AGRICULTURAL WATER MANAGEMENT AND FOOD SECURITY IN A SUSTAINABLE ENVIRONMENT

Bart Schultz[1]

Abstract

The Worlds' population is expected to grow from 7.4 billion at present to 10.0 billion by 2055. Combined with the expected rise of living standards, improvement in life expectancy, urbanisation and growing demands for animal feed and energy from crops this requires, among others, a substantial increase in cereal production to ensure food security. Overall, global cereal production meets the current demand and the global cereal stock is stable. Achieving the required increase in cereal production in a sustainable way seems to be possible.

In the framework of rural reconstruction irrigation and drainage will have to play a major role in achieving the required increase in cereal production, while most of the increase will have to be realised at already cultivated land and land reclamation can only result in a relatively small contribution. This implies a focus on approaches and solutions that on the one hand will result in the required increase and on the other hand are environmentally sustainable. In light of this upgrading, modernisation and expansion options for irrigation and drainage schemes will be presented with special attention to the role of drainage. This will be done with due attention for the Sustainable Development Goals (SDG) and the draft Action Plan 2030 of the International Commission on Irrigation and Drainage (ICID).

Introduction

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Population, population growth and urbanisation

The World population is expected to grow from 7.4 billion at present to 10.0 billion by 2055, with thereafter a limited further growth till 11.2 billion by the end of the Century (Figure 1). The growth is especially expected in urban areas of countries with a low, medium and high Human Development Index (HDI) in Asia as well as in sub-Saharan Africa (Figure 2).[1] In addition the standard of living in countries with a medium and high HDI - almost 75% of the World population - is rapidly rising, among others resulting in changes in diets that require more and diversified food per person and in general more water to be produced. A third development is the significant improvement in life expectancy from 46 years in the 1950s to 71.4 years by 2015 (World Health Organisation (WHO), 2014 and 2017).

World food situation and prospectives

Up to present cereal production has been in line with the increase in utilisation and the

[1] Low Human Development Index. Most of the countries in Africa, five countries in Asia, one country in Central America and one in Oceania;

Medium and High Human Development Index. Most of the Eastern European countries (including Russia), most of the countries in Central and South America and in Asia (including China, India, Indonesia and Bangladesh) and several countries in Africa;

Very High Human Development Index. Most of the countries in Western and Central Europe, North America, several countries in Central and South America and in Asia, and the larger countries in Oceania.

global cereal stock even increased in the past years (Figures 3 and 4).

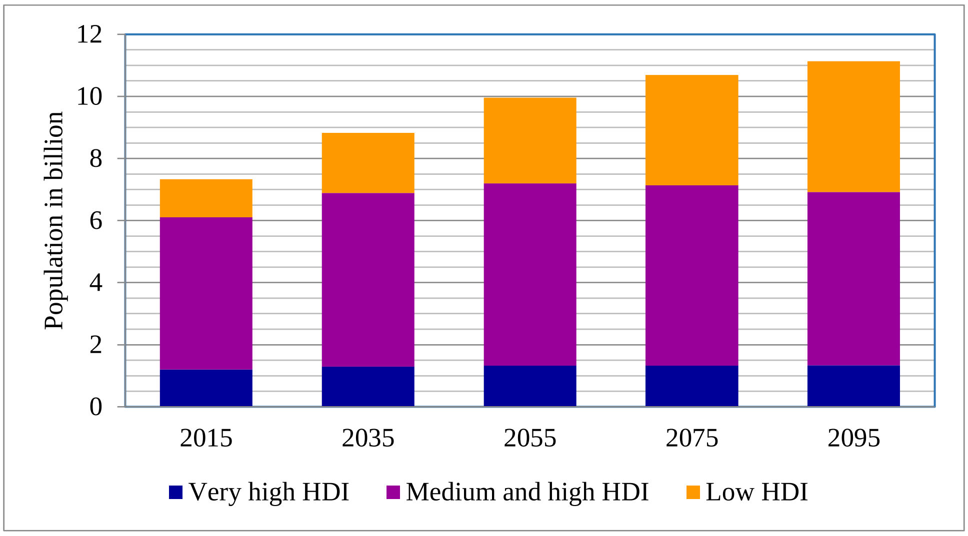
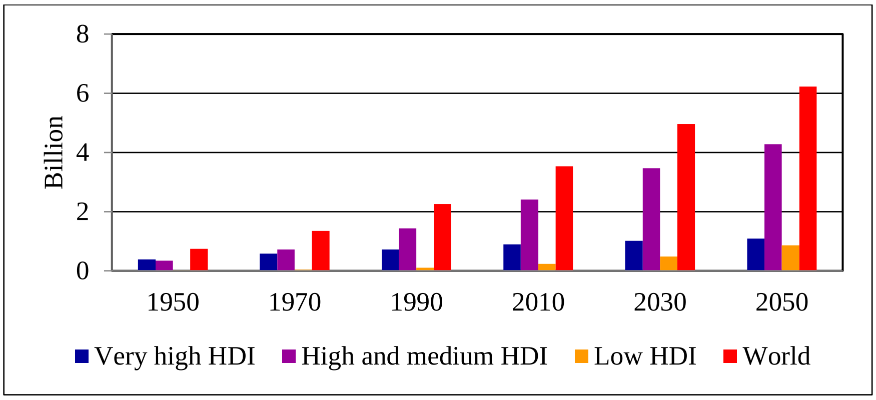
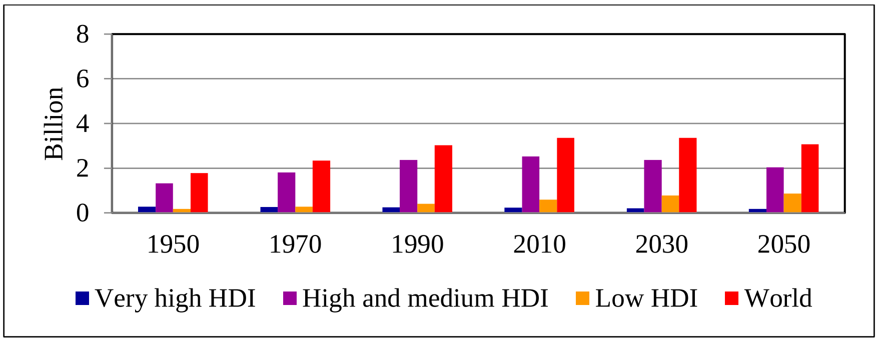


