FOOD SECURITY

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OPINION PAPER

Reflections on food security under water scarcity

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Abstract

Forecasts on population growth and economic development indicate that there will be substantial increases in food demand for the forthcoming decades. We focus here on the water requirements of food production, on the issue of whether there would be enough water to produce sufficient food in the future, and we offer options to face this challenge based on recent trends observed in some agricultural systems. Given the competition for water faced by the agricultural sector, and the uncertainties associated with climate change, improving the efficiency of water use in both rain-fed and irrigated systems is the main avenue to face the challenge. In rain-fed agriculture, managing the risk associated with rainfall variability is a promising option to increase productivity. In irrigated systems, a case study on the improvements in water productivity in Andalusia, Spain, is used to illustrate some of the opportunities to make progress. Progress in reducing irrigation water use in recent decades has been substantial, but decreasing the consumptive use of crops is a much more difficult challenge. The need for more research and technology transfer on improving water-limited crop production is highlighted, and emphasis is placed on interdisciplinary approaches to gain the insight needed to achieve new breakthroughs that would help in tackling this complex problem.

Key words: Food security, water productivity, water scarcity, water stress, water use.

The water and food connection

Water has a wide diversity of roles in Planet Earth. It supports the primary production of all terrestrial ecosystems, including those from where we manage to obtain our food and that of the animals we eat. In addition, water is directly connected to the food needs of man as an essential food, perhaps the most essential. Humans cannot survive without drinking water for more than a few days. The irony is that while drinking water requirements are a few litres a day, the water embodied in the human daily diet may be a thousand times more! The lack of public awareness of this simple fact is just one example of the limited understanding and the low visibility that most water problems have in modern societies.

The connection between food production and water consumption is due to the inexorable linkage of the exchange of CO_2 and H_2O between the vegetation and the atmosphere through the processes of carbon assimilation and transpiration (Nobel, 2005). Both processes share the same pathway through stomata and thus it is very difficult to alter the rate of water vapour loss without affecting the intake of carbon dioxide. Despite this limitation, the recognition that water limits crop productivity has led scientists to focus strongly on the efficiency of water use in crop production, as discussed below.

The population growth and economic development of recent decades have driven the demand for food and hence the associated water demand. At the same time that agricultural water demand increased, other sectors of society also increased their demands, notably for the environment. Given the economic and environmental limitations to increase the supply of water to meet the increased demand, the prospects for water scarcity are increasing in many world regions (Molden, 2007). Among the many dimensions of the food security issue, water availability for food production has become most critical. For instance, there is the perception among water experts that the increased demands from other sectors of society would, in the future, limit the allocation of water to irrigated agriculture (Jury and Vaux, 2005). The water required to meet human food needs is substantial and is driven inexorably upwards by population growth and also, by economic development. Our estimates of the embedded water in the Spanish diet show an increase between 1964 and 1991 of about 20% in the water footprint of the average diet, during the time when modern economic development took place. By contrast, changes since 1991 in the water footprint of the Spanish diet have been small, less than 5%. Worldwide FAO average diet figures (FAO, 2002) used by us to estimate the water footprint of the diet suggest that there has been an increase between 1964 and 1999 of 25–30%, and a further increase of similar magnitude may be predicted by 2030. In all cases, the increase in the water footprint was associated with increased consumption of animal proteins and fats. Thus, even if population growth is checked, the per capita increase in the water demand for food due to economic development is also unavoidable, unless drastic changes in the diet occur in the future.

Following the fast increase in crop productivity worldwide between 1960 and 1990, science policy makers became convinced that the capacity of the Earth to produce food was sufficiently large to meet any future demand. This led to a decline in agricultural research efforts, with the exception of the significant research investments on plant molecular biology and on climate change. The few early warnings regarding the uncertainties faced in meeting the food security challenge (e.g. Penning de Vries, 2001, on land degradation) have been followed more recently by renewed interest on this subject, mostly as a consequence of the sharp increase in food prices in 2008. The subsequent fluctuations in world prices depicted in Fig. 1 show a consistent upward trend that certainly has many drivers (ill-directed policies, speculation, competition from biofuel production, etc) but which is also affected by a fundamental imbalance between supply and demand. It is therefore not surprising that food security has not only moved to the forefront of agricultural research, but is now perceived as an important topic for more fundamental research (Nature, 2010; Science, 2010).

