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The Institution of Engineering and Technology

Water for UK agriculture – key challenges and opportunities

Accurate application to minimise losses and reduce environmental impacts is critical

UK agriculture

UK agriculture has a multifunctional role that sits at the interface between the natural environment and society. It contributes to a wide range of both 'food' and 'non-food' services including environmental and landscape enhancement, leisure and recreation, as well as providing various raw materials. This insight outlines some of the key components of UK agriculture, and the important risks, challenges and opportunities facing the sector, in the context of water use and water impacts. It focuses on the 'food crop' production elements of agriculture (e.g. arable, horticulture); livestock, forestry, marine and fisheries, and other 'non-food' services including environmental and landscape enhancement, biofuels are not included.

A multifunctional sector

Although UK agriculture accounts for a relatively small proportion of the national economy and employment, it occupies almost 75% of the total surface area (Angus *et al.*, 2009) and provides a range of important benefits to society. Perhaps the most obvious of these is production of 'food' and 'non-food' crops with UK agricultural land,

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contributing around 50% to UK food consumption (Defra *et al.*, 2010). Agricultural ecosystems provide a range of other important services too, including regulation of air quality, climate and water purification. Agricultural land also delivers significant non-material cultural benefits, such as land for recreation and valued characteristic landscapes.

The agricultural landscape represents the dominant image of nature for much of the UK's population and is a valuable part of our heritage, with around 80% of England's national park land sited on agricultural land. Agricultural land also supports a range of semi-natural habitats, helping to support wildlife and biodiversity, and contributing to ecosystem services (Sugden *et al.*, 2008). The importance of agricultural land, therefore, goes far beyond food production – the actions of farmers can thus have positive or negative effects on the range of services provided (FAO, 2007). All of these services are likely to be affected by a range of factors including changes in environmental regulation, socio-economic policy, economic development including urbanisation and climate change (Knox *et al.*, 2012).

Water use in agriculture

In 2005, a baseline assessment of agricultural water use in England and Wales was conducted, which estimated total on-farm abstraction to be in excess of 300 $Mm^3\ y^{-1}$; approximately 60% was used for irrigation of outdoor field-scale agricultural and horticultural crops (128 $Mm^3\ y^{-1}$, notably potatoes and field vegetables) or protected and nursery cropping (53 $Mm^3\ y^{-1}$). Compared with total national abstractions, including those for public water supply and industry, agricultural irrigation constitutes only a minor use (1 to 2%). However, the problem is that irrigation is consumptive (that is, water is not returned to the environment in the short term), concentrated in the driest areas, in the driest years and driest months when resources are most constrained (Knox *et al.*, 2010).

Most agricultural cropping in England and Wales is rainfed and, even in a dry year, only a small proportion of land (<5%) is typically irrigated. Since 1955, the government has published statistics on agricultural irrigation, based on surveys carried out roughly triennially, most recently in 2005. These provide statistics on the areas irrigated, volumes applied and water sources used for irrigation. Over the last 20 years, there have been significant changes in the types of crops irrigated. The proportion of irrigation on grass, sugar beet and cereals has declined steadily. In contrast, there has been a marked increase in irrigation of high value crops, particularly potatoes and field vegetables. This trend is driven by supermarket demands for quality, consistency and continuity of supply, which can only be guaranteed by irrigation.

Most water for agriculture is abstracted from rivers and streams, and is used direct with relatively little on-farm storage. Over half (54%) of all irrigation abstraction in 2005 was from surface sources (rivers, streams). Groundwater abstraction (boreholes) accounted for 41% and other sources (e.g. water harvesting) was 4%. Only 1% of water used for irrigation was taken directly from public mains supplies, mainly because peak demands for agricultural irrigation exceed those that can be supplied from the public mains supply. Public mains water is only used on small horticultural units (e.g. strawberry production) where lower rates of water use are required, or where water quality is an important factor (e.g. glasshouse production). In field-scale irrigation, very little rainwater is harvested and re-used due to the small volumes that can be captured and requirements for storage, but it is widely used and economically justifiable for small-scale holdings (e.g. protected cropping).

