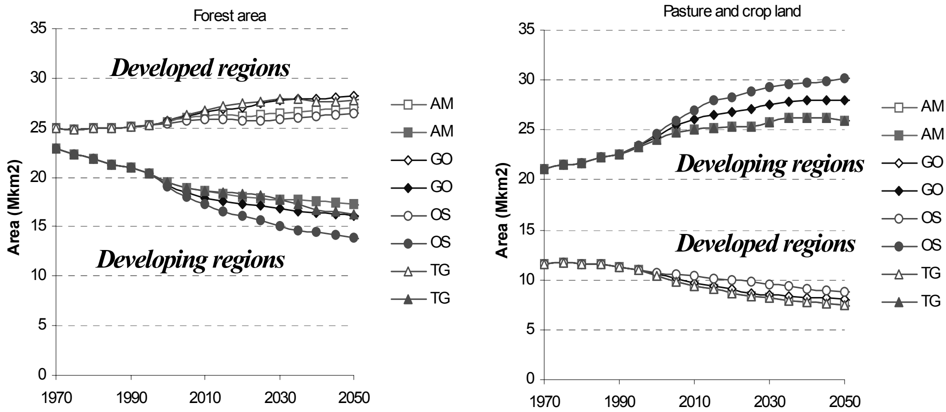

Figure 2 Change in land use, agriculture versus forests (AM = Adapting Mosaic; GO = Global Orchestration; OS = Order from Strength; TG = Techno Garden). Source: IMAGE 2.2 Projections

The smallest change in land use occurs under the TG scenario, where net forest cover is expected to increase. Production of biofuels becomes an important land use category, especially in FSU, OECD and Latin America. Due to the much lower growth for meat products, increases in irrigation area and crop yields, there is a small decrease in pastureland, and only a small increase in arable land or food production in developing regions. Deforestation in SSA and Southeast Asia is still substantial.

Under the AM scenario, changes in land use are similar to the TG scenario. Due to the application of agroecological approaches in SSA, deforestation in the region is lowest among the four scenarios. However, deforestation continues apace elsewhere, particularly in South Asia, and pastureland increases in the developing countries.

Irrigated pasture under increasing water scarcity

What are the likely implications of these alternative water and land use changes for irrigated and rainfed pasture? The models utilised do not separate irrigated and rainfed pastureland, but an understanding of the economics of irrigated pasture juxtaposed with the trends described above provide insights into the likely consequences for water and pasture development.

The literature suggests that farmers find alternative ways to respond to increased scarcity of water. Adjustments can be made through decreased water usage on a given crop, adoption of water-conserving irrigation techniques, shifting water applications to more water-efficient crops, and changing the crop mix to favour high valued crops (Gardner, 1983; Rosegrant *et al*., 1995). The available evidence shows that the short run elasticity (responsiveness of consumers) of water demand in terms of water prices is relatively low, particularly in the agricultural sector. The longer-term response of beneficial irrigation water demand to water prices is also determined by the response of water use efficiency to water prices. Farmers respond to higher water prices not only by a direct reduction in water withdrawals and consumption, but by improving water use efficiency so that a greater portion of it is used beneficially for crop production (Caswell & Zilberman, 1985: 1986; Shah *et al*., 1995; Varela-Ortega *et al*., 1998;

Zilberman *et al.*, 1997). Water use efficiency can be increased by investment in water-conserving irrigation technology, such as drip and sprinkler irrigation, or by improving the on-farm management of the water to reduce losses to non-beneficial consumption.

Both types of responses in cropping patterns and increasing water use efficiency, were induced by reform of the Chilean water policy in 1975, to a system of tradable water rights that increased the value of water. With the increasing value of water due to tradable water rights, the area planted to fruits and vegetables, which require more water per hectare, but far less water per value of output, than most field crops, increased during the period 1975-1982 by 206,000 hectares, replacing traditional crops and irrigated pastures that needed less water (Schleyer & Rosegrant, 1996). Studies (Frías, 1992; Munita, 1994) attempted to measure the increase in aggregate water use efficiency in agriculture from 1975 to 1992, reported 22 and 26 % increase in efficiency respectively.