Figure 1. Population and population growth (updated after Schultz, 2012; based on data of the United Nations Department of Economic and Social Affairs, Population Division, 2015)



(a)



(b)

Figure 2. Development from 1950 - 2050 of urban (a) and rural (b) population in the three different groups of countries and at the global scale (updated after Schultz, 2012; UN Population Division, 2014)

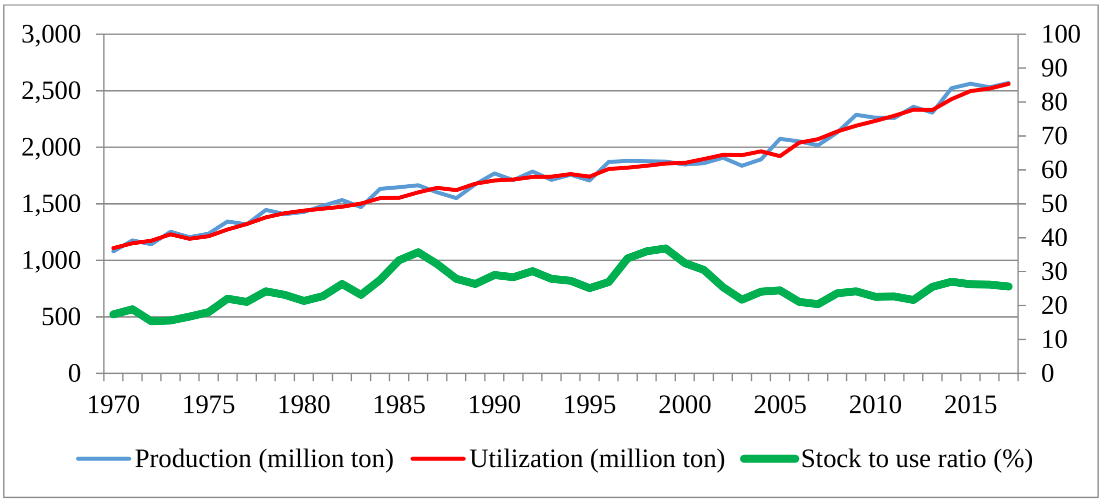


Figure 3. Development in World cereal supply and demand (Data Food and Agriculture Organisation of the United Nations (FAO), 2010 - 2016)

