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Global water crisis and future food security in an era of climate change

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ABSTRACT

Food policy should serve humanity by advancing the humane goals of eradicating extreme poverty and hunger. However, these goals have recently been challenged by emerging forces including climate change, water scarcity, the energy crisis as well as the credit crisis. This paper analyses the overall role of these forces and population growth in redefining global food security. Specifically, global water supply and demand as well as the linkages between water supply and food security are examined. The analysis reveals that the water for food security situation is intricate and might get daunting if no action is taken. Investments are needed today for enhancing future food security; this requires action on several fronts, including tackling climate change, preserving land and conserving water, reducing the energy footprint in food systems, developing and adopting climate resilient varieties, modernising irrigation infrastructure, shoring up domestic food supplies, reforming international food trade, and responding to other global challenges.

Introduction

"When the well is dry, we know the worth of water" (Benjamin Franklin).

Food policy must not lose sight of surging water scarcity. Water is a key driver of agricultural production. Water scarcity can cut production and adversely impact food security.[1,2] Irrigation has helped boost agricultural yields and outputs in semi-arid and even arid environments and stabilized food production and prices (Hanjra et al., 2009a, 2009b; Rosegrant and Cline, 2003) and the revenue from the agriculture sector (Sampath, 1992). Only 19% of agricultural land cultivated through irrigation supplies 40% of the world's food (Molden et al., 2010) and has thus brought substantial socioeconomic gains (Evenson and Gollin, 2003). Water for agriculture is critical for future global food security. However, continued increase in demand for water by non-agricultural uses, such as urban and industrial uses and greater concerns for environmental quality have put irrigation water demand under greater scrutiny and threatened food security. Water scarcity is already a critical concern in parts of the world (Fedoroff et al., 2010). Further, there are growing public concerns that the footprints (i.e. negative impacts) of food security on the environment are substantial (Khan and Hanjra, 2009; Khan et al., 2009a,b). Continued increase in demand for irrigation water over many years has led to changed water flows, land clearing and therefore deteriorated stream water quality. Addressing these environmental concerns and fulfilling urban and industrial water demand will require diverting water away from irrigation. This will reduce irrigated area and its production and impact on future food security.

New investments in irrigation infrastructure and improved water management can minimise the impact of water scarcity and partially meet water demand for food production (Falkenmark and Molden, 2008). However, in many arid or semi-arid areas and seasonally in wetter areas, water is no longer abundant. The high economic and environmental costs of developing new water resources limit expansion in its supply (Rosegrant and Cai, 2000). Once assumed unlimited in supply, now even in developed countries water is considered scarce. Further, it is believed that climate change will increase water scarcity in the coming decades (Lobell et al., 2008). Even if new supplies are added to existing ones, water might not be sufficient for increased food demand (Brown and Funk, 2008).

The severity of the water crisis has prompted the United Nations (UNDP, 2007) in concluding that it is water scarcity, not

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[1] Water scarcity refers to a situation where there is insufficient water to satisfy normal human water needs for food, feed, drinking and other uses, implying an excess of water demand over available supply. It is a relative concept, therefore, difficult to capture in single indices (Falkenmark, 2007).

[2] Food security has generally been defined as (Barrett, 2010) the ability of a country to supply an assured access to food – in an adequate quantity and quality to meet basic food demands by all social groups and individuals at all times (FAO, 2003; Sanchez and Swaminathan, 2005).

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a lack of arable land, that will be the major constraint to increased food production over the next few decades. For instance, Australia is one of the major food producing and land abundant countries but recent drought reduced its agricultural and food production substantially (Goesch et al., 2007). According to 2001 and 2006 land use data by the ABS (2008), in the Murray–Darling Basin (MDB) of Australia, there was a decline of about 40% in rice and cereals production. Drought in other food producing countries such as parts of the United States of America and Europe is regarded as one of the major factors that contributed to the global food price crisis of 2008 (Piesse and Thirtle, 2009). Inequitable distribution of available food supplies, poverty, and inequality result in entitlement failure for the poor to exacerbate the food security issues because those lacking water entitlements are often food insecure (Molden et al., 2007; Sen, 1989, 2001). The high and widening inequality and income gap between the rich and the poor is a serious concern; though it is amazing that while one billion people are hungry in the developing world (Barrett, 2010), a significant proportion of the population in the developed countries is obese (Schäfer-Elinder, 2005).

This thematic paper examines the current and future global situation of water and food in terms of supply and demand, and their impacts on food security in the context of climate change. Food production and demand in the global market are investigated, and the impact of increasing water scarcity in redefining global food security is examined. This paper juxtaposes the findings of the existing models including PODIUM (Mu et al., 2008), WATERSIM (de Fraiture et al., 2007) and IMPACT-WATER (Rosegrant et al., 2005) as well as other empirical studies published in topical journals to distil global water and food projections, and provides a comprehensive assessment of the global water and food security challenges.

Global water supply and demand

Global demand for water has tripled since the 1950s, but the supply of fresh water has been declining (Gleick, 2003a). Half a billion people live in water-stressed or water-scarce countries, and by 2025 that number will grow to three billion due to an increase in population. Irrigated agriculture is the dominant user of water, accounting for about 80% of global water use (Molden et al., 2007). Population and income growth will increase the demand for irrigation water to meet food production requirements and household and industrial demand. The global population is projected to increase to about 9 billion by 2050. In response to population growth and rising incomes, worldwide cereals and meat demand has been projected to increase by 65% and 56%, respectively (de Fraiture et al., 2007). Fulfilment of calorie requirements and dietary trends will translate into even higher water demand if more calories will be supplied from meat (Rosegrant and Cline, 2003). At the same time, the limited easily accessible freshwater resources in rivers, lakes and shallow groundwater aquifers are dwindling due to over-exploitation and water quality degradation (Tilman et al., 2002).

Being the largest user of water, irrigation is the first sector to lose out as water scarcity increases (Falkenmark and Molden, 2008; Molden, 2007). The challenges of water scarcity are heightened by the increasing costs of developing new water sources (Hanjra and Gichuki, 2008), land degradation in irrigated areas (Khan and Hanjra, 2008), groundwater depletion (Shah et al., 2008), water pollution (Tilman et al., 2002), and ecosystem degradation (Dudgeon, 2000). With current water utilization practices, a fast growing population, and a nutritional transition towards diets that rely more on meat (Popkin, 2006), global water resource limits will be reached sooner. For example, the 2025 projections on water scarcity by the International Water Management Institute (IWMI) were reached in 2000 (de Fraiture et al., 2007).

Data on water supply and demand are startling: about 450 million people in 29 countries face severe water shortages (Serageldin, 2001); about 20% more water than is now available will be needed to feed the additional three billion people by 2025 (Seckler et al., 1999a); as much as two-thirds of the world population could be water-stressed by 2025 (Seckler et al., 1999b); aquifers, which supply one-third of the world's population, are being pumped out faster than nature can replenish them (Shah et al., 2006); half of the world's rivers and lakes are polluted; and major rivers, such as the Yellow, Ganges, and Colorado, do not flow to the sea for much of the year because of upstream withdrawals (Richter et al., 2003).