Efficient water use will be essential for securing future world food supplies

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Water footprints in agriculture

Agriculture requires large volumes of freshwater and has the largest water footprint of any sector in England and Wales. Understanding the magnitude of the water footprint of irrigated crop production can help to contribute to sustainable food production, by identifying activities that appropriate large volumes of water. However, unlike ‘carbon footprints’, the ‘water footprint’ needs further elaboration before it becomes a useful indicator. It is important to separate ‘blue’ from ‘green’ water, but it is not all about ‘size’ – large water footprints are not necessarily ‘bad’. It is important to relate the magnitude of the water footprint to its impact on society and the environment. It is clear that in some parts of England and Wales, and at some times of year, abstraction of water for irrigated production places considerable stress on freshwater resources. There are opportunities to alleviate this stress, by making better use of water on-farm, or through better abstraction control. However, the contribution of irrigated agriculture to domestic food production and rural livelihoods must not be ignored. Growers, regulators and the food industry need to work together to encourage benign water use, rather than simply reduce the ‘water footprint’ in particular crop sectors.

Location of irrigated production

Irrigation of food crops can be the largest abstractor in some catchments in dry summers and concerns have been raised over the potential impacts of irrigation abstraction on the environment, particularly in catchments where irrigation is concentrated and resources are under pressure. In many catchments, summer water resources are already over-committed and additional summer licences for surface and groundwater irrigation abstraction are unobtainable. Hess *et al*. (2010) analysed the spatial distribution of agricultural holdings involved in potato, field vegetable and soft fruit production relative to resource availability, by catchment using a (GIS). That analysis showed that on average only 10-15% of agricultural holdings were located in catchments where additional water abstraction would be available during summer low-flow periods (“water available”). About half of all holdings are located in catchments defined as having ‘no (more) water available’ or were already ‘over- licensed’. Nearly a fifth were in ‘over- abstracted’ catchments. Therefore, in water stressed catchments, where water demand for irrigation (abstractions) exceeds available surface or groundwater water supplies, reducing the blue water component of the water footprint would mean that water resources could be released to sustain environmental flows or support other uses.

Managing water better in agriculture

Internationally, irrigation has a reputation for low water efficiency. However, in the UK irrigation is supplemental to rainfall. Growers use relatively little water by international standards and are generally highly conscious of the need to improve water efficiency. But even in a humid climate, there is scope for using less water in agricultural food production. Making the maximum use of soil moisture and rainfall, knowing precisely where and when irrigation needs to be applied and then applying it accurately and uniformly, are fundamental steps in the ‘pathway to efficiency’ (Knox *et al.*, 2012). Introducing new technologies and management practices, often developed in arid countries, together with efforts to bring the average irrigator nearer to the best, can help improve both on-farm water management and reduce the environmental impacts of irrigation.

Managing water better predominantly focuses on using water more wisely. Most irrigators aim to do this because saving water usually means saving money, by reducing pumping, storage and labour costs. But more can be done on-farm to make better use of existing sources, to obtain more ‘crop per drop’ (t m^{-3}) and more ‘value per drop’ (£m^{-3}). In England and Wales, it is a requirement for renewing agricultural irrigation licences that abstractors demonstrate ‘efficient’ water use. This is a strong regulatory measure for driving water efficiency upwards. However, the cost of pumping water and providing labour and equipment for irrigation also provides a strong economic case. Conversely, the costs and implications of inefficient irrigation - poor quality, unsaleable produce – are significant.

Although water is becoming scarce in many catchments in England at critical times of year, there are still opportunities for improving the sustainable use of water resources. Surprisingly, most of the water allocated to irrigated agriculture is not actually used, even in dry years, due to a variety of agronomic, economic and water-resource constraints. In many instances, the water is in the wrong place and/or available at the wrong time. Finding environmentally and financially viable methods of transferring it to where it is needed, or storing it for use in the following summer, would go a long way towards resolving present water shortages.

One of the most popular strategies for increasing water security on-farm is through the use of storage reservoirs (either individual or shared), harvesting high flows during the winter and storing for use the following summer. Although storage would slightly increase the total water footprint due to leakage and evaporation losses, it should reduce the environmental impact of the water abstraction, reducing pressure on summer supplies when resources are most stressed, in addition to enhancing the local landscape and providing new opportunities for biodiversity.