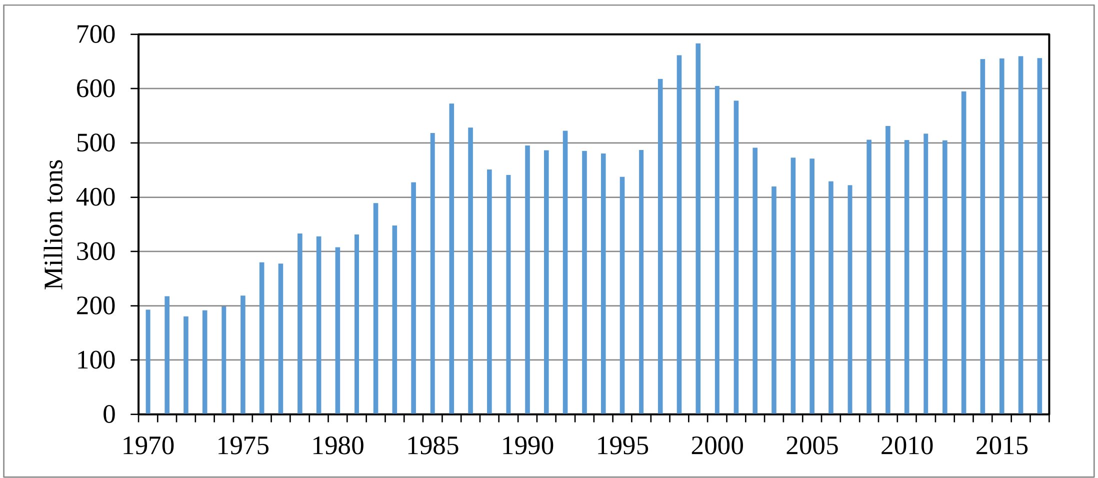


Figure 4. Development of the Global cereal stock since 1970, including forecast for 2017 (Data FAO, 2010 - 2016)

The long downward trend in cereal prices made a turnaround in the period 2000 - 2002 and prices rapidly increased in the period 2007 - 2008 (Figure 5). However, since 2008 prices did not show further increase and even went down for the most important cereals. With respect to farming the on-going urbanisation in countries with a medium and high HDI and to a certain extent in countries with a low HDI will have its impact. In countries with a very high HDI farming has gone through a significant up-scaling. For example in my country, the Netherlands, a farmer could have a living from 5 hectares at the beginning of the 20th century and from 50 hectares by the end. Similar processes can be observed in several countries with a medium and high HDI and to a certain extent already as well in some countries with a low HDI. In several other countries, especially in Africa, where despite rapid urbanisation the agricultural population is not decreasing and may even continue to increase, smallholder agriculture will retain an important place. However, the overall consequence will be that farmers will have to produce significantly more food for urban people in a competitive environment (Figure 6). This will require an increase in farm sizes, transfer to higher value crops and mechanisation. Especially in the countries with a low HDI it also implies that infrastructures have to be strengthened in order to secure the transport of food to the necessary places. Such trends will have to play an important role in measures with respect to food security at affordable prices.

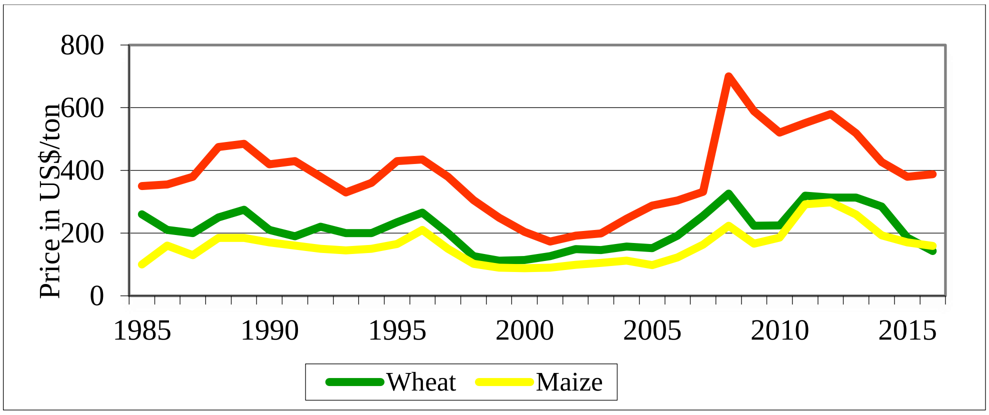


Figure 5. World market prices for wheat, maize and rice. Prices not corrected for inflation (data International Monetary Fund (IMF))