Some of the most densely populated regions of the world, such as the Mediterranean, the Middle East, India, China and Pakistan are predicted to face severe water shortages in the coming decades (Postel and Wolf, 2001) (Table 1) (ABS, 2008; Rost et al., 2008). Areas of the USA (such as the southwest and parts of the midwest) and Australia are vulnerable to water shortages. In Australia, for example, over the last decades there has been a significant decline in rainfall and runoff and as a result water allocations for irrigation (CSIRO, 2008). Rosegrant and Cai (2002) estimated that under their baseline scenario, total global water withdrawals for agricultural, domestic and industrial use will increase by 23% from 1995 to 2025. The availability of sufficient water resources is one of the major crises with overarching implications for many other world problems especially poverty, hunger, ecosystem degradation, desertification, climate change, and even world peace and security (Khan and Hanjra, 2009). Water scarcity is projected to become a more important determinant of food scarcity than land scarcity, according to the view held by the UN (UNDP, 2007).

Scarcity and declining water quality in many areas of the world are held to pose key challenges, including:

- Increased competition for water within and between sectors, transferring water out of agriculture (Molden, 2007) and leaving less water for food.
- Increased inequity in access to water creating water "haves" and "have nots", perpetuating poverty (Hussain and Hanjra, 2003) and widening the inequalities in access to water for food.

Table 1
Agricultural water withdrawals and consumption estimates (in km^3 $year^{-1}$) for selected countries for the period 1971–2000.

Country	Previous estimate (various years)	Withdrawals, Model 1	Withdrawals, Model 2	Consumption, Model 1	Consumption, Model 2
China	352–408	404–409	253–267	203–206	128–135
India	353–655	710–715	181–203	385–387	100–114
Pakistan	97	117–120	35–57	54–55	18–29
Australia	19	336,117	286,943		
World	2236–2942	2534–2566	1161–1249	1353–1375	636–684

Note: Model 1 (IPOT) accounts for fossil groundwater and non-local blue water such as diverted from rivers whereas in Model 2 (ILIM) they are not accounted for (Rost et al., 2008).
Data for Australia under Model 1 gives the total water resources in gigaliters for 2004–2005, while the data under Model 2 does not account for deep drainage inflows (ABS, 2008) and must therefore be used and/or interpreted with care.

- Surge in the incidence of water borne diseases (Prüss et al., 2002) affecting human health and labour productivity.
- Deterioration of freshwater ecosystems (Scanlon et al., 2007) impacting ecosystem health and services.
- Tension over the use and control of water and potential for conflict at local, national and transnational levels (Giordano et al., 2005; Yoffe et al., 2004) with a potential to afflict harm on the agricultural communities dependent on water for food.
- Reduced rainfall and enhanced vulnerability to extreme wet and dry events (Ragab and Prudhomme, 2002) can potentially reduce crop yield, cause short-term crop failure and long-term production declines.
- Decline in global per capita food production threatening future food security (Brown and Funk, 2008).
- Constrain on human capacity for crafting institutions and policies for responding to emerging food security challenges (Gilman et al., 2008; Lobell et al., 2008).

Global food supply and demand

Current global food production comes from 1.5 billion ha of cultivated land, representing 12% of the total land area (Schultz and de Wrachien, 2002). About 1.1 billion ha are rainfed with no irrigation systems. Thus rainfed agriculture is practiced on about 80% of world's physical agricultural area and generates about 60% of the world's staple food (FAO, 2008). Irrigated agriculture covers only 279 million ha or 19% of cropland (Thenkabail et al., 2010) – (it becomes 400 million ha when multiple crops/cropping intensity is considered), but contributes 40% of agricultural output. It also accounts for about 70% of water withdrawals from global river systems (Molden et al., 2007). In the last 50 years, cropland has been reduced by 13% and pasture by 4%. According to the Food and Agriculture Organisation (FAO), world agricultural production growth is expected to fall by 1.5% per year to 2030 and then a further reduction by 0.9% to 2050, compared with 2.3% growth per year since 1961 (FAO, 2003). In fact, the growth by 2009 has fallen relative to the growth in 2000. A deceleration in agricultural growth will affect world food security (Narayanamoorthy, 2007). Future food supply will be determined by prudent management of the global agricultural resources and smart investments in technologies along with reforms in institutions and policies to achieve sizeable increase in food production (Herrero et al., 2010). Food demand management measures are unlikely to be a major pathway, as human diets and food traditions might be extremely difficult to influence (Alexandratos, 2008; Stokstad, 2010), especially as income grows (Mancino et al., 2008). However, the development of a strong ethical sense in many people that food choices must change urgently cannot be ruled out, and could lead to radical impact on food demand. Also, interventions aimed at reducing food wastage from farm to fork can help recover safe and nutritious food that would otherwise be wasted (Kantor et al., 1997).

Drivers impacting food supply

The key drivers which have recently impacted and will impact on food production and supply include: (a) water (and to some extent land) crisis; (b) climate change crisis; (c) energy prices and (d) credit crisis.

Water scarcity

Competition for water resources among sectors, regions and countries, and associated human activities is already occurring. About 40% of the world's population live in regions that directly compete for shared transboundary water resources (Yoffe et al., 2004). In China, where more than 300 cities already are short of water, these shortages are intensifying (Khan et al., 2009a). Worldwide, water shortages are reflected in the per capita decline in irrigation water use for food production in all regions of the world during the past 20 years. Water resources, critical for irrigation, are under great stress as populous cities, states, and countries require and withdraw more water from rivers, lakes and aquifers every year (Gleick, 2003b). A major concern to maintaining future water supplies is the continuing over-draft of surface and groundwater resources (Loehman, 2008). As a result, there is decline in available surface water and groundwater for irrigation (Shah et al., 2006). For example, in Australia, CSIRO estimated that there will be a major decline in irrigation water for diversions in the MDB which is the food basket of Australia (CSIRO, 2008).

Climate change

Climate change poses significant threats to global food security and peace due to changes in water supply and demand (Alcamo et al., 2007; Barnett et al., 2005; Döll and Siebert, 2002; Spash, 2008a), impacts on crop productivity (Droogers, 2004; Droogers and Aerts, 2005), impacts on food supply (Arnell et al., 2004; Rosenzweig and Parry, 1994), and high costs of adaptation to climate change (Kandlikar and Risbey, 2000).

Climate change may affect agriculture and food security by altering the spatial and temporal distribution of rainfall, and the availability of water, land, capital, biodiversity and terrestrial resources. It may heighten uncertainties throughout the food chain, from farm to fork and yield to trade dynamics, and ultimately impact on the global economy, food security and the ability to feed nine billion people by 2050. Modelling by IIASA (Fischer et al., 2007) shows that future socioeconomic development and climate change may impact on regional and global irrigation requirements and thus on agricultural water withdrawals. Net irrigation requirements may increase by 45% by 2080. Even with improvements in irrigation efficiency, gross water withdrawals may increase by 20%. Global irrigation requirements with climate change will increase by 20% above the reference base case scenario (without climate change). The simulation shows that the global impacts of climate change on irrigation water requirements could be as large as the projected increase in irrigation due to socioeconomic development.