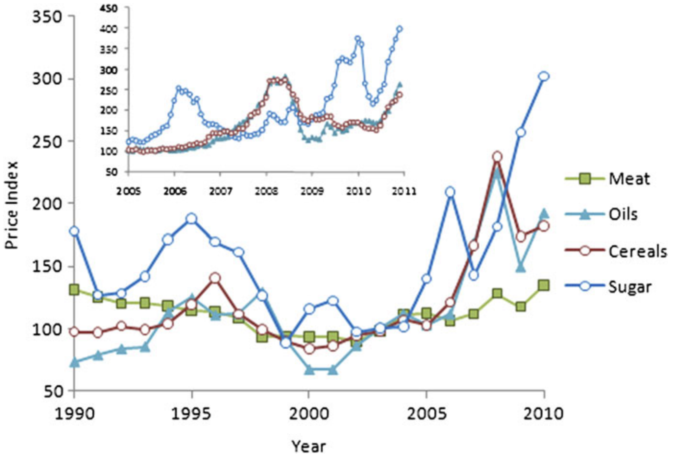

Fig. 1. Yearly evolution of prices for meat, vegetable oils, cereals, and sugars from 1990 to 2010. The price index is standardized to a value of 100 for the global food prices from 2002 to 2004. The inserted figure represents the detailed monthly evolution for oils, cereal, and sugar prices between 2005 and 2010 that highlights recent spikes in prices.

Global assessments of future food production and of agricultural water use under an uncertain climate

It is remarkable than in less than five years so many different initiatives have coalesced to address the subject of global food security. Some have focused on the role of science to meet the challenge of feeding the world by 2050 (Royal Society, 2009) whereas others have concentrated on the development of future scenarios (Agrimonde, 2009) or have carried out expert consultations to explore the different facets of food security by 2030 and 2050 (FAO, 2009). Given the general agreement that further net expansion of agricultural lands will be limited, the question is whether the productivity (yield) increases will be able to match future food demands, estimated to be between 80–100% more than current needs by 2050 (FAO, 2009). Farm yields have been increasing steadily in most major agricultural regions, albeit at different rates. The difference between average farm yield and potential yield (maximum yields of the best varieties limited only by the environment) is termed the yield gap (Lobell *et al.*, 2009). The challenge for increasing production lies in raising average yields by closing the yield gap (via agronomy and plant breeding) and on increasing potential yield through breeding. Fischer *et al.* (2009) have performed a thorough and realistic analysis of the prospects for increasing future yields of wheat, rice, and maize, the cereal crops that supply 50% of food calories globally. They showed that global cereal yields have increased linearly at a constant rate for the last 50 years (Fischer *et al.*, 2009), although they rightly pointed out that linear growth implies declining exponential growth as absolute yields increase. After examining the opportunities for closing the yield gap and for increasing potential yield against future needs, uncertainties, and threats, Fischer *et al.* (2009) are cautiously optimistic about the ability of the world to feed itself to 2050. This view may be threatened by a possible expansion of biofuel production at the expense of edible crops, a questionable option from both social and ethical considerations. The demand for biofuels will increase in future due to its promotion by government policies, such as those of the European Union. To avoid direct competition with human food or animal feed production, biofuels would have to be produced from cellulosic materials obtained from forestry or agricultural residues. Such technology already exists, but awaits a breakthrough to improve its economic viability.

In relation to water use in agriculture, an important study is the comprehensive assessment carried out a few years ago (Molden, 2007) which has been revisited recently (de Fraiture *et al.*, 2010). The United Nations also periodically conducts an assessment of the world water situation, and their latest report, which addressed agricultural water use issues, was released recently (World Water Assessment Programme, 2009). Relative to the food production issue, there are many more differences of opinion regarding future water availability. There are good reasons for this. If global food security assessments disguise the vast differences among regions and the tragedy of the hungry today, similar exercises on agricultural water cannot hide the dynamic nature of water availability and its variations both in space and time which are always associated with a high degree of uncertainty. To summarize current views, it is fair to say that there are more clouds on the future of water availability for food production than on the ability to produce sufficient food in the future. This is particularly the case for irrigated agriculture, which will need additional water supply to meet the challenge of producing more in the coming decades (Molden, 2007). However, in many water-scarce areas, there is already a shortage of agricultural water and additional allocation at the expense of other users, notably the environment, would probably be unacceptable to society. The trade-offs that will be faced in the allocation of water to the different sectors will cause important conflicts in some regions that will be very difficult to resolve.