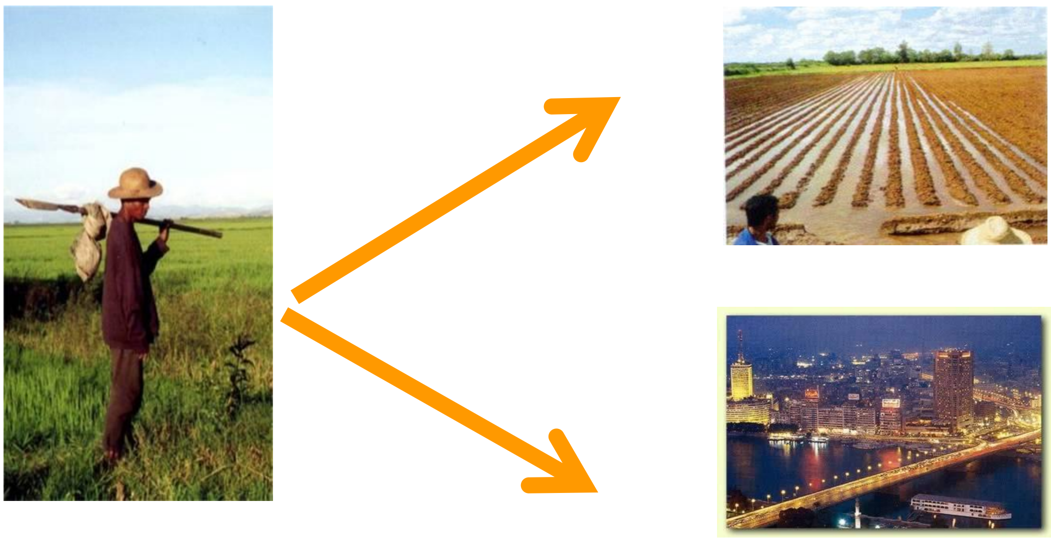


Figure 6. Increase in farm size to produce food for urban people at affordable prices (source: H. Tardieu)

There are different ways to achieve the required increase in cereal production. It can be increase in yield at the existing cultivated area, expansion of arable land, or increase in cropping intensity. There is a common understanding that 80 - 90% of the increase in production will have to be realised at the existing cultivated land and only 10 - 20% by expansion of agricultural land (FAO and ICID, 2014). This can, for example, for several regions be clarified by a study of FAO (2011) as shown in Figure 7.

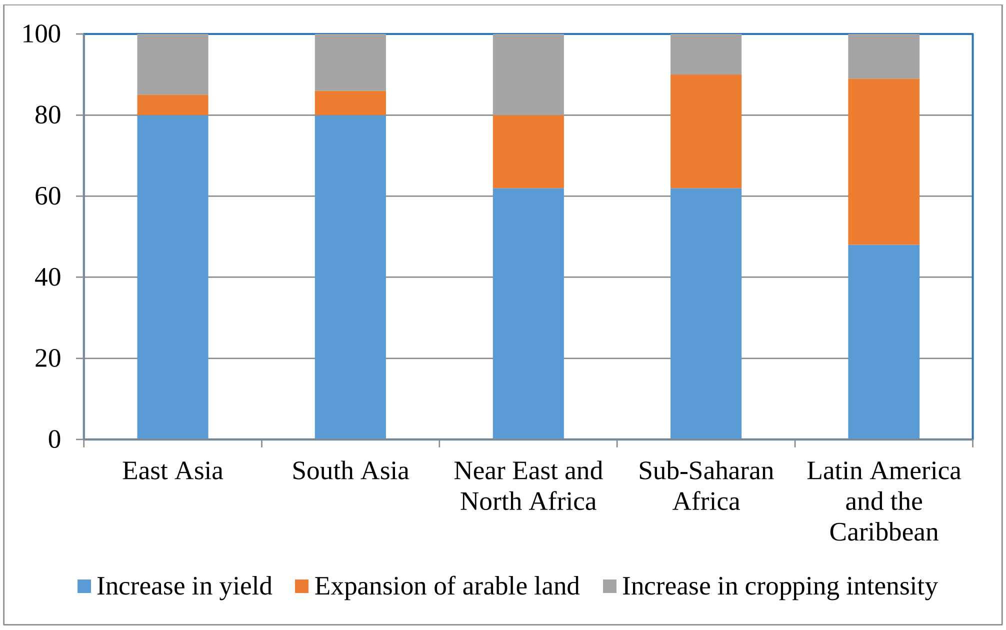


Figure 7. Anticipated sources of growth in crop production 1997 - 2030 (based on FAO, 2011)

Agricultural water management

In the last fifty years, agricultural water management has helped to meet the rapidly rising demand for food (Figures 3 and 4), and has contributed to the growth of farm profitability and poverty reduction as well as to regional development and environmental protection. The Green Revolution has enabled many countries with a medium and high HDI to transform from agrarian to industrializing economies. The technology of high inputs of nitrogen fertilizer, applied to responsive short-strawed, short-season varieties of rice and wheat, often required irrigation to realize its potential (FAO and ICID, 2014). In principle developments can be based on the various options of water management as shown in Figure 8.