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The impacts of climate change on global food production are small but geographically very unevenly distributed, with losses felt mostly in arid and sub-humid tropics in Africa and South Asia (Parry et al., 2001) and particularly in poor countries with low capacity for adaptation (Kurukulasuriya et al., 2006). Some fairly robust conclusions that emerge from climate change analysis on agriculture and food availability (Parry et al., 2001; Tubiello and Fischer, 2007) show that: (a) there will be food shortages due to decrease in net global agricultural production and disrupted access to water and energy; (b) a likely increase in the number of people at risk of hunger; (c) the impact on undernourishment will depend mainly on the level of economic development and poverty reduction achieved in the future and its positive effects on distribution, and human responses to climate change; (d) mitigation of climate change can have significant positive effects on agricultural productivity and food security; and (e) current production and consumption gaps between developed and developing countries will deepen; and unmitigated climate change and the small risk of abrupt climate change may cause "human carrying capacity deficit", suggesting insufficient resources leading to economic menace, global conflict and population contraction (Alley et al., 2005).

Climate change will impact on crop productivity, with implications for food security (Spash, 2008a,b). Global warming has been speculated to increase yields due to the "fertilizer effect" of rising atmospheric carbon, but the impacts are likely to be net negative for poor countries. For example, global warming will reduce food production in countries closer to the equator (Droogers and Aerts, 2005). African countries will experience prolonged droughts and further food shortages. It is likely that the Pacific Islands and Indonesia will be more dependent on imports and face more poverty and other social problems. A recent IWMI study (de Fraiture et al., 2008) anticipates a 50% decline in South Asian wheat production by 2050 – equal to about 7% of the global crop production. The Peterson Institute (Cline, 2007) states that agricultural production in developing countries may fall between 10% and 25%, and if global warming is unabated, India's agricultural capacity could fall by as much as 40%.

Climate change could impact on rainfall and runoff and the availability of water for irrigation in many regions and countries in the world. A decline in rainfall along with an increase in temperature will increase crop water requirement due to high evapotranspiration while less rainfall will increase crop net irrigation water requirements. As a result, the already existing water scarcity problem will exacerbate in many regions and countries, and affect food production. The hardest hit will be the areas with intense water scarcity and food security issues, such as the arid countries of sub-Saharan Africa and parts of South Asia, which are already prone to malnutrition, poverty, and even episodes of hunger (Brown and Lall, 2006; Brown and Funk, 2008; Funk et al., 2008).

Energy crisis

In the last 8 years, energy prices have more than trebled, driving up the cost of farming through higher prices of fuel and fertilizer (World Bank, 2008). High energy prices also raise food prices through increased cost of transporting and shipping. The increase in energy prices also feeds through to the demand side. High fuel prices are creating new markets for agricultural crops that can be used for biofuels (Pimentel, 2007; Runge and Senauer, 2007). Land and water resources traditionally used for food crops are being diverted to fuel crops. High oil prices make biofuel production competitive with oil and gas, which encourages food crops to be diverted to energy production (Demirbas, 2008). To address climate change concerns and high oil prices (such as those in 2008 when the oil price went up to $140/barrel), many countries are setting up and trying to reach biofuel targets. As a result, grains, sugar and palm oil are increasingly used to produce ethanol and biodiesel. A significant amount of land is set aside to cultivate crops that are being used to "set on fire" rather to produce food to eat. Despite a respite in oil prices in 2009, biofuel targets and land conversion from food to biofuel crops could have major implications for food security and equity. Biofuelling for a continued rise in the living standards of people in the west can hardly prevent poor people from hunger and starvation in the south; policy steps are needed to conserve energy and diversify ethanol's production inputs away from food crops (Runge and Senauer, 2007).

Credit crisis

The 2008 Credit Crisis had a capital contraction effect in the global economy (Graafland, 2008). Less capital means less investment in the agricultural sector and ultimately less production. Dearer credit means higher cost of food production in smallholder systems, as few save and many borrow (Zeller and Sharma, 2000). This means deferred investments in medium and long term measures for improving crop production (such as investments in modern irrigation technology and earthworks and lower use of yield enhancing inputs such as fertilizers or seeds). As a result, food production dwindles, making food unavailable and unaffordable for many around the globe.

The credit crisis gives additional stagflation (i.e. high prices and low growth) along with the stagflation due to the energy crisis (Graafland, 2008). Livelihoods are compromised as cost of living has gone up while borrowing has become more difficult. Water scarcity has a compounding effect. For example, in Australia, institutional lenders use water entitlements and allocations in each season as a key credit criterion for lending to farmers. With continued drought and associated decline in water allocations and farm income, the farmers are caught in liquidity squeeze. Moreover, the credit crisis causes a deleveraging of the money market. Investors (including farmers) turn their back to currencies, stocks and banks and move investments to static/safe harbours like gold or commodities, or convert real assets into financial ones, e.g. investments in property and land. Farmers hold more capital in liquid assets and unproductive forms to ward against uncertainty and finance operational costs out of their own funds, reducing investments in food production. Donors cut back funding to agriculture and irrigation, and adjust their portfolio away from these sectors due to the global financial crisis and its negative effects on investor confidence. International and food aid dries up and support for agricultural research centres wilts as the global credit crisis turns into a global economic crisis (Normile, 2008).

Other factors

Other key factors affecting food supply include a reduction in per capita arable land, a decline in soil fertility due to soil losses (Lal, 2004) and worldwide decline in investments in agricultural research (Hanjra and Gichuki, 2008; Pingali and Traxler, 2007). A key finding of food security studies is that most fertile lands are already being exploited and that most future increases must come by raising crop yields. In major food-producing areas of Asia, yields are slowing or stagnating and technology and productivity fatigue are becoming obstacles to raising crop yield, especially cereals (Narayanamoorthy, 2007).

Greater concerns for the environment require that more agricultural land should be set aside for conservation. If the environmental requirement is fulfilled, this will reduce agricultural land and food production (Gordon et al., 2010). Further, carbon trading and soil and tree carbon sequestration require more land for trees, reducing land for food production. The focus on better soil management for soil carbon sequestration may entail a reduction in land use for food production as well as a reduction in yields, at least during the initial years, from the land put to conservation farming (Knowler and Bradshaw, 2007; Lal, 1997; Mazvimavi and Twomlow, 2009).

Nevertheless, water scarcity remains the primary constraint to global food production. Reduction in irrigation water will cause decline in agricultural and food production. Major food-producing areas such as the Punjab of India and Pakistan, and the central and northern areas of China suffer from the depletion of aquifers and the transfer of water from irrigation to growing cities, with implications for food security. While irrigation almost always doubles productivity (Hanjra et al., 2009b; Namara et al., 2010), higher energy and fertilizer prices present complex issues to these smallholder's irrigated systems. Loss of productive land to urbanization, and waterlogging and salinity are critical constraints (Khan et al., 2008). For example, in Indonesia in the last 5 years, about one million hectares of farmland have been lost to urbanization due to industrial and infrastructure development (Halim et al., 2007).