Climate change (CC) will affect both future agricultural production and water availability. However, most modelling exercises and experimental evidence (Kimball *et al.*, 2002; Ko *et al.*, 2010) indicate that CC would have a neutral to a relatively modest positive effect on agricultural production processes globally, at least to 2050. Although there are many complex interactions (Leakey *et al.*, 2009), one generalization that can be made from the studies conducted so far, is that the negative effects of the higher temperatures more or less balance the positive effects that the increase in CO_2 concentration will have on the photosynthesis of C_3 species. By contrast, the effects of CC on future water availability for agriculture are much more uncertain. There is already evidence of an ongoing intensification of the hydrologic cycle, as shown by changes in some key variables globally and regionally (Huntington, 2010). However, its impact on agricultural production is very difficult to predict as it depends on other variables such as the frequency, intensity or duration of extreme-weather events, for which the evidence for an increase due to CC is mixed and remains uncertain (Huntington, 2010). Nevertheless, when the socio-economic trends are added to the biophysical evidence, all that can be said today from a scientific viewpoint is that, at the very least, CC adds another dimension of uncertainty to the challenge of dealing with climate variability in the path of meeting food demand by 2050.

Dealing with water scarcity in food production

Food security has many dimensions but, regarding water availability, the question of whether there will be enough food in the future should immediately be followed by the question: Will there be enough water to produce sufficient food? There are essentially three main strategies to cope with water scarcity in the production of food. The first is to increase the supply of water and land above present levels. The second is based on increasing water productivity either by enhancing yield or by improving the efficiency of water use, or both. Finally, the third strategy would be to import water in the form of food (virtual water), an option to cope with regional water scarcity which is mostly dependent on economics and world trade.

Developing new sources of water and/or the reallocation of water from other sectors to increase food production has limited potential in some areas and is no longer possible in other world regions. Furthermore, if the reallocation is done at the expense of the environment, it could lead to the degradation of environmental services and to irreversible negative impacts on ecosystems. The expansion of agricultural lands is another option which has been responsible for 20% of the increase in food production of recent decades, but which has limited potential because further expansion has to balance the land lost to urbanization and soil degradation (Penning de Vries, 2001).

The strategy of increasing productivity, the main avenue responsible for around 80% of recent production increase, has not come without negative impacts on the environment in ways that threaten the sustainability of agricultural systems. There is little question that enhanced productivity is the principal strategy for the future, but at the same time that water-limited potential yield is enhanced, agricultural systems would have to be more sustainable. Productivity increases have arisen primarily as a consequence of increasing yield (Fischer *et al.*, 2009) and much less due to reduced water use. Agricultural water use has two components: the water consumed in the evapotranspiration process (ET), and the water lost as runoff or deep percolation. Water use efficiency has increased substantially by reducing water losses (and some of the water consumed in evaporation from soil) through improved agronomy and engineering of irrigation systems. Science has been much less successful so far in reducing the water consumed in transpiration.

The efficiency of water use may be assessed at different scales, from individual plants to single fields, farms or watersheds. At the scale of an individual plant it is measured as the ratio of CO_2 assimilation to transpiration (TE). For almost a century, it has been known that TE is more or less constant in a given environment, as demonstrated by the assessment of Tanner and Sinclair (1983). It is true, however, that some genetic variation in TE has been found (Condon *et al.*, 2004) which has been exploited to obtain modest improvements in wheat yields under dry conditions (Richards, 2006). Only when the assessment of TE is scaled up from leaves to canopies and beyond, does a broader concept of water productivity arise (WP; yield per unit water used) and there are more opportunities to improve WP (Steduto *et al.*, 2007; Hsiao *et al.*, 2007). However, they are mostly related to environmental manipulation and to crop and water management, while only a few have been based on modifying the plant genetic make-up until now (Sinclair *et al.*, 2004; Richards, 2006).

