IAL Travel Fellowship 2009

The water-energy-emissions nexus in irrigated agriculture

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Summary

The topic of this travel fellowship was the water-energy-emissions nexus in irrigated agriculture. This fellowship allowed me to meet with world class researchers working on various aspects of this topic, extending my network of industry contacts. A key benefit was the exposure to the latest research and ideas, which will provide an opportunity for these to potentially be adapted to the Australian situation. Similar research carried out as part of my PhD studies is pertinent to the major challenges facing irrigators both in Australia and internationally. Given the current global focus on water and food shortages in conjunction with a drive to reduce emissions, this fellowship provided a timely opportunity to explore the links between these factors in irrigated agriculture.

The countries visited were Turkey, Israel, the UK and US. The irrigation industry in each of these countries is very different in terms of scale, technology, legislation and state of research. In Turkey I met with researchers from three universities, several of whom were working on energy in irrigation for pumping. Discussions with Dr Bilal Acar and Dr Ramazan Topak were useful in terms of understanding their approach to quantifying energy consumption.

In Israel, the highly technological state of irrigation and water resources management was evident everywhere. I had the opportunity to travel from the relatively fertile north to the extremely arid south of the country, witnessing throughout the abrupt changes in landscape and methods of adaptation. The high input irrigation sector was explored in nurseries/greenhouses, horticultural, viticultural and broad acre production systems.

In the UK, my experiences focussed on water and carbon accounting and climate change impacts, where there is a lot of interest in these areas, both on the part of researchers but also driven by consumer demand through supermarkets as well as government departments.

The USA gave me the chance to discuss the issues surrounding biofuel development, as well as to meet with several irrigators to explore their methods of coping as water availability declines. A particular highlight was meeting with Professor David Pimentel at Cornell University, who was the pioneer of research into energy in ecosystems and agriculture in the 1970s, and continues his research to this day.

This travel fellowship has allowed me to both contribute my ideas and learn from others regarding the issues facing irrigated agriculture internationally, and to explore the potential impacts of climate change on this vital sector of the agricultural industry. A better understanding of these challenges will help with the development of strategies to adapt to changes brought about by a changing climate and related policies.

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Dr Bilal Acar, Dr Ramazan Topak and colleagues at Selcuk University, Konya

Israel

Professor Avi Shaviv and staff at the Technion, Haifa
Mr Dubi Raz and colleagues, Netafim

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Dr Jerry Knox, Dr Keith Weatherhead, Dr Andre Daccache, Dr Tim Hess, Dr Ian Holman, and Dr Adrian Williams Cranfield University
Professor Pete Smith, University of Aberdeen

USA

Mr Mike Shannon and Mr Bob Farvad, USDA ARS
Professor David Pimentel, Cornell University
Mr Mike Wade, California Farm Water Coalition
Mr Jose Ramirez, Manager, City of Firebaugh
Dr David Zoldoske, Center for Irrigation Technology, California State University
Mr Chuck Dees, Elena Stefanopoulos, Stamoules Produce
Mr Dan Errotabere, Errotabere Ranches
Mr Bill Taube, Wheeler Ridge-Maricopa Water Storage District

1 Background to study topic

Water and energy are critical drivers for life as well as agricultural production. Agricultural processes combine water and energy resources to produce food and fibre crops for human and animal consumption. The current level of global growth and development achieved can be attributed to the quality and quantity of water and energy being consumed (Hellegers *et al.,* 2008). However, the consumption of these resources is not without consequence. It is therefore imperative that we consider the sustainability of these precious but limited resources in relation to agriculture, if we are to continue to provide food for the global population and to achieve the required gains in production necessary in the future.

The world is currently facing a number of social and environmental issues. Socially, the expanding population and improved standards of living are resulting in increased demands for food and water in terms of both quantity and quality (Oenema *et al.,* 2001). The world's population is expected to reach eight billion by the year 2025, which is projected to require an additional water supply of 15-20% for adequate agricultural production (Hamdy *et al.,* 2003). Environmentally, concerns include competing demand for water and the impacts of climate change due to global warming, attributed to anthropogenic greenhouse gas (GHG) emissions. It is inevitable that technology can and will play an important part in reaching a solution to these problems; however, care must be taken to balance the benefits of any new systems implemented with potential costs in terms of changes in energy consumption and therefore potentially higher contributions to GHG emissions from agriculture.