Drivers impacting food demand

Global future food demand will be largely determined by population growth (Tweeten and Thompson, 2009) which is becoming more and more affluent and urbanized. For instance, population growth in Asia requires an increase in cereal grain production of 344 million metric tons (MMT) from 1997 to 2020. Of the increase by 557 MMT which is believed to be needed globally, China would need 26% and India 12%. An increase by just 3% in food imports by China would claim 10% of the global food trade (Hongyun and Liange, 2007). China would import up to 216 MMT of grain by

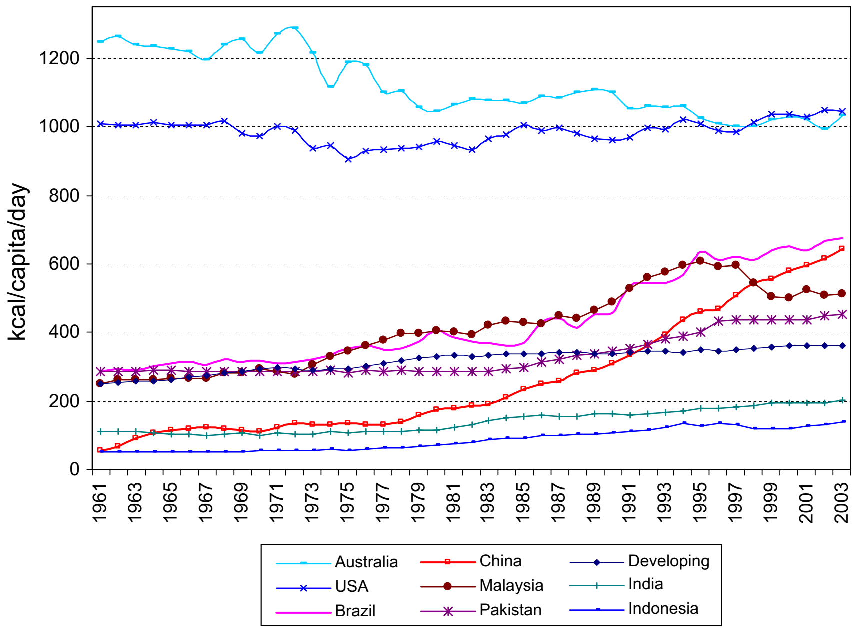

Fig. 1. Trends in calorie consumption from animal products 1961–2003 (FAO, 2008).

2030 (FAO, 2003) or about $10.8 billion of grain deficits (Mu et al., 2008). A more moderate estimate is for China's grain imports to increase from 8 MMT in 1997 to 48 MMT in 2020 (Heilig, 1999). Although future food production and demand estimates for China differ widely, depending on the population growth scenario and water availability (Mu et al., 2008), they have clear implications for global food demand.

More affluent populations have tended to diversify diets towards animal food items (Popkin, 2003) which require several multiples of water per calorie of dietary energy (Molden et al., 2010). The consumption of calories has also increased significantly in the last four decades in many developing countries (Fig. 1) (FAO, 2008). For example, meat demand (including demand for beef, meat, eggs and more dairy products) or calorie consumption has grown in the Chinese diet from less than 100 kcal/capita/day to more than 600 kcal/capita/day between 1961 and early 2003. All of this increase in calorie consumption requires enormous amounts of grain to feed livestock. China alone may account for 43% of additional meat demand worldwide in 2020 compared to 1997, placing higher demand on world water resources and upward pressure on commodity prices in the longer term. An increase in food prices will directly hit food security for the poor nations[3] (Mahal and Karan, 2008).

A key challenge facing agriculture in the 21st century is how to feed a world with a continuously growing and increasingly affluent population with greater meat demand. Due to strong economic growth, millions of people will buy diets far richer in protein – in the cases of China and India, three to five times richer (Pingali, 2007). To meet such level of increase in demand as shown in Table 2 (UNDP, 2007), global food output must rise by 110% in the next 40 years. According to FAO (2003) and International Food Policy Research Institute (IFPRI) (von Braun, 2008), this goal is technically feasible – provided most countries have modern farming systems. However, the continued increase in population growth in the poorest countries poses immense challenges for their food security. More than half of the world's population will live in urban areas and China and India will be the biggest economies in the world, for the first time in modern history (Henderson, 2002). Feeding a growing, urbanized and affluent population in a rapidly globalized world will be a global challenge. Unprecedented global cooperation will be inevitable in sustaining food production and improving global food security (Khan and Hanjra, 2009), and water scarcity is projected to become a more important determinant of food scarcity than land scarcity, as mentioned above.

Water scarcity and food security linkages

With continued increase in population, limits are being met on the basic resource needed to produce food, as shown in Fig. 2 (Khan and Hanjra, 2009 and references therein). World food production is now consistently outpacing consumption. In 2008, world food security came at its lowest ebb in half a century. Grain carryover stocks in mid-2007 were the lowest since records began in 1960; in 2007 the stocks were only 53 days of grain supply or only half of what was available in 2002 (FAO, 2008). Adverse climatic conditions and droughts in some major food producing countries including Australia, Georgia, and US were the key drivers.

A daily dietary energy intake of 2700 kcal is a widely used indicator for measuring food security (FAO, 2008) and to produce one kcal for the average diet one litre of water is needed (Molden et al., eh... 2007). This means that about 2700 l/capita are required for daily food needs.

According to the Comprehensive Assessment of Water Management in Agriculture (de Fraiture et al., 2007; Molden et al., 2007) today's food production requires a consumptive water use of about 6800 km^3/year. Out of this, 1800 km^3/year are supplied by irrigated water (i.e. blue water resources). To feed humanity by 2050 on 3000 kcal per person per day (the basis used by the Assessment, assuming worldwide growth in incomes and calorie consumption), an additional 5600 km^3/year will be required; out of which a maximum of 800 km^3/year will come from blue water resources (i.e. due to irrigation expansion and efficiency improvement) while the remaining 4800 km^3 will have to come from new green water resources (e.g. from horizontal expansion or from turning evaporation into transpiration). There is a possibility that improved efficiency in rainfed areas will result in 1500 km^3/year. This means that there will be a gap of about 3300 km^3/year. The

[3] Poor countries and households will be the most vulnerable to price increases and social unrest.

Table 2
Global food demand for agricultural commodities (million tons).