Facing the challenge: improving the productivity and sustainability of agricultural systems

Science and technology have provided humanity with a vast array of options to meet the demand for food, but to make up for the time lost in the last two decades when the food security issue was ignored, there is a need for renewed research efforts focused on actions that would have high rates of return. Here, we outline what we consider are the options with the highest probability of success to ensure food security from the standpoint of water availability. Most of these options are embedded in the philosophy that more will have to be done with less while protecting the resource base, hence the need for further simultaneous improvement of productivity and sustainability. Furthermore, while acknowledging the crucial role of socio-economic measures such as those dealing with economic development and international food trade, the focus here is on the biophysical components of agricultural systems.

Rain-fed agriculture

It is important to emphasize that the boundaries between rain-fed and irrigated agriculture are becoming fuzzy. On the one hand, the uncertainty in water supply to many irrigated areas generates variations in the irrigated versus rain-fed acreages every season. On the other hand, rain-fed farmers in many world areas are keen to develop on-farm storage facilities to provide supplementary irrigation to their crops whenever possible. Furthermore, in most areas, rainfall is an important part of the seasonal consumptive use of irrigated crops, making the current fashionable habit of separating 'blue' from 'green' water (Falkenmark and Rockstrom, 2006) questionable. Evidently, only a small proportion of the world cultivated area is equipped for irrigation (between 15–20%), and important economic, environmental, and institutional limitations restrict further irrigation expansion. In fact, irrigated agriculture at the regional scale will be very dynamic in future, expanding in some areas and shrinking in others, modulated by water availability, salinity, and by markets.

Increasing the productivity of rain-fed systems will be crucial as they cover the majority of agricultural lands. Here, rainfall variability is the primary source of uncertainty and the main cause for the large fluctuations in farmers' income. The threat that the low-income years pose to the sustainability of farming, explains the conservative nature of most farm-management practices adopted by rain-fed farmers. However, practices designed to avoid extreme drought years tend to leave resources unused in the good years, because they do not fully exploit the favourable conditions that periodically arise. In many rain-fed systems, the balance between productivity and sustainability should be tilted more towards productivity in the future, either by accepting more risk or by diminishing the risk. To diminish the risk, the focus should be on augmenting the crop water supply either by using conservation tillage where appropriate or by developing supplementary irrigation where feasible. The best option to diminish risk is to manage it wisely, based on a number of tools and approaches that are being developed to provide pre-season rainfall predictions and anticipated outcomes of management decisions (Cooper *et al.*, 2008). This is an area of research that deserves much more attention, as it would lead to more sustainable rain-fed agriculture.

Irrigated agriculture

There is no question that irrigated agriculture is essential to meet future food demand, but it is also faced with numerous problems that threaten its sustainability. The focus here is on the salinity threat and on water scarcity. Typically, depending on the quality of the water, irrigation adds to the soil anywhere from 2 to 50 t ha^{-1} of salts annually, which must be removed by drainage to prevent salinization and land degradation. Failure to do so has historically led to the end of irrigated agriculture. However, drainage waters cause problems at different scales, impacting all the way from the farm to the basin. At present, the characterization of irrigated land degradation due to salinity is inadequate and so the magnitude of the problem is not well known. Improving crop salt tolerance can only buy time, but it may be part of the solutions focused on controlling both irrigation and drainage. The salinity-drainage problem is inherent to irrigated agriculture and cannot be solved permanently, but long-term research is needed to optimize the management of salinity and to minimize the environmental impact of irrigation. Future water shortages will probably lead to a widespread use of deficit irrigation, a practice that increases the efficiency of irrigation water use but that requires precise monitoring of both water stress levels and of salinity build-up. New tools for stress detection with high-resolution remote sensing (Berni *et al.*, 2009) should assist in the development of precision irrigation. Until now, the allocation of water to meet maximum consumption (ET), as dictated by the evaporative demand of the environment, has been legally considered as reasonable use. In water-scarce areas, in many years there are insufficient water resources to meet ET; thus, new water allocation strategies, institutional change, and novel legal frameworks will all be needed to cope with scarcity.

Another important threat to the sustainability of irrigation is groundwater overdraft, a growing problem in many world areas. For instance, in the North China Plain, the consumptive use of the current wheat–maize rotation far exceeds the sustainable yield of the aquifers in the area, causing the water table to decline steadily over the last decade. Progress in the conjunctive use of surface and groundwater will mitigate those problems, but the unsustainable use of groundwater cannot be a valid path for future increases in productivity and alternative approaches must be found to cope with water scarcity.