When growing food crops, the timing and reliability of water supply and drainage is crucial. In the arid and semi-arid zone, as well as in the humid tropical zone irrigation allows cultivation of crops when rainfall is erratic or insufficient. In the temperate humid and the humid tropical zones drainage is generally required to prevent waterlogging during the winter or monsoon seasons. In the arid and semi-arid zone drainage may be required to prevent waterlogging and salinisation, especially in irrigated areas (Schultz, 1997). For the three groups of countries Table I shows the areas with and without a water management system. Table II shows these data for the different Continents. The data in the two Tables have been determined as good as possible, but have to be considered as rough estimates, while in quite some cases data are not available.

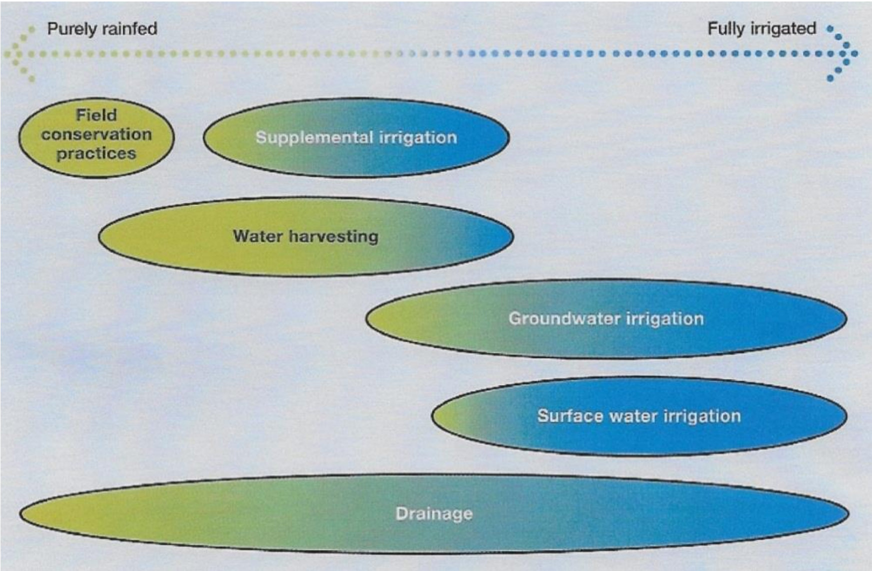


Figure 8. Diverse options for agricultural water management (International Water Management Institute (IWMI - CGIAR), 2007)

The irrigated area of the World increased significantly during the early and middle parts of the 20th century. Production and average yields of irrigated crops in these countries have responded to this demand by increasing two- to fourfold. Irrigated agriculture now provides approximately 45% of the Worlds' food, including most of its horticultural output, from an estimated 20% of the agricultural land. Irrigated agriculture accounts for about 70% (2,850 km^3 per year) of the freshwater withdrawals in the World, and up to 85% in countries with a low, medium and high HDI. In addition rainfed agriculture uses 6,400 km^3 per year. In the 20th century global water use has been growing at more than twice the rate of population increase (FAO and ICID, 2014).

Table I. Cultivated area with and without a water management system in the three groups of countries in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Countries with a very high HDI	436	33	23	56	99	10	109	271
Countries with a medium or high HDI	828	182	78	260	51	24	75	493
Countries with a low HDI	260	28	6	34	2	16	18	208
Total	1532	242	107	349	153	49	202	972

Table II. Cultivated area with and without a water management system in the different Continents in million hectares (Mha) as far as could be identified (based on data of FAO - AQUASTAT and FAOSTAT, ICID, 2017 and Irstea, 2015)

	Cultivated area	Area equipped for irrigation			Drained area			No system
		Surface water	Groundwater	Total	Rainfed	Irrigated	Total	
	Mha	Mha	Mha	Mha	Mha	Mha	Mha	Mha
Asia	530	184	79	262	68	31	69	199
Africa	239	12	3	14	1	4	5	220
Europe	303	18	3	21	54	3	57	225
Americas	400	27	22	48	57	11	68	284
Oceania	49	3	0	3	1	1	2	44
Total	1532	242	107	349	96	49	202	972

The challenge is how to meet the ever-rising demand for food in the context of the above mentioned processes and expected developments, while at the same time increasing farmer incomes, reducing poverty and protecting the environment (FAO and ICID, 2014). While the major part of the increase in food production will have to be achieved at the existing cultivated area the focus will have to be on a higher yield per hectare, and where possible on double or triple cropping. A significant part of the increase can already be achieved by improved operation and maintenance of existing schemes. As far as the contribution of improvement options of water management schemes is concerned the increase can be achieved by (Schultz *et al*., 2005 and 2009):

- modernization of existing irrigation and drainage systems;
- installation of drainage in irrigated areas;
- installation of irrigation in rainfed areas with drainage;
- installation of irrigation and/or drainage systems in areas without a system.