Year	Cereals			Other crops			Animal products		
	1989	2025	2050	1989	2025	2050	1989	2025	2050
Less developed	940	1882	2419	1870	3950	5502	307	903	1405
Developed	754	952	961	1110	1298	1262	565	666	660
World	1694	2834	3380	2980	5248	6764	872	1569	2065

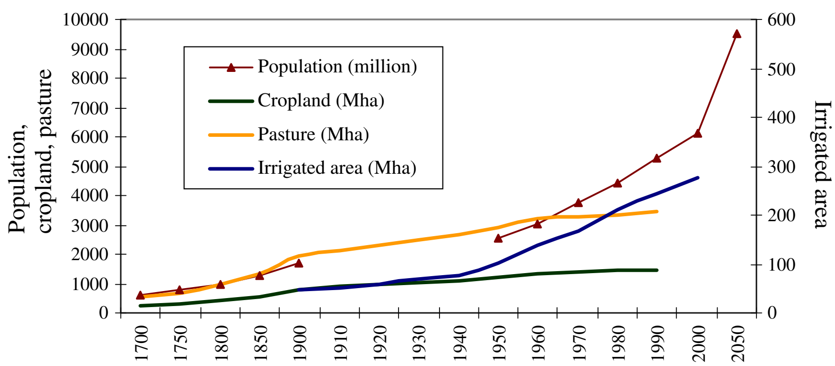

Fig. 2. Global food chain and human population growth (Khan and Hanjra, 2009 and references therein).

issue is how to fill the water gap of 3300 km^3/year, shown in the second column of Fig. 3 (de Fraiture et al., 2007; Molden, 2007; Molden et al., 2007), to feed the population by 2050. If not filled this water gap will leave a food gap and affect global food security. When comparing future water needs with projected water requirements, experts show that a hunger gap will prevail in South Asia and sub-Saharan Africa (Falkenmark, 2007). Therefore, the challenge is to reduce food demand by avoiding or minimising the consumption of animal products (Deckers, 2010), restricting the increase in population growth by peaceful means, using non-conventional water such as saline and wastewater for irrigation (Qadir et al., 2010), allocating more existing water and food supplies to food insecure areas along with addressing the issue of distributional inequity in water and food.

A recent IFPRI study (Rosegrant et al., 2006) used a global model (IMPACT-WATER) to project world water and food demand by 2025, for three forecast scenarios of water use (including business as usual, crisis, and sustainable water use). The study predicts a severe food crisis unless fundamental policy changes are made in future water use. The study found that a failure in water policy reform will result in a global grain production decline by 10% by 2025, increasing malnutrition, health risks and damages to the environment. Increased water use in the future will largely be driven by urbanization, population growth, industrialization and environmental needs. Increased water competition and diversion from irrigation will reduce irrigation area and/or diminish crop yields and seriously limit food production. The losses in food production could total 350 million tons which are slightly above the current annual USA grain crop production. Any decline in the global food supply could cause price spikes. The prices of rice, wheat and maize are projected to rise by 40%, 80% and 120%, respectively (Rosegrant et al., 2005).

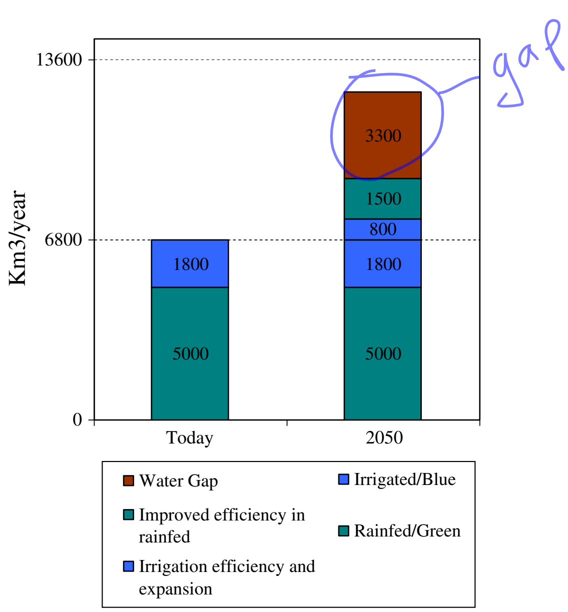

Fig. 3. World water demand to 2050 food security (de Fraiture et al., 2007; Molden, 2007; Molden et al., 2007).

Other environmental factors are also working against agriculture and food security. About 8.5 million ha of rainfed land and 1.5 million ha of irrigated land are lost to salinization every year. Global productivity loss from irrigated, rainfed, and rangeland due to land degradation over three decades has been estimated at 0.4% per annum (Khan and Hanjra, 2008, 2009). An estimated 15% of the system's productivity was lost due to land degradation alone for the Thungabhadra irrigation project in southwest India; while 1/3rd of the total factor productivity growth from technological change, education, and infrastructure investments was lost in Pakistan Punjab due to resource degradation caused by the intensification of land and water resources (Khan and Hanjra, 2008, 2009). Soil salinity, water logging, and impaired drainage cause significant damages to natural and built infrastructure and weaken the fight against poverty and hunger (Molden et al., 2010).

These challenges pose significant risks to food security, even in areas with high productivity and production. How humans respond to these challenges depends fundamentally on how water scarcity and food security issues are conceptualized (Renwick, 2001; Ward, 2007) and addressed. Water scarcity is typically conceptualized in absolute physical terms resulting in a focus on physical resource availability. A focus on interactions between water resources and humans rather than the resource only could enable better insights on how humans adapt to water scarcity; how these adaptations transform food security, especially for smallholders and women farmers (due to their lower socioeconomic status and high cost of adaptation); and what interventions, technologies and policies may encourage them to produce more crops and socioeconomic benefits with less water. A better understanding of these interactions could address institutional, governance and financial constraints in planning, implementation and management of water resources, and increase food production and security.

Global food trade and food security linkages

International food trade is vital for global food security. Food trade improves physical and economic access to food by increasing food availability and lowering food prices for domestic consumers. Food trade and aid also enable the global exchange of surplus food. In other words, they improve entitlements of water through exchange and, in so doing, widen the range of food available for consumption, improving diets and satisfying food preferences. For instance, from 1961 to 2000, the worldwide food export increased by 400% (de Fraiture et al., 2007). Through food trade there is a virtual flow of water from producing and exporting countries to importing and consuming countries. The volume of water imported and exported by six major importing and exporting countries is shown by Table 3 (Hoekstra and Chapagain, 2007). As shown in Table 3, the combined volume of the six exporting countries is close to 1800×10^9 m^3 while the combined volume of the six importing countries is close to 12×10^9 m^3. Several authors (Allan, 1998; Ramirez-Vallejo and Rogers, 2004; Wichelns, 2001, 2005) have described how water short countries can enhance their food security by importing water intensive food crops, i.e. food security through virtual water trade.[4] The virtual water trade has become a silent alternative for most water-scarce countries as it is used as an instrument to achieve water security given its increasing importance for food security in many countries with a continuous population growth (Islam et al., 2007).