What are the limits of agricultural productivity? Steady increases worldwide have been seen for decades now, but it is instructive to examine the recent evolution of productivity in the irrigated systems of a region facing water scarcity. The case study that is presented here for Andalusia, Spain, illustrates how productivity gains can be made without developing additional water for irrigation, but it also points to the limits of a path that has been undertaken in the last 15 years.

Case study: trends in irrigated agriculture in Andalusia, Spain

The importance of irrigated agriculture for Andalusia cannot be overemphasized. Nowadays, using only 25% of the agricultural lands, it represents over 65% of the total production and of the agrarian employment. Its modern development is quite recent, starting in 1950 when only 250 000 ha were irrigated. A vigorous hydraulic infrastructure development programme expanded irrigation in the following decades, reaching 650 000 ha by 1996. At that time, the Water Authority ascertained that future expansion would be limited by water availability, as only minor new surface water development was envisaged. This was reflected in the 1992 Hydrologic Plan, where future irrigation expansion followed the moderate trend depicted in Fig. 2. It was stated that the additional water resources needed for such an expansion would have to come mostly from water saved in the modernization of traditional irrigation networks.

Soon after 1992, a dramatic change took place in the irrigated agriculture of Andalusia. The expansion in irrigated area had been greater than anticipated (Fig. 2), with a strong shift towards tree and horticultural crops of greater socioeconomic importance than the traditional field crops. Strikingly, the increase in irrigated area was performed without increasing the irrigation water supply in the region, which has remained around 4000 hm^3 $year^{-1}$ for the last 15 years. There have been significant water savings over that time though; average water delivery which was 4900 m^3 ha^{-1} in 1997 has been reduced to 3600 m^3 ha^{-1} in 2008 (Inventario de Regadíos, 2010). The question is how this transformation occurred and what role science and technology played in achieving this change. Firstly, there was a shift from crops with high irrigation requirements, such as cotton or sugar beet, to crops that have much lower needs, such as olive. The evolution of the main crops in the region is shown in Fig. 3, with steady increases in the production of horticultural crops and in olives whereas the production of irrigated field crops drastically declined. Substantial investments were made in irrigation engineering, from eliminating losses in the distribution networks to shifting from surface to drip irrigation. The proportion of drip irrigation went from 37% in 1997 to 64% of the total irrigated area in 2008 (Inventario de Regadíos, 2010). The quantitative assessment of irrigation needs and other irrigation management technologies were introduced and adopted, together with the dissemination of deficit irrigation practices, which are now widely used. Given the asymptotic relationship between applied irrigation and crop yield (Fereres and Soriano, 2007; Fig. 1), water productivity increases substantially as irrigation is reduced. As an example, WP in maize increases from 0.35 kg m^{-3} at an irrigation level of 8000 m^3 ha^{-1}, up to 1.8 kg m^{-3} at an irrigation level of 3500 m^3 ha^{-1} in Cordoba (Mantovani *et al.*, 1995). The expansion of irrigated area without additional water development has been achieved by using deficit irrigation in the olive and in winter annuals such as wheat and sunflower.

The positive aspects of recent changes in Andalusian agriculture are evident, as demonstrated by the capacity of the agricultural sector to sustain an annual productivity increase of 3.6% without increases in water supply. Furthermore, the average annual growth of Andalusian agricultural income in the same period was 4.8%, at a time when the annual income of Spanish agriculture has declined. However, in relation to food security (i.e. calories) there are trade-offs, as the productivity and income increases were not accompanied by the production of more edible energy, as shown by the constant trend in total calories during the period of Fig. 3. Under Cordoban conditions, the maximum economic WP of maize is 0.27 € m^{-3} and the grain produced is equivalent in edible energy to 6300 kcal m^{-3}. Olive has a much higher maximum *WP*, 1.1 € m^{-3}, but the energy of the oil produced is only 5400 kcal m^{-3}. There will be situations where crop