In light of this it is expected that the amount of water withdrawn by irrigated agriculture will have to be increased by 11% by 2050 (FAO, 2010; FAO and ICID, 2014). This will be a considerable challenge in water-constrained areas. An increasing number of regions are already reaching the limit at which reliable water services can be delivered (Figure 9). The situation will be exacerbated as demands of fast growing urban areas place increased pressure on the quality and quantity of local water and land resources.

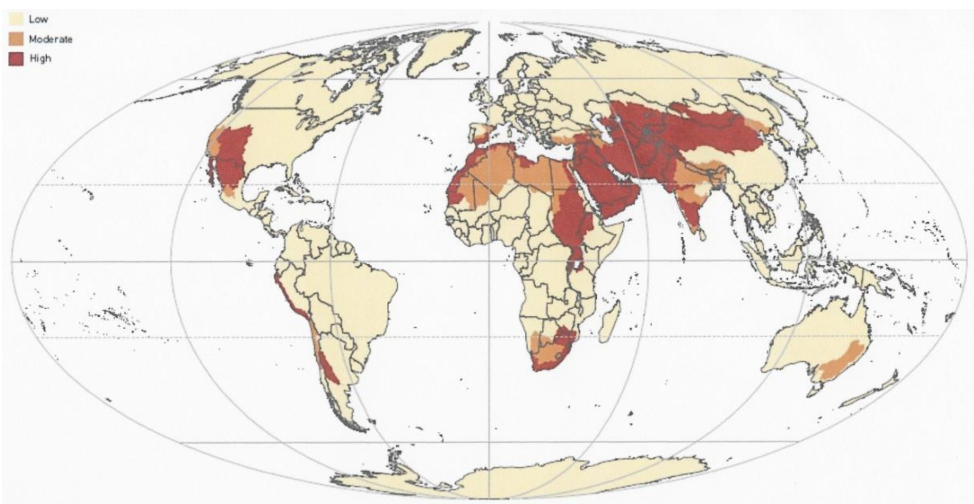


Figure 9. Global distribution of water scarcity by major river systems (FAO, 2011).

Another important point is who are really the actors in agricultural water management. This is shown in Figure 10. A distinction has been made in those who are responsible and those who are contributing. Key issue in this simple scheme is that when the three parties that are responsible have an agreement on their roles and responsibilities, the water management schemes will generally be operated and maintained in a proper way. If they cannot reach such an agreement there will generally be under performance of the water management scheme, resulting in lower yields.

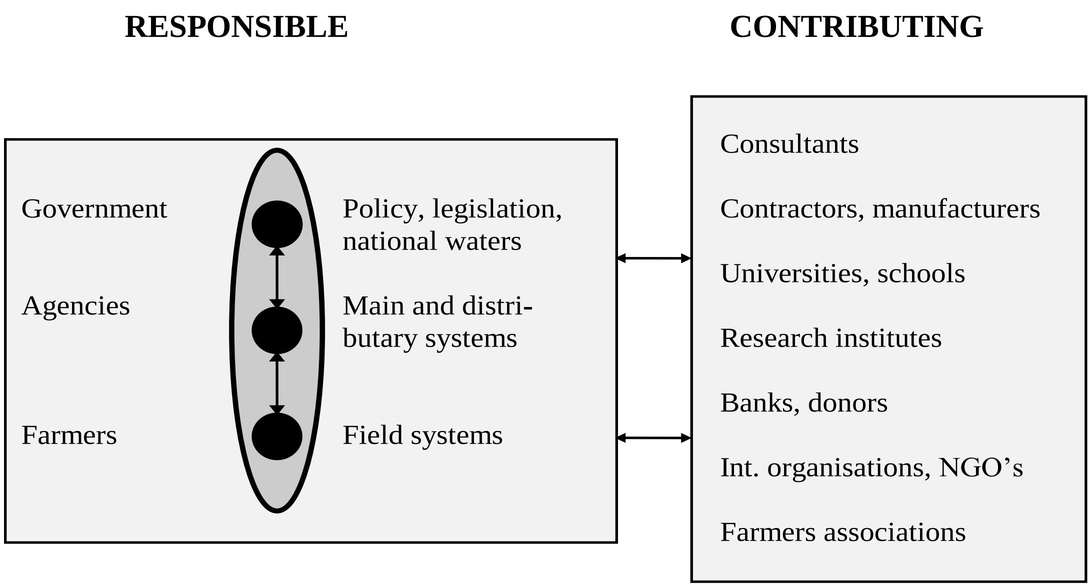


Figure 10. Actors in agricultural water management (Schultz, 2001)