The global volume of crop-related virtual water trade between nations is estimated to be 695 G m^3/yr over the period 1995–1999, of which 67% relates to crops, 23% to livestock and the products derived from them and 10% to industrial products (Hoekstra and Chapagain, 2007). Cereals have the largest share in the total virtual water trade, accounting for about 78% of the annual crop-related virtual water. Wheat is the single largest contributor (30%) to the global virtual water export (between 1995 and 1999), followed by soybeans (17%), rice (15%), maize (9%) and raw sugar (7%), as shown in Fig. 4 (Hoekstra and Chapagain, 2007).

Promoting international agricultural trade from water-abundant to water-scarce areas can enhance food security. For instance, international trade is important in national food security goals, with implications for global water resources. Without international trade in cereals, water consumption and irrigation consumption in 1995 would, respectively, have been 6% and 11% higher than with the virtual trade (de Fraiture et al., 2007). It is to be noted that about 13% of the water used for crop production globally was not used for domestic consumption but for export in virtual water, and three major crops including wheat, rice, and maize accounted for about 55% of global virtual water flows between nations during 1995–1999 (Hoekstra and Hung, 2005). Globalization of water resources and domestic virtual water trade from water-abundant to water-scarce areas within large countries, such as China, can enhance food security.

[4] Virtual water describes the water used to produce crop and livestock products that are traded in international markets (Wichelns, 2004). The mechanism of food trade which accounts for water is called 'virtual water trade'. Virtual water trade addresses resource endowments but it does not address production technologies or opportunity costs of trade. Optimal trading strategies are therefore not always consistent with expectations based solely on resource endowment. Trading positions are determined by geopolitical and economic factors and some nations may not have capacity to pay for food imports (de Fraiture and Wichelns, 2010).

Table 3
Top 6 virtual water exporting and importing countries (1995–1999).

Exporters		Importer	
Country	Net export volume (10^9 m^3)	Country	Net import volume (10^9 m^3)
USA	758.3	Sri Lanka	428.5
Canada	272.5	Japan	297.4
Thailand	233.3	Netherlands	147.7
Argentina	226.3	Korea Republic	112.6
India	161.1	China	101.9
Australia	145.6	Indonesia	101.7

Data source: Hoekstra and Chapagain, 2007.

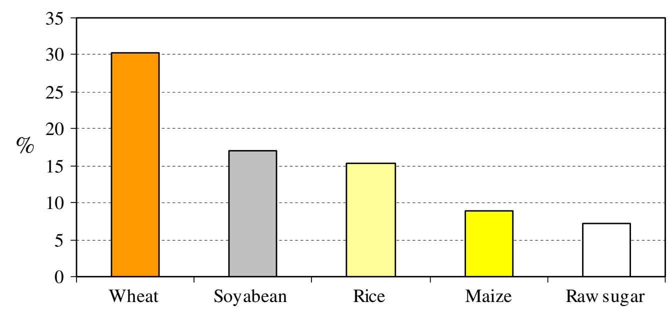

Fig. 4. Global virtual water trade in top five crop products (1995–1999) (Hoekstra and Chapagain, 2007).

Future food security and investment policy

Future food security depends on investments decisions made today for tackling climate change, conserving water and energy resources, developing and adopting new seeds, renewed investments in agricultural water, shoring up domestic food production, reforming international trade, and diversification of food production away from farming. Future food security requires governments and the public to deal forcefully with the issues critical in food production and food security, including population growth, widespread poverty and income disparity, climate change, water scarcity, land degradation and energy and food price inflation. Addressing these interlocking issues simultaneously is inevitable to prevent famine in poor nations. This is only possible through greater international collaborations and strategic investments on several fronts, as discussed below.

Tackling climate change

Climate change challenges to future food security seem immense. There are two potential pathways in dealing with climate change, i.e. mitigation and adaptation. Mitigation is about gasses. Adaptation is about water, therefore our focus in this paper is on adaptation. Water sector adaptations can address water scarcity and food security issues but the costs of adaptation are particularly high in the developing world (Kandlikar and Risbey, 2000). Under population growth and climate change scenarios, irrigated land will be expected to produce most or about 70% of the additional food supplies, placing increased pressure on existing water supplies (Döll and Siebert, 2002). Uncertainties as to how the climate will change and how irrigation systems will have to adapt to these changes pose complex issues that water policies and water institutions must address. The major challenge is to identify short-term strategies to cope with long-term uncertainties regarding climate change and its impact on food security.

The response to climate change must:

- Adapt implementation of core water programs to maintain and improve program effectiveness in developed countries (EPA, 2008), and tailor such programs in developing countries in the context of changing climate, as they will be hard hit.
- Use a river basin approach (with an emphasis on spatial consequences at basin scale) to adapt core water management programs to climate change challenges (Molden et al., 2010).
- Strengthen the link between water programs, food security, energy security, and climate change research to highlight the synergies and tradeoffs.
- Educate water program stakeholders on climate change impacts on water and food security, through knowledge sharing and capacity building.
- Establish the management capacity in food insecure hotspots to address climate change challenges on a sustained basis.

Further, studies are needed to identify and quantify more clearly the potential impact of climate change on water resources, water productivity and poverty to help identify the current adaptation deficit in water resources management.[5]

Getting consumers to eat more grains rather than meat (Mancino et al., 2008) or – better – go vegetarian (Deckers, 2009), and reducing energy intensive lifestyles offers the best hope to tackle climate change and food security issues. Governments must provide incentives to mitigate greenhouse gas emissions and promote the more efficient use of energy and water resources as well as reduce food wastage from farm to fork. Global level collective action frameworks and policies and investments are needed to adapt to and mitigate the effects of climate change on agriculture and global food security.

Conserving water and energy resources

As there is no additional water available, the needed increase in food production must come from increasing water productivity through two basic pathways (Molden et al., 2007), namely:

- Extending the yield frontier in areas where present yields are close to their potential yield.
- Closing the yield gap where considerable yield gains can be achieved with modern technology.

Producing more crop per drop of water and energy can achieve a further increase in food production, using already available land, water and energy resources. Water and energy saving measures would allow considerable gains in yield. In many irrigated systems now facing water scarcity, water use efficiency and productivity could easily be doubled (Molden et al., 2007); rainwater harvesting and light irrigation would enable significant production growth in rainfed systems (Rockström et al., 2010).

Enhancing water use efficiency holds the key to tackling water scarcity and food security issues in smallholder agricultural systems. A case study in the Kaithal and Karnal districts of Indo-Gangetic Plain in Haryana, India suggests that varying irrigation and fallowing for rainwater conservation and groundwater recharge would increase productivity by 23% of wheat equivalent, and might stabilize the watertable at the desired level (Ambast et al., 2006). Extensive modelling of actual crop water requirements and water supply in major irrigation systems in Australia (Khan and Hanjra, 2008) and the Indus basin of Pakistan (Kahlown et al., 2005) also suggests that the present system of irrigation water supply and water allocation requires adjustments to avoid over-irrigation and inefficient use of water, and to address the twin-issues of waterlogging and salinity to maintain crop productivity (Bossio et al., 2010).