There are substantial opportunities to obtain better value from available water by trading or sharing resources, by promoting water benchmarking to improve irrigation performance and by developing conjunctive use of surface water and groundwater to improve reliability of supply. Whilst such measures do not necessarily result in reductions in water use, they do improve levels of water use efficiency (t m^{-3}) and water value (£m^{-3}) within agriculture. Businesses need to assess which measures are technically and economically appropriate and then prioritise accordingly.

Managing agricultural abstractions

Becoming more ‘efficient’ at the farm level may not necessarily reduce the water footprint of irrigated food production if the water that is released is used to increase the irrigated area or the depth applied. In some catchments, it may be necessary to manage abstraction by regulation. All water abstractions in England and Wales (>20 m^3 d^{-1}) require a licence from the water regulatory authority (EA). New licences and renewals are set in accordance with the Catchment Abstraction Management Strategy (CAMS) developed for each catchment, for both surface and groundwater. Tiered “hands-off” flow or groundwater level limits protect the sources from over-abstraction. If conditions alter, for example due to climate change, the regulator will be able to revise these limits periodically to take account of the changes. Unfortunately, many of the older licences did not include such constraints and most were not time-limited. In those cases, the EA can still stop abstraction through “Section 57” restrictions and Drought Orders, though these are blunter instruments, as all abstractors are treated in the same way.

Climate risks to UK agriculture

Climate change will influence the way in which crops grow, develop and yield. As a biological system, the driving force in outdoor crop production is photosynthesis. UK grown crops will be directly sensitive to any future changes in sunshine, rainfall, temperature and CO_2 concentration levels. There will also be indirect impacts on the agricultural potential of soils by modifying soil water balances, affecting moisture availability and land management practices including trafficability and workability (Daccache *et al*., 2012). Reduced water availability for agricultural abstraction as a result of lower river flows will impact on supplemental irrigation, both for existing irrigated crops and on new crops which may need watering to cope with increased droughtiness. Climate change may lead to more frequent and extended periods of water logging, and more frequent and larger areas of inundation of high grade (floodplain) agricultural land, with consequences for agricultural productivity. There may be many other indirect effects – including, for example, changes in the range of native/non-native pests and crop diseases (e.g. potato blight, *fusarium*), increased crop damage (e.g. wheat and salads) at extreme temperatures, crop diversification and introduction of new or novel crops (e.g. maize, sunflowers), as well as changes in land suitability. Many of these impacts are inextricably linked and could have either a positive or negative impact, or a combination, depending on the assumed future socio-economic scenario and farmer perceptions to climate risk.

For outdoor livestock and animal farming, the effects of climate change will be complex and variable. Grass production may be enhanced by increases in the

Harvesting and storing high flows in winter reduces water resources pressure and drought risks in summer length of the growing season, especially in upland areas, although future water shortages could limit production in some years especially in lowland areas. A changing climate would impact on livestock health, forage yields, feedstuff quality, availability and cost, water availability, thermal stress and related welfare issues, including disease spread and control measures. The main impacts are likely to relate to changes in CO_2 levels (impacting on grass productivity and dietary quality), temperature (causing heat stress, influencing reproductive capacity and increasing pathogen and fly problems), water availability (for grassland production), and weather extremes (changing housing and supplementary feed needs). Many of the issues identified for outdoor livestock are equally relevant to housed animals, although increasing energy costs pose a significant additional risk (Knox *et al.*, 2012).

The impacts of a more unpredictable and warming climate on UK cropping are likely to result in a range of threats and opportunities. Increases in temperature and radiation coupled with elevated levels of CO_2 could increase crop yields, but only to a point where other management factors, including water and nitrogen availability, are not limiting. It will not be the gradual change in climate which will impact on growers, but rather the greater annual variability of climate and frequency of extreme events (flooding, drought and heatwaves). Any increase in the frequency of such events will have both an agronomic and economic impact on agriculture. In this context, climate change is likely to exacerbate production fluctuations and lead to the return of buffer stocks and intervention buying –there are signs that this phenomenon, which was last seen in the 1930s, is re-occurring. Growers will also need to deal with an increasing number of 'non-climate' risks, both on and off-farm, as these may pose a much greater degree of uncertainty on crop production.