Irrigated pasture area

FAO (2004) land-use statistics indicate a global total land area of 13.43 billion hectares, with 5.64 billion hectares (42%) in the developed countries and 7.79 billion hectares (58%) in developing countries in 2002. Out of the total land area, 3.48 billion hectares (26%) belongs to pastureland. The developed world contributes around 34% (1.20 billion hectares) pastureland compared with 66% (2.29 billion hectares) from the developing. However, no global estimate for irrigated land area could be found. While many countries have a small amount of irrigated pasture, the majority is found in developed countries like the USA and Australia. Statistics from US Department of Agriculture show that out of 121 million hectares of harvested cropland, 21.2% (26 million hectares) belongs to forage area with 16% (4 million hectares) irrigated (USDA, 2002). Irrigated pasture together with orchards, cotton and other hay consume over 0.615 million hectare-meter (MHM) of total water applications. Irrigated water application is the water application rate per hectare times hectares irrigated. Among crops in the western US, *Medicago sativa* (Lucerne) hay has the most water applied at 1.78 MHM, followed by corn for grain at 1.29 MHM.

The total area of crops and pasture under irrigation in Australia, expanded from 1.5 million hectares in 1984, to over 2.5 million hectares in 1994 (Hamblin, 2001). About half the total volume of water used in agriculture in Australia is for irrigated pasture, but these irrigated pastures return only one-tenth the value of irrigated fruit, vegetable and vine crops (Hall *et al.*, 1993). Quiggin (2001) provides a more comprehensive comparison of the value of water in alternative agricultural use in Australia (Table 1)

Table 1 Water required for A$1,000 gross profit, Australia

Commodity (MI)	Water use
Fruit	2.0
Vegetables	4.6
Dairy products	5.0
Gossypium hirsutum (cotton)	7.6
Oryza sativa (rice)	18.5
Pasture	27.8

Source: Quiggin (2001), adapted from Hall *et al*., (1993) As can be seen in Table 1, irrigation of pasture is extremely water-inefficient. Implications of changes in water prices for profitability can be drawn from the table. For example, if the price of water increased by $40 per Ml, the use of irrigation for pasture would become unprofitable, and the gross margin from irrigated *Oryza* production would fall by nearly 75%. By contrast, the profitability of fruit and vegetable production would barely be affected (Quiggin, 2001). With water scarcity projected to increase dramatically in the future, there will be significant shifts in the pattern of water use, away from low value agricultural uses to higher valued agricultural (and non-agricultural) uses. In such a situation, the first big agricultural adjustment is likely to be a shift away from the use of irrigation for pastures.

Can growth in rainfed pasture production compensate for the likely global decline in irrigated pasture area? There appears to be considerable potential for improvement in rainfed pasture production through intensification. Improved or intensive grassland includes pasture that is treated regularly with artificial fertilizer and/or herbicides, often following reseeding. Intensively grazed pasture systems comprise a number of paddocks that are grazed for one to four days with some period of rest between grazing. This is one of the most cost effective management strategies for pastures. In the UK, areas of improved grassland have increased by approximately 90% due to increased intensification in farming over the last 50 years (Marshall, 2001).

Water consumption by livestock

The projected rapid growth in livestock production is a significant factor in increasing water demand, particularly due to the demand for water to grow crops that are used as livestock feed, such as *Z. mays*, other coarse grains, and *Glycine* spp. However, extreme estimates of livestock water consumption e.g. the 100,000 l of water/kg of beef production estimated by Pimentel *et al*. (1997) for the US are not realistic. A careful and well-documented analysis by Beckett & Oltjen (1993), of the highly water-intensive US feedlot beef production system shows that 3,682 l of water is required to produce 1 kg of boneless beef. This figure is much lower compared to other studies (10,060 l/kg Chapagain & Hoekstra, 2003; 20,559 l/kg Robbins, 1987; Kreith, 1991). Based on Beckett & Oltjen (1993), direct consumption of water accounts for only 145 l/kg of boneless beef; with the vast majority of water for beef production consumed by irrigated pasture and feed crops.

Peden *et al*. (2003) examine the opposite extreme of livestock intensity - extensive beef production in Northern Africa. Intake of water by livestock depends on biological make-up, nutrition and environmental conditions where the animals are being reared, including feed and salt ingested, lactation, temperature and the animal's genetic adaptation to its environment. In a typical Northern African system (over a two-year period), one head of cattle consumes 25 l of water per day to produce 125 kg of dress weight, and consumes crop residues for which no additional water input is required. This equates to a direct water consumption of 146 l/kg. Under the most extreme hot/dry conditions, direct consumption could double to nearly 300 lkg. Even these values overstate the actual consumptive use of livestock, since much of the water consumed by livestock is released into the soil as urine providing soil nutrients and soil moisture.