Food production is an energy intensive process. The industrial food system is highly dependent on petroleum. Thus fuel shortages will compromise our ability to grow food, affecting global food security. Phrases such as "man eating potatoes made from diesel" pointed to this dependency in the 1970s (Pimentel, 2007). Today, petroleum and other fuels are inside every calorie bite that we eat. Irrigation helps improve crop productivity yet irrigation infrastructure construction, management and operation all require energy. Crop sowing, harvesting, food processing and packaging, and transporting food to markets all require fuel. A typical USA meal travels about 1800 km from farm to plate (Kantor et al., 1997). Every calorie of food produced expends about 10 calories of fossil fuel (Frey and Barrett, 2007). Global food exports and inland deliveries are fuel dependent. The current fuel-food dependency is an unsustainable equation, and the global food system's vulnerability to fuel price increases poses a major challenge to global food security with serious implications for those households that are already living in poverty and are on the brink of hunger. Maintaining food security amid a peak oil crisis needs two parallel strategies:

- Improving energy use efficiency in food production and transportation.
- Dramatically increasing the amount of food grown locally.

\ contradicts VW & WF

It is estimated that by 2020, humanity will be burning around 400 million tonnes of grain as biofuels – an amount equal to the entire world rice harvest (Gerbens-Leenes et al., 2008). This will place pressure on food prices globally. In Australia (for example), biofuels are expected to add around $40 a week to the average household grocery bill. Humanity needs nothing less than an energy technology (ET) revolution to secure its economic and food future (Raghu et al., 2006).

Developing and adopting resilient varieties and building resilient farming systems

Modern rice and wheat varieties were developed during the Green Revolution to feed the growing population of the developing world. Their adoption has helped to build food barriers against hunger, protecting millions from malnutrition. However, the adoption rates of modern varieties remain far below universal, particularly in the developing countries. Hardy seeds and wild crops/landraces adopted to aridity, drought, heat, freezing, and salinity stress must be secured from relatively natural ecosystems such as the central Asian states and parts of Africa (Fentahun and Hager, 2009). These landraces have evolved over thousands of years and have survived under harsh climatic conditions and are thus more resilient to climate change. Farmers living in harsh environments in the regions of Asia, Africa and Latin America have developed/inherited enduring farming systems that offer solutions to many uncertainties facing humanity in an era of climate change (FAO, 2010). Multiple cropping farms in Africa are predicted to be more resilient than specialized farms in the future, across the range of climate predictions for 2060 (Seo, 2009) though the design and large scale implementation of more resilient farms based on non-traditional species in arid areas will pose new research and regula-

[5] The adaptation deficit means that best-bet options in water sector adaptations to climate change are known but not adopted, leaving the current adaptation deficit in water management as a response to climate change. This may be due to high cost of adaptation, lack of water sector programs and policies in the developing countries, institutional failure or stakeholder exclusion in the decision making processes.

tory challenges with respect to food safety and ecological impacts and public acceptability.

The bulk of past investments targeted the foods of the average citizen (such as wheat and rice) while the foods of the poorest (such as millet, oats, barley, yellow maize and cassava) were largely neglected. Future investments must address this imbalance, while harnessing the potential of new varieties through better technologies, particularly genetically modified cropping. Genetically modified (GM) crops could help in addressing water scarcity through water stress tolerance traits, and through a reduction in pesticide use, thus lowering the risk of soil and water pollution. GM cash crops can also contribute to food security along with maximising farm profitability by: reducing crop yield losses (Qaim and De Janvry, 2005); protecting against pests and diseases (Thirtle et al., 2003); reducing pesticides and herbicides usage (Rozelle et al., 2004); reducing exposure of farmers to toxic chemicals (Pingali et al., 1994); reducing machinery, labour and fuel costs (Shankar and Thirtle, 2005); and second-round or multiplier effects on total production and demand for goods and services and resultant welfare impacts as seen in India (Qaim, 2003; Qaim and Zilberman, 2003) and China (Huang et al., 2004).

To date GM crops have been dominated by multinational corporations using copyrights to remove peasant farmer's control over seed stocks. Such copyrights can strip farmers off food-rights (Eide, 1996) (by creating dependency on corporate seed), thus high-jacking the world food supply (Shiva, 2000, 2004). Harnessing their potentiality entails building public–private partnerships between local institutions, governments, farmers and global biotechnology firms (Kulkarni, 2002) along with addressing community and public concerns. The question is whether the GM technologies will survive ethical scrutiny. Also, the reasons why it might survive ethical scrutiny may not necessarily be restricted to concerns about safety and environmental impacts. The benefits of technology have not been realized for the vast majority of crops and people (Tester and Langridge, 2010) and greater success will depend on acceptance and use of contemporary crops as well as increasing the development of climate resilient farming systems utilizing saline water and integrated nutrient flows (Qadir et al., 2010).

Reengaging in agricultural investments

Past investments in agriculture have helped meet rapidly rising demand for food, and has contributed to growth in farm productivity and poverty reduction (Evenson and Gollin, 2003; Hussain and Hanjra, 2004). Such investments are profitable even today and offer large returns in productivity growth and poverty reduction (Fan and Chan-Kang, 2004). Nevertheless, everyone's right to food, as defined by the UN's defence of the right to food (Eide, 1996) must be secured, regardless of profit. Stagnation in productivity and decline in yields amid resource degradation pose new challenges in many areas (Postel and Wolf, 2001), and point to the need for further investments to address these challenges. Reengaging in agriculture through renewed investments in technology, water infrastructure and management, and policies and institutions is the main pathway to addressing the complex future food security challenges. For the first time in the last three decades, the World Bank's World Development Report (2008, p. 8) has been devoted to Agriculture for Development. The report states "the world of agriculture has changed radically. It is time to place agriculture afresh at the centre of development, taking account of the vastly different context of opportunities and challenges that has emerged". This indicates that agriculture is firmly back on the global development agenda. The challenge would be to reach to those poor households and smallholder farmers who were largely bypassed during the past Green Revolution and whose productivity did not rise. Future investments must target geographic areas and food crops of the poorest to make such investments more pro-poor (Alene et al., 2007).

International donors and national governments must reengage in activities critical to safeguard global food security, including:

- Invest in global public agricultural research and development, with emphasis on water for food security and poverty reduction.
- Disseminate new food production technologies to small farmers in both irrigated and rainfed systems.
- Promote Global Water Stewardship and Food Sovereignty as an alternative development paradigm encompassing water security, food security, energy security and poverty alleviation through national ownership and participatory approaches across the full spectrum of water stakeholders.[6]

Reinventing today's irrigation for tomorrow's need to feed another 4 billion people by 2050 remains a daunting task (Molden et al., 2007, 2010). Future agricultural investments must avoid ills of the past while focusing on:

- More water storage including large and small irrigation schemes, modern water infrastructure, recycling and water conservation, upgrading rainfed agriculture, paying irrigators to use less water, and better targeting of subsidies to reach the smallholders and female farmers.
- Better policy packages to take advantage of technical, financial, institutional and organisational synergies between sectors such as agriculture, irrigation, food, trade, energy, health, water supply and sanitation, communication, and global cooperation.
- Integrated service delivery including irrigation water, agrochemicals, microcredit, extension, harvesting, processing, storage, transport, and price information for food production and trade.
- A paradigm shift towards integrating water and energy management for eco-agriculture and for stewardship among consumers and smallholder producers.
- Better agricultural governance to adapt to the changes in water and related sectors, brought by global change.