With respect to modernisation of schemes in countries with a low, medium and high HDI it is important to point out that the Governments developed most schemes. These Governments can or will generally not continue to take full responsibility for operation and maintenance. Due to this transfer of responsibilities and/or of ownership of schemes to farmers, or companies is an on-going process. The sustainability of schemes through shared cost-recovery, for which the sustainability cost may be expected from the farmers, is essential (Tardieu, 2005). In parallel to such processes there will be an important role for innovation by better implementation of available research results in practice and by linking research projects and programmes to improved applications in practice. In addition to surface water also groundwater provides a resource and helps maintain the pace of, mostly private, irrigation expansion (Tables I and II). However, in many river basins groundwater is being mined and environmental stress is growing. In such cases measures will be required to assure sustainable exploitation of groundwater resources. An important issue in the arid and semi-arid zone is how to lessen the pressure on agricultural water by bringing in low quality water and reuse of wastewater in agriculture.

Role of drainage

The objective of drainage in agriculture is such that excess water, and may be salts will be removed from the fields in such a way that a good growth of the crops can be assured. With respect to the objectives of drainage different situations can be applicable:

- *prevention of waterlogging outside the main growing season*. Its effect on crops will be indirect. It is referred to as 'off-season drainage';
- *prevention of waterlogging during the main growing season.* This will have a direct effect on crop growth. It is referred to as 'crop-season drainage';
- *prevention of salinization of the soil by irrigation or by capillary rise of groundwater.* It is referred to as 'salt drainage'.

The drain depth and spacing determine the capacity of the system. The best capacity can be formulated in economic terms as that capacity where the net benefits of drainage are maximal. This economic criterion for design purposes is to be translated into hydrological criteria: the design discharge which is the quantity of water the system should be able to discharge during peak periods and the depth at which the groundwater table is to be controlled in those periods. The design discharge is commonly expressed as the required discharge rate in mm/day or l/s/ha. The criteria are different for: off season, crop season and salt drainage.

In many cases drainage systems are installed in lowland areas. This implies that the discharge of drainage water by outlet structures, or pumping stations and flood protection provisions may be of importance as well. In such cases the possible impacts of changes in land use, land subsidence and climate change will have to be taken into account (Schultz, 2000, 2008 and 2016).

As outlined above a significant part of the increase in cereal production has to be achieved at existing cultivated land. As described above this generally implies modernisation of existing irrigation and/or drainage systems, or installation of new systems. It may also apply to increased application of fertilisers and/or pesticides. Here is a very critical point with respect to environmental sustainability, while dependent on the application and the conditions a certain part of the fertilisers and/or pesticides cannot be absorbed by the plants, but will be discharged with the drainage water. In that case pollution of the receiving water body may become a problem. Therefore such applications have to be controlled in a strict way. A good example for this may be the development of environmental legislation in the European Union, among others by the European Water Framework Directive (European Commission, 2000). By this legislation the application by the farmers is being controlled in such a way that the discharge through the drains is at an acceptable level. In order to determine the criteria at several places research has been done. Figure 11 shows field research on the discharge of chemicals in relation to the application through drains under apple trees. Based on results of such researches quality criteria for surface waters have been developed that are applicable to all the member countries. These criteria are binding and have to be fulfilled when developing new projects.

Figure 11. Field research on the discharge of chemicals through subsurface drains under apple trees in relation to the application

Role of drainage in the arid and semi-arid zone

In quite some countries with a low, medium and high HDI drainage has been neglected in irrigated areas. This is especially the case in the arid and semi-arid zone, where the drains only may have a role in the control of waterlogging and salinity development. When in such regions irrigation systems are installed, sooner or later a certain amount of leaching will become required in order to prevent the development of waterlogging and salinity in the root zone. Generally in such cases subsurface drainage at a relatively deep level becomes required. There has been quite some discussion on the preferred depth of such drains. Smedema has made an analysis on the optimal depth that can well be used as a reference (Smedema, 2007). He found that in quite some cases the drains were located at a greater depth than required.

All in all agricultural water management has played and will play a central role in reducing the risk of food insecurity in countries with a Low, Medium and High HDI. To a large extent solutions to facilitate expansion of efficient irrigation and drainage through improved infrastructure and increased water productivity are known and available. Crucial question is what is best applicable under the local conditions (Figure 8).