Given that irrigated agriculture can be doubly as productive as rainfed agricultural land (Entry *et al.,* 2002), it can contribute greatly to increases in food production and is therefore a vital part of world agriculture. Irrigation consumes 71% of the world's freshwater supply (Zehnder *et al.,* 2003), and increasing competition for freshwater resources from industry and the environment means that the required increases in food production will need to come from the same or a reduced quantity of water than is currently used. Water use efficiency (WUE) in agriculture is currently low, with over 50% of water diverted for irrigation lost from the system (Hamdy *et al.,* 2003). This means that there is great scope to meet the growing demand for water from water savings in agriculture. It has been identified that for many irrigation systems, up to 55% of water that arrives at a farm is lost through poorly maintained and designed distribution systems and inefficient field application practices (Zehnder *et al.,* 2003). Thus, changes to on-farm practices which increase WUE have the potential for water savings that can meet the growing demand for water.

Much research into increasing WUE and therefore generating water savings focuses on the conversion of gravity-fed irrigation systems to pressurised systems (Zehnder *et al.,* 2003; Lal, 2004; Pratt Water, 2004). Whilst the implementation of pressurised systems may be a viable option due to the potential increase in water use efficiency (Phocaides, 2001), it must be remembered that irrigation is a primary consumer of energy on farms (Naylor, 1996), and these conversions may increase on-farm energy consumption. Singh *et al.* (2002) found that irrigation always consumed the largest proportion of on-farm energy in their case studies of agricultural production in India's arid zone.

It is recognised that energy use is necessary for increasing agricultural productivity and improving food security (Sayin *et al.,* 2005); indeed, intensification of fossil energy use has been associated with an increase in agricultural productivity during recent decades (Conforti and Giampetrio, 1997). The assessment of water and energy consumption in agricultural production is vital to identify the major sources of wastage, and to determine strategies for best allocating scarce resources to maintain production. The need to assess the resource consumption and impacts of irrigation systems in light of current issues mean that there are several factors that must be considered. Water use efficiency is currently a common measure of the performance of irrigation systems; however it is important to assess these systems in a broader sense, incorporating technical, economic and environmental aspects. The trade-offs between these factors must be addressed, and the level of affordability of a society determined in order to achieve the most appropriate balance between water and energy consumption and the environmental consequences associated with GHG emissions.

Energy use by the agricultural sector depends on the amount of arable land available and the level of mechanisation (Ozkan *et al.,* 2004). Inanimate energy use is likely to be greater in developed countries which have a higher level of mechanisation than developing countries. Thus, the impacts of energy consumption are likely to be higher from developed countries until or unless more technologically advanced options are adopted in developing countries. If this occurs, the impacts of increased energy consumption will be of concern.

The inclination towards higher input systems and current levels of energy inefficiency in agricultural systems may be due to low energy costs. A similar trend has been experienced in regard to water consumption. However, this scenario is changing under current conditions, where energy costs are becoming a primary consideration for producers, and one of the fastest growing cost inputs (Chen et al., 2008).

There are many studies that seek to quantify the energy consumption associated with crop production in various countries (Pimentel *et al.,* 2002; Barber, 2004; Canakci *et al.,* 2005; Tzilivakis *et al.,* 2005; Chamsing *et al.,* 2006; Chaudhary *et al.,* 2006; Hatirli *et al.,* 2006; Erdal *et al.,* 2007; Esungen *et al.,* 2007; Ozkan *et al.,* 2007; Singh *et al.,* 2007; Khan *et al.,* 2009; Jackson *et al.*, 2010). While irrigation energy use is included where appropriate by these studies, the integration of water and energy consumption is not considered, with the exception of Khan et al. and Jackson et al.