Shoring up domestic food supplies

A commonly held view articulates that local food security through food self-sufficiency is a misguided concept in today's globalized world (Wichelns, 2001). Others argue that regional food security issues can be better addressed at regional or country level (Chand, 2008). It is important that developing countries place renewed emphasis on shoring up domestic food supplies since they cannot afford dependence on expensive food imports. The main aim of any regional food security policy should be to improve the access for all the people of the region at all times to adequate food for a healthy and productive life through increases in productivity, production and trade of food crops (FAO, 2000).

Strategies to improve productivity must focus on sound macroeconomic management, policy formulation and review, investments in subsectors of agriculture, and sound projects for domestic and regional financing. Regional programs for food security must:

- Focus on supply of seeds, tools and equipment and other strategic components such as credit, on-farm water management, small scale irrigation, better water control and drainage, rain

[6] Global Water Stewardship refers to the global way for high volume water users to take responsibility and receive due credit for improving water management practices, across the water usage cycle, and demonstrate social responsibility and gain competitive advantage through their actions, products and services.

water harvesting, crop intensification and diversification, aquaculture and fisheries, and livestock production, with overall emphasis on technical modernisation and targeted support to smallholders and female farmers.
- Implement policies that increase physical and economic access to food, including through social safety nets.
- Promote participatory policies and practices in the sectors holding key to food security such as food, agriculture, livestock, fisheries, and forestry.
- Promote investments in human resources, sustainable food, and rural development.
- Ensure national ownership, engagement with development partners, and smallholders and gender inclusion.

Reforming international food trade

Food trade in global markets helps match food supply to food demand, and optimise the productivity of technology, land and water resources globally. Economic and trade policies that boost agricultural productivity and contribute to better functioning and more open markets for agriculture and food products are a key factor to improve global food security (Diao et al., 2003). International food trade is vital to food security as only few countries can realistically be entirely self-sufficient (Wichelns, 2001). Even advanced nations with no known food security issues and a very small population such as Australia can suffer from droughts and crop failure, causing a surge in local food prices. The liberalization of world food markets can reallocate resources towards more efficient uses thus boosting productivity and global output but may adversely impact small producers in developing countries (Anderson et al., 2004). International trade reforms must create a level playing field for all actors, including developing countries, through multilateral trade agreements and comprehensive global trade reforms to genuinely liberalize across all sectors including food and agriculture. Harmonized policies for trade must deliver on easing phytosanitary trade barriers, significant cuts to overall trade distorting domestic support (farm support ceiling), cuts to import tariffs, the elimination of export subsidies, and new disciplines on export credits. In particular they must strengthen the incentives for developing countries to boost investments in their agricultural and food systems, to increase their share of global food output and trade.

Moving beyond the farm paradigm

New policies can make food production more sustainable within the carrying capacity or ecological threshold of land and water resources (Khan and Hanjra, 2008). New breakthroughs in human knowledge can change the potential food production landscape. New technologies can extend the production function or carrying capacity beyond its current biophysical limits: first, additional food could be secured by increasing production on bases other than farming, such as production of seaweeds and marine animals. The mariculture (green light spectrum) and agriculture (red spectrum for photosynthesis) approaches could thus be combined to make the best use of natural resources, using the same sunlight twice, and remedying phosphorous lost to the sea. This will require better control of nutrients in open water systems, and their linking to offshore fish and shellfish culture.[7] Second, food/feed may also be produced in a controlled environment such as industrial biological systems by exploiting the nutritious value and high input-use efficiency of certain algae, photobacteria and chemo-autotrophic organisms (Spolaore et al., 2006). Third, using nanobiotechnology for securing foods directly from inorganic inputs can bypass biological organisms altogether (Niosi and Reid, 2007) – synthetic foods could move the food production beyond the farm paradigm. The new food production landscape could complement the farming based approach to food security but would pose unprecedented challenges to the definition and scope of global food policy. These challenges include: food-demand driven factors beyond consumer control *per se*; food as security vs. dependence on commercially-grown food; copyrights and intellectual property issues vs. food as a global commons; corporate greed; and the vent for profit, which would compromise the food security of those who were able to produce *at least* some food for themselves.

[7] The ethical questions related to some aspects of mariculture must at least be recognized, as some people may not find it acceptable to use marine animals. Where this is valid, some aspects of mariculture (those that involve the production of animals) may not be an option.

Conclusion and implications

Debate about global water scarcity and food security has intensified in recent times, and precise estimates of future water and food demand are elusive. Climate change is adding another layer of complexity. The global human population may hit a record 9 billion people by 2050. The much needed increase in food production is not forthcoming. Crop yields are not increasing fast enough either. Instead, limits are faced due to carrying capacity in some areas of the world. Public investments in agricultural research and irrigation are dwindling (Turral et al., 2010). The bulk of the increase in food production must come from areas currently cultivated through increase in water and energy use efficiency.

The analysis showed that, population and income growth will increase the demand for food and water. Irrigation will be the first sector to lose water as water competition by non-agricultural uses increases and water scarcity intensifies. Increasing water scarcity will have implications for food security, hunger, poverty, and ecosystem health and services. Feeding the 2050 population will require some 12,400 km^3 of water, up from 6800 km^3 used today. This will leave a water gap of about 3300 km^3 even after improving efficiency in irrigated agriculture, improving water management, and upgrading of rainfed agriculture (de Fraiture et al., 2007; Molden, 2007; Molden et al., 2010). This gap will lead to a food gap unless concerted actions are taken today. Disrupted access to energy can further deepen the food production gap. The currently unknown adaptation deficit in water management as a response to climate change poses further challenges to future food security.

Food consumption and its immense role in the demand for and types of food and volumes of water, and unfair trade relations must be recognized as challenges to food security. The developing economies and especially the African economies have dismal crop yields for many reasons but one of the most important is global food prices over the past half century. Farmers never had a chance to make a surplus – and then invest – as governments could not resist the opportunity to import cheap food.

A fundamental shift is needed in water and energy use in food systems policy to avoid a severe food crisis in the future. Enhancing food security requires governments and donors to deal forcefully with the underlying issues driving food security, such as population growth, widespread poverty and income inequality, climate change, water scarcity, land degradation, energy and food price inflation. This requires investments for: tackling climate change; conserving water and energy resources; developing, adopting and adapting climate resilient varieties; modernising irrigation; shoring up domestic food supplies; reengaging in agriculture for further development; and reforming global food market and trade. The issues and approaches may be well accepted but investing in the global commons is the greatest challenge faced by the global community. Unprecedented global cooperation is required to address the institutional, governance and financial constraints to ensure future food security for *all* by 2050 and beyond.

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