Non-climate risks to UK agriculture

Internationally, agriculture is widely regarded as one of the sectors at most risk from a changing climate, due to the impact of increased temperatures, reduced rainfall and increased frequency of extreme events, not only in the tropics, but also in temperate environments. In the UK, agriculture also faces a range of 'non-climate' risks, which are often argued present a potentially greater and more immediate threat to UK sustainable food production than climate change. A summary of the main 'non-climate' risks are given in Table 1, grouped according to whether they are economic, environmental or technological in nature, recognising there are overlaps. The majority occur 'off-farm' and impact via various national and European agro-economic policy interventions; the increasing burden of environmental regulations; limitations in the availability of finance; fluctuating exchange rates; and the relative power of supermarkets as these affect the operation of markets, including requirements for auditing and traceability.

The most significant economic impacts on-farm relate to CAP reform, as it could affect farm income support, compliance requirements and incentives for environmental sensitive farming. Rising production costs for water, energy, labour and fertiliser, coupled with increasing risks associated with infrastructure damage due to flooding are other sources of economic risk. Much depends on whether these increased costs are offset by higher commodity prices arising from strong global demand - the latest OECD-FAO (2010) forecast is that average crop prices over the next ten years will be 15-40% higher in real terms relative to 1997-2006. The main environmental impacts off-farm relate to changes in water availability due to low surface water flows and groundwater levels, increasing demands for water from other sectors, increasing environmental regulation and abstraction control, and the risks associated with GMO cultivation.

The on-farm risks relate mainly to the control of the use of pesticides and fertilisers and their consequent impacts on local environments via diffuse water pollution, the risks of new disease and poor soil management. The main technological risks off-farm are insufficient R&D investment in agriculture (Royal Society, 2009), coupled with a lag in technological uptake compared to European neighbours. A decline in the capacity of skills in UK agriculture, as well as the number of people willing to work on the land are also constraints (Spedding, 2009) common to other parts of Europe and North America (IAASTD, 2009b). On-farm technological risks relate to the observed widespread deterioration in maintenance of land drains, inadequate staff training and the rising costs of energy on which new technologies are dependant.

In addition, there are a raft of international drivers that will affect UK agriculture including the consequences for world trade, affecting both demand for, supply and

Table 1

Summary of 'non-climate' risks to UK crop production, grouped according to whether they are economic, technological and environmental, and off or on-farm (Source: Knox *et al.*, 2010).

	Economic risks	Environmental risks	Technological risks
Off-farm	■ Impacts of European agro-economic policy and CAP reform on business viability ■ Impacts of instability in commodity markets at global and European levels on UK crop prices ■ Foreign exchange rates, especially £:Euro and £:US$ ratios ■ Supermarket pressures on the food supply chain ■ Cheap overseas food imports ■ High costs of borrowing limiting investment in new technologies and mechanisation ■ Reduced availability of loans and finance reduce investment and promote risk-avoidance in decision making ■ Higher UK taxes deter on-farm investment ■ Rising environmental costs associated with charges for water and pollution	■ Low river flows limiting availability and reliability of water for irrigation abstraction ■ Environmental regulation (e.g. Birds, Habitats Directives) constraining agricultural production ■ Imported, or mutated indigenous, plant diseases ■ Monoculture reduces biodiversity (increases epidemic risks) ■ Fear of GMOs and novel technology ■ Actual damage caused by GMOs and novel technology ■ Unidentified tipping points that lead to catastrophic failure of ecosystems e.g. rapid soil loss, disease epidemics	■ Inadequate research and development of new technologies appropriate to UK farming conditions ■ Adoption and uptake of technological advances lags behind European competitors ■ Improved storage and transport technologies remove barriers to imports ■ Cross-contamination of genetically modified plant material ■ Lack of investment in new research and technology (resulting in reduced competitiveness) ■ Reduced number of people employed in the agricultural sector with a risk of dislocation to urban areas
On-farm	■ Energy costs for crop production ■ Rising labour costs and labour supply problems ■ Rising environmental costs relating to meeting supermarket grower protocols ■ Rising costs of fertiliser (linked to energy costs) and seed ■ Reduced expenditure on flood defence and land drainage infrastructure	■ Soil degradation: compaction (heavy machinery, inappropriate management)/salinity build up (excessive use of fertilisers) ■ Excessive use of pesticides and herbicides (risks of soil, air and water pollution affecting human and animals health and disrupting the pray-predator equilibrium) ■ New diseases	■ Reduced standards of land drainage (including flood defence) ■ Inadequate knowledge transfer and understanding of new technologies which limit technology uptake ■ Rising cost of energy on which technology is dependent (affect irrigation abstraction and machinery used in agriculture/food processing)