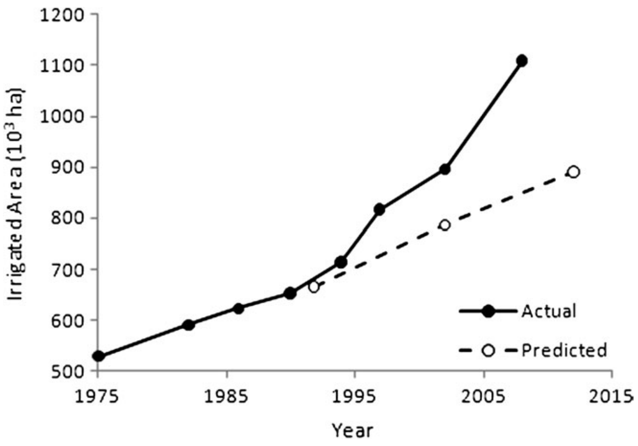

Fig. 2. Evolution of irrigated area in Andalusia, Spain. Dashed line indicates the expansion anticipated in the National Hydrologic Plan of 1992. Solid line depicts the actual evolution of the irrigated area of the region.

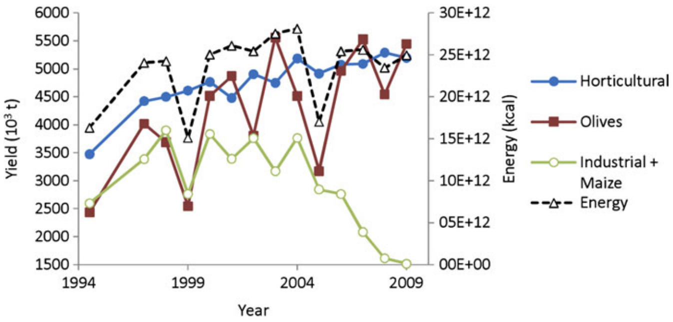

Fig. 3. Evolution in Andalusia, Spain, of the production of: (a) olive (irrigated plus rain fed; squares); (b) horticulture (solid circles); and (c) irrigated field crops (open circles). The dashed line indicates the evolution of total edible energy. Sharp declines in the production of some years were caused by the impact of periodic droughts (developed from original data reported in the Annual agricultural production report, Consejeria de Agricultura y Pesca, Junta de Andalucia).

diversification towards high value crops may lead to the production of less edible energy per unit of water used.

The challenge ahead for Andalusian irrigated agriculture is to sustain the present productivity levels, as further area expansion is not possible or desirable. Recent increases in groundwater use suggest that the limits of area expansion have already been reached. Also, an additional reduction in irrigation water allocation may not be efficient, as there are optimum levels of deficit irrigation below which WP declines quite sharply (Fereres and Soriano, 2007). The control of salinity under deficit irrigation in the long run would be critical in the areas where annual rainfall is insufficient. More emphasis on enhancing the sustainability of current agricultural systems will be required.

As water and energy costs rise, production costs in irrigated systems will increase. One trend that is already occurring in the search for higher productivity and profitability in water-scarce areas is a shift from field to horticultural crops, generally ones of higher value. This is evident in the Andalusian case study, but it is expressed even more dramatically in the case depicted in Fig. 4 for Monterey County, California, an area gifted with a very favourable climate and excellent soils. There, the increase in the area devoted to horticultural crops (Fig. 4) can be totally accounted for by a concomitant decrease in the area of field crops during the same period. The increase in crop value in Monterey County reflects both the productivity increase with time, but also an ability to add value and to innovate which comes from intensive public–private partnership research efforts in that region. Equally important is the capacity to sustain highly intensive horticultural production over the same land for many decades, an achievement which requires significant efforts in maintenance research, for instance in breeding for disease resistance. While the examples discussed above represent a small fraction of irrigated agriculture, they signal a trend in water-scarce areas where the growing of traditional field crops under irrigation is no longer economically viable, with the implications that this has for future grain production.