Livestock water use is accounted for in the IMPACT-WATER model projections discussed previously, with the irrigated feed and pasture water consumption included in the figures for crop water demand. Direct water usage by livestock for 1995 baseline estimates was; 15.3 km^3 for developed countries, 21.8 km^3 for developing countries and 37 km^3 worldwide (Rosegrant *et al*., 2002). Thus, compared to other uses of water, direct consumption by livestock is relatively small, accounting for only about 2% of total water consumption. Driven particularly by the rapid increase of livestock production in developing countries, global livestock water demand is projected to increase by 71% (from 37 km^3 in 1995) to 63.4 km^3 in 2025.

Implications for the future

Grassland is caught between two countervailing forces: a requirement for increasing meat demand that boosts the need for additional pasture to support livestock production, and rapidly increasing water scarcity that makes pasture irrigation uneconomical. Pasture production must therefore increase through extensive expansion into previously unused grassland areas, and intensification of rainfed pasture systems. The balance between these sources of growth will determine the extent to which expansion of pasture leads to negative environmental impacts. Excessive area expansion can lead to declines in biodiversity, a reduction in carbon storage and a reduction in ecosystem services.

The scenarios described here point to appropriate strategies for national governments, international donors, and water users that could minimise the negative environmental consequences of expanded pasture production. It is crucial to invest in expanding household and industrial water supplies, but rising financial and environmental costs will limit the expansion of irrigation water supply. Overall, the most effective means of dealing with water scarcity is likely to be conserving water in existing water uses. Improvements in the irrigation sector to increase water use efficiency must be made at the technical, managerial, and institutional levels. Technical improvements bring advanced irrigation systems, including drip irrigation, sprinklers, conjunctive or collective use of surface and groundwater, and precision agriculture, such as computer monitoring of crop water demand. Irrigation management can be improved by the adoption of demand-based irrigation scheduling systems and improved equipment maintenance. The establishment of effective water user associations and water rights, the introduction of water pricing, and improvements in the legal environment for water allocation are all examples of institutional improvements in the irrigation sector. Industrial water recycling can also be a major source of water savings in many countries to reduce water scarcity. Domestic water use can be made more efficient by steps ranging from repairing leaks in municipal systems to installing low-flow showerheads. Innovative water pricing policies that increase the prices for domestic and industrial water while preserving incomes for farmers and the rural poor will encourage water-saving innovation.

Rainfed agriculture - including rainfed pasture also emerges as a potential key to the sustainable development of water and food. Improved water management and crop productivity in rainfed areas would help relieve pressure on irrigated agriculture and on water resources. Exploiting the full potential of rainfed agriculture will require investing in; water harvesting and conservation tillage technologies, expanded investment in crop breeding targeted to rainfed environments, agricultural extension services, and improved access to markets, credit, and input supplies in rainfed areas.

Key improvements such as those mentioned above are necessary in order to address the pressures facing pasture production. The appropriate mix of water policy and management reform and investments, and feasible institutional arrangements and policy instruments employed, must be tailored to specific countries and basins. Specific plans to address these issues will vary based on underlying conditions in the regions, including levels of development, agroclimatic conditions, relative water scarcity, level of agricultural intensification, and degree of competition for water.

References

Beckett, J.L. & J.W. Oltjen (1993). Estimation of the water requirement for beef production in the United States. *Journal of Animal Science,* 71 (4), 818-826.

Caswell, M. & D. Zilberman (1985). The choices of irrigation technologies in California. *American Journal of Agricultural Economics*, 67, 224-234.

Caswell, M. & D. Zilberman (1986). The effects of well depth and land quality on the choice of irrigation technology. *American Journal of Agricultural Economics*, 68, 798-811.

Chapagain, A. & A. Hoekstra (2003). Virtual water flows between nations in relation to trade in livestock and livestock products. Water Research Report, Series No. 13, Delf, the Netherlands. 198pp.

FAO (Food and Agriculture Organization of the UN), (2004). FAO Stat-Agriculture. FAO statistical database. <http://www.fao.org/waicent/portal/statistics_en.asp>

Frías, J.L. (1992). Evolución reciente de la industria del agua en Inglaterra, Francia y Chile (Recent evolution of water industry in England, France and Chile). McKinsey & Company Inc., Mexico.