Both Hodges *et al.* (1994) and Lal (2004) found that approximately 23% of direct energy use for crop production in the US was used for on-farm pumping, indicating that irrigation can be a significant energy cost for primary producers. Where a groundwater source is used for irrigation, the use of pressurised micro-irrigation systems can decrease energy consumption where reduced operating pressures and pumping volumes are experienced (Hodges *et al.,* 1994; Srivastava *et al.,* 2003). This is an important factor that needs further exploration.

Given that water and nutrients are the principle limiting factors for crop production, the supply of these inputs in cropping systems allows large gains in production (Martin *et al.,* 2006). However they can also represent large energy inputs into a system; therefore methods that allow a reduction in the use of these inputs will reduce energy use by agricultural systems. It is imperative that the criteria used to assess the sustainability of agricultural systems reflect the issues of the time (Lal, 2004). Thus, a combined assessment of water, energy and environmental impacts is essential in order that improvements to systems on a global scale that will result in efficient and environmentally sound production systems (Ozkan *et al.,* 2004).

1.1 The Australian situation

South-eastern Australia is currently experiencing the worst drought since European settlement, which has reduced agricultural outputs and resulted in water stress in many regions. Irrigation allocations have been highly variable during the past ten years, with 0% allocation in many regions. Climate forecasts for 2030 relative to the climate of 1990 predict a reduction in annual rainfall by between 2-5% in the south of the continent, and an increase in average temperature in southern Australia of approximately 1.0ºC, with warming of around 0.7-0.9ºC in coastal areas and 1-1.2ºC inland (CSIRO, 2007). These conditions are likely to reduce water availability and increase water requirements by agricultural crops. Policy makers and landholders will therefore need to adapt their policies and farming practices to these new conditions.

Current government policy in Australia supports the modernisation of irrigation systems, with the aim of generating water savings of over 2,500 GL per year within the Murray-Darling Basin, where 85% of Australia's irrigation takes place (Department of the Environment, Water, Heritage and the Arts, 2008). It is reasonable to assume that irrigators will be encouraged to adopt pressurised irrigation systems in order to generate significant water savings, despite the fact that there are few details regarding the specific methods for modernisation. This will have far-reaching implications for water and energy consumption, as well as environmental impacts.

There is a wealth of information regarding crop water use under Australian conditions, but energy use and GHG emissions in agriculture have been less thoroughly researched. Examples of energy consumption are limited in scope, concentrating on only energy use by irrigation systems (Amaya, 2000; Michael Young and Associates, 2005) or direct energy inputs (Chen and Baillie, 2007; Chen *et al.*, 2008). The work done by Khan *et al.* (2009) and Jackson et al. (2010) as previously described, are the only exception. Greenhouse gas calculators that have been developed for agricultural production in the Australian context are a good base to start, but more information is required. Thus there is a need to explore the current state of research into water and energy consumption and GHG emissions associated with crop production.

2 Itinerary

Country	Date	Activities	Institution	Host
Turkey	11-12th February	• Irrigation and energy use workshop with university staff members, State Hydraulic Department staff members, local farmers i) Water resources & irirgation in Turkey ii) South Eastern Anatolian Project (GAP) iii) State Hydraulic Works: irrigation and energy infrastuructures in Turkey and particularly in Thrace Region iv) Ipsala State Hydraulic Works will present on rice irrigation practices (50% of Turkey's rice production is from this region), water resources, energy use, irrigation methods, etc. • Field visit to local irrigated farm, agricultural machinery factory	Nekim Kemal University, Tekirdag	Dr Fatih Konukcu
	15th February	Meeting with university staff and presentation to staff and final year Agricultural engineering students	Irrigation Department, Agricultural Faculty, Ankara University	Dr Duygu Kesmez
	16-17th Feb	Meetings with university staff and discussions on energy use in irrigation	Irrigation Department, Agricultural Faculty, Selcuk University, Konya	Dr Bilal Acar
Israel	21-22nd February	• Meetings with university staff in the faculty of Civil and Environmental Engineering, and discussions on energy use in irrigation • Visit to BaHa'ai Gardens • Field