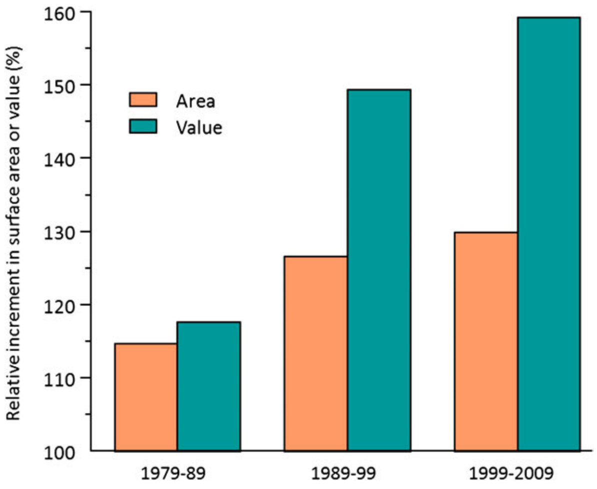

Fig. 4. Evolution of the relative increase in the irrigated area devoted to horticultural crops and of relative crop value (in constant dollars per hectare) over three decades starting in 1979, in Monterey County, California (developed from original data reported in the Archived Crop Reports, Monterey County Agriculture on-line).

Conclusion: areas of future research

Increasing water-limited food production beyond present levels is a very complex problem which has been the subject of substantial research that has achieved only modest progress so far. Before focusing on future research, it is worthwhile to point out that there is still a significant gap between the level of water management technology currently used and that already available, calling for substantial efforts in extension and technology transfer in water-scarce areas. Regarding future research, if we are to build on past successes, combining research on plant breeding, crop physiology, and agronomy, and exploiting their interactions should be the main strategy to follow in the future. Reversing the decline in these disciplines that has occurred over the last two decades, and achieving a more balanced funding of agricultural research, spanning plant molecular biology to climate change, are prerequisites to achieve success.

The recent advances in molecular genetics have been extremely successful in developing new cultivars resistant to herbicides and to some of the major pests. Similar progress in tackling water limitation has not been so successful because of the myriad of genes involved in the plant response to water deficits. Genetic traits considered promising at the lower levels of biological organization (from cells to organs) must demonstrate their benefits at the level of crop community, where plant performance under drought is the result of the interactions between the genetic make-up with a changing environment and with farm management (Passioura, 2007). A novel approach that appears promising to deal with the formidable task of scaling up to the crop level combines molecular genetics with phenotyping and simulation modelling (Chenu *et al.*, 2009). Future progress will increasingly be based on such interdisciplinary approaches to gain the insight needed to unravel the complexity of breeding crops for water-limited production.

Progress towards increasing yield potential will be required as yield gaps close in high-yielding environments. However, there are barriers limiting further increases in both harvest index (HI) and in biomass via genetic improvement. Research focusing on fundamental modifications of the CO_2 assimilation processes to enhance photosynthesis has not been successful, and is unlikely to deliver in the short term. In the main cereals, HI is approaching its theoretical maximum and further progress will be slow, but it should be based on a better understanding of the physiological processes underlying yield potential. In the short term, there is little doubt that research investments focused on closing the gap between actual and potential yields should have greater rates of return than those aimed at increasing yield potential.

Improving the drought tolerance of crops may be attempted in many different ways, but the most promising avenues are increasing the fraction of the water available that is consumed as crop transpiration (T), and the maintenance or even enhancement of harvest index under drought conditions. Agronomic research will form the basis for progress in maximizing T, but improved physiological understanding of root systems and of their role in capturing water will also be required. Direct attempts at improving transpiration efficiency per se may not be the most efficient pathway towards improving drought tolerance. There is an indirect approach that may be much more promising to enhance TE and that is based on improving crop growth rates under low temperature. The early establishment of a full canopy under low temperatures would increase TE and would also assist in drought escape. Although low temperature constraints affect most basic growth processes, there is no reason why recent advances in genetic manipulation could not be applied to tackle this problem.

A fundamental understanding of the physiology of biomass partitioning and yield determination is a prerequisite for success in addressing the maintenance of harvest index under stress. Plant breeding to improve the stress tolerance of the reproductive organs of major crops stands out as probably the best option to improve production in rain-fed agriculture. Similarly, as deficit irrigation becomes more common in irrigated systems, the maintenance of HI will also be critical for maximizing water-limited yield (Fereres and Gonzalez-Dugo, 2009). There is no doubt that, given the uncertainties in future water availability and its implications for food security, research efforts on how to cope with the water limitation to food production should escalate to unprecedented levels in the coming years, as it is becoming evident that time is running out.

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