Sustainable development goals and the draft icid action plan

In January 2016, the sustainable development goals (SDG) as adopted by the United Nations in September 2015 came into force. Six of the seventeen SDGs are of special importance for agricultural water management. These are:

- *Goal 1*. End poverty in all its forms everywhere;
- *Goal 2*. End hunger, achieve food security and improved nutrition and promote sustainable agriculture;
- *Goal 6*. Ensure access to water and sanitation for all;
- *Goal 12*. Ensure sustainable consumption and production patterns;
- *Goal 13*. Take urgent action to combat climate change and its impacts;
- *Goal 15*. Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss;
- *Goal 17*. Revitalize the global partnership for sustainable development.

In this context, ICID is developing its *ICID Action Plan 2030.* The intention of the plan is to show the results of reviews and to propose planning principles, design criteria, operating rules, contingency plans and management policies for new water management systems.

Challenges

In the discussions on the draft *ICID Action Plan 2030* Prof. Daniele de Wrachien has formulated the following key challenges on agricultural water management (Editorial Board, 2016).

Despite the enormous advances in our ability to understand, interpret and ultimately manage the natural world we have reached the 21st century in awesome ignorance of what is likely to unfold in terms of both the natural changes and the human activities that affect the environment and the responses of the Earth to those stimuli. One certain fact is that the planet will be subjected to pressures hitherto unprecedented in its recent evolutionary history. The "tomorrow's world" will not simply be an inflated version of the "today's world", with more people, more energy consumption, more industry, rather it will be qualitatively different from today in at least three important respects:

- *first*, new technology will transform the relationship between man and the natural world. An example is the gradual transition from agriculture that is heavily dependent on chemicals to one that is essentially biologically intensive through the application of bio-technologies. Consequently, the release of bio-engineered organisms is likely to pose new kinds of risks if the development and use of such organisms are not carefully controlled.
- *second*, society will be moving beyond the era of localized environmental problems. What were once local incidents of natural resource impairment shared throughout a common watershed or basin, now involve many neighboring countries. What were once acute, short-lived episodes of reversible damage now affect many generations. What were once straightforward questions of conservation versus development now reflect more complex linkages;
- *third*, climate variations. It is nowadays widely accepted that the increasing concentration of the so-called greenhouse gases in the atmosphere is altering the Earth's radiation balance and causing the temperature to rise. This process in turn provides the context for a chain of events which leads to changes in the different components of the hydrological cycle, such as evapotranspiration rate, intensity and frequency of precipitation, river flows, soil moisture and groundwater recharge. Mankind is expected to respond to these effects by taking adaptive measures including changing patterns of land use, adopting new strategies for soil and water management and looking for non-conventional water resources (e.g. saline/brackish waters, desalinated water, treated wastewater, hydroponics and aeroponics).

While the draft *ICID Action Plan 2030* is still under preparation input and comments have been requested from the ICID National Committees and Work Bodies. All this information is expected to be included in the revised Action Plan that will be presented, discussed and hopefully approved during the forthcoming ICID Congress in October this year in Mexico City. For the draft Action Plan six operational goals have been identified. These are:

- *Goal 1*. Enable higher crop productivity with less water and energy;
- *Goal 2*. Be a catalyst for change in policies and practices;
- *Goal 3*. Facilitate exchange of information, knowledge and technology;
- *Goal 4*. Enable cross disciplinary and inter-sectoral engagement;
- *Goal 5*. Encourage research and support development of tools to extend innovation into field practices;
- *Goal 6*. Facilitate capacity development.

These operational goals have been detailed in strategies, targets and indicators that will be further refined in the coming months.

Conclusion

Global food production is sufficient to feed the Worlds' population; shortages are of a regional and local nature. Although they may be caused by drought or other climatologic phenomena they can be prevented when sufficient action is being taken. First responsibility rests with the National and/or Regional Governments and the farmers or agricultural producers.

Over the past years an impressive increase in food production has been achieved. However, population growth and increase in standard of living, especially in countries with a medium and high HDI, require that food production will have to be doubled over the next 25 – 30 years. It is therefore required that governments have a clear policy on the level of food self sufficiency and on the measures that would be required to achieve this. In addition it will be of importance that they enable that the remaining food can be imported and sold at affordable prices. Based on the common understanding that 80 - 90% of to increase in food production will have to come from existing cultivated land and that the remaining has to come from land reclamation this will require a significant improvement in water management measures and their operation, maintenance and management. In principle this can be achieved.

The Sustainable Development Goals and the goals, strategies and activities as formulated in the draft *ICID Action Plan 2030* create a good frame in which the actual activities in the field of irrigation, drainage and flood control can be developed. However, we have to realise that the problems and activities will become more pronounced in the years to come, as society enters an era of increasingly complex paths towards the global economy. It will require wisdom, spirit, innovation and intense cooperation of all involved to achieve in the coming decades that agricultural water management will be further developed, operated and maintained to assure food security in a sustainable environment.

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