Gardner, B. (1983). Efficient redistribution through commodity markets. *American Journal of Agricultural Economics*, 65, 225-234.

Gardner-Outlaw, T. & R. Engelman (1997). Sustaining water: a second update. Population Action International, Washington DC, USA, 20pp.

Hall, N., D. Poulter & R. Curtotti (1993). ABARE model of irrigation farming in the southern Murray-Darling Basin, ABARE Research Report 94.4, Canberra, Australia.

Hamblin, A. (2001). Australia state of the environment report 2001 (theme report). CSIRO Publishing, Department of Environment and Heritage, Commonwealth of Australia, 155pp.

Hopkins, A. (2004). Climate change impacts and grassland. IGER Innovations, 47-51. <http://www.iger.bbsrc.ac.uk/Publications/Innovations/incon04.htm>

Kreith, M (1991). Water inputs in California food production. Water Education Foundation, Sacramento, California.

Marshall, B. (2001). Grassland. Hull Biodiversity Action Plan. Hull Biodiversity Partnership. <http://www.hull.ac.uk/HBP/Action Plan/Grassland.htm>

Millennium Ecosystem Assessment (2005). Chapter 9: Changes in Provisioning and Regulating Ecosystem Goods and Services and their Drivers Across the Scenarios. Millennium Ecosystem Assessment Volume 2: Scenarios Assessment. Ecosystems and human well-being. Island Press, Washington, DC, (in press)

Munita, J. (1994). Aumento de Eficiencia en el Uso Del Agua por Incorporación de Nuevas Técnicas y Arrendamientos Temporales (Increase in efficiency in the use of water by the incorporation of new technology and temporary rentals). Universidad de Chile, Santiago.

Peden, D., G. Tadesse & M. Mammo (2003). Improving the water productivity of livestock: an opportunity for poverty reduction. Paper presented during the Integrated Water and Land Management Research and Capacity Building Priorities for Ethiopia Conference, December 2-4, 2004, Addis Ababa, Ethiopia, 57-65. <http://www.ilri.cgiar.org/InfoServ/Webpub/Fulldocs/IntegratedWater/iwmi/Documents/Papers/Don.htm>

Pimentel, D., J. Houser, E. Preiss, O. White, H. Fang, L. Mesnick, T. Barsky, S. Tariche, J. Schreck & S. Alpert (1997). Water resources: agriculture, the environment and society. *BioScience*, 47 (2), 97-106.

Quiggin, J. (2001). Environmental economics and the Murray-Darling river system. *Australian Journal of Agricultural and Resource Economics*, 45 (1), 67-94.

Robbins, J. (1987). Diet for a new America. Stillpoint Press, Walpole, NH, 23pp.

Rosegrant, M.W., X. Cai & S. Cline. (2002). World water and food to 2025: dealing with scarcity. International Food Policy Research Institute, Washington DC, USA, 322pp.

Rosegrant, M.W., R.G. Schleyer & S. Yadav (1995). Water policy for efficient agricultural diversification: market-based approaches. *Food Policy*, 20 (3), 203-233.

Schleyer, R.G. & M.W. Rosegrant (1996). Chilean water policy: the role of water rights, institutions, and markets. *International Journal of Water Resources Development* 12 (1), 33-48.

Shah, F, D. Zilberman & U. Chakravorty (1995). Technology adoption in the presence of an exhaustible resource: the case of groundwater extraction. *American Journal of Agricultural Economics*, 77, 291-299.

UN World Water Development Report (2003). Water for people, water for life. <http://www.unesco.org/water/wwap/wwdr/>

USDA (United States Department of Agriculture) (2002). National agricultural statistics service database. Census of Agriculture - state data, USA. <http://www.nass.usda.gov/QuickStats/>

Varela-Ortega, C., J.M. Sumpsi, A. Garrido, M. Blanco & E. Iglesias (1998). Water pricing, public decision making and farmers' response: implications for water policy. *Agricultural Economics*, 19, 193-202.

Zilberman, D., U. Chakroavorty & F. Shah (1997). Efficient management of water in agriculture. Chapter 22. In: D. Parker & Y. Tsur (eds.) Decentralization and coordination of water resources. Boston: Kluwer Academic Publishers, 221-246.