prices of agricultural commodities in global and regional markets and an increased volatility of market conditions. There are also the actions being taken by governments to address climate change effects – with consequences for agricultural markets, including protectionism. There is likely to be greater instability in international food and energy prices, affecting fuel costs and fertiliser use, and greater global water scarcity with consequent impacts on food production, especially in relation to food exports to the UK from Southern Europe (Yang *et al.*, 2007).

There are also likely to be societal factors, such as public and political resistance to the use of GMOs that could help to adapt to environmental change; changing dietary preferences towards healthy eating via for example, the Food Standards Agency 'Eatwell Plate' campaign; increasing demand for year-round fresh supplies favouring food imports; and competition for land and water for development and non-agricultural use, such as nature conservation and recreation.

Agriculture, water and food security

There are also issues surrounding the links between water footprints and food security. At present, the UK has the security of being able to produce approximately half of all the food consumed in the UK. However, the UK has been ranked in the world's top six virtual water importing countries. In one sense this offers security against drought, but it also makes the UK vulnerable to droughts in those countries that supply the UK with fresh food. In the global market, water now connects people across the world in ways that were unimaginable 50 years ago. Importing food from places where water is scarce can be seen as exporting drought and environmental problems to places where there are fewer regulations, poor environmental protection and a lack of financial resources to deal with the problems this can create. It may also cause food shortages in the exporting countries and drive up local food prices. Policies which support home production are important for the UK's food security, but food must be produced in ways that protect and enhance the natural environment.

Concluding comments

It is important to recognise the wide ranging role that agriculture plays in the UK economy. It has a multifunctional role, sitting at the interface between eco-systems and society, contributing to a range of 'non-food' services as well as 'food' production. Producing food sustainably in a changing and uncertain climate will be a priority - but dealing with the externalities on agriculture needs to be handled in ways that are sensitive to both ecosystems and the diversity of benefits that agriculture provides, and not just to food production. Recent concerns regarding possible future global food shortages, exacerbated by climate change, have raised questions about food security at a national scale. The UK government does not prescribe targets for national self-sufficiency, but seeks to achieve 'food security' by guaranteeing household access to affordable, nutritious food.

UK agriculture, along with the food industry as a whole, is charged with 'ensuring food security through a strong UK agriculture and international trade links with EU and global partners which support developing economies'. In this regard, UK agriculture is required to be internationally competitive, whether this is delivering to domestic or international markets. Factors such as climate change and consumer demands for knowledge on water footprints could affect not only the relative productivity of UK agriculture and the demand for water for food production, but also its competitive position in international markets (Knox *et al.*, 2010).

Opportunities for innovation

The efficient use of water to support food production is fundamental to the progression of mankind. Opportunities for innovation, integrated appropriately, abound across the whole system.

Improvements in forecasting weather, both rainfall and evapotranspiration, in the long, medium and immediate term on a site specific basis, linked to information on the market requirements for produce, will allow the harvesting storage and application of water to be optimised.

There is a need to apply the available water with increasing precision both spatially and temporarily according to need. This will be informed by combinations of soil, plant and aerial based sensors operating in real time to control application systems.

Application systems, in turn, will need to be designed to provide these increasing degrees of precision incorporating appropriate levels of automation to reduce both operator and management dependence.

This insight has been written by Dr Jerry W Knox, Cranfield Water Science Institute, Cranfield University. Images courtesy of Jerry Knox and Istock.

Sensors help integrate information on plant growth and soil moisture under changing weather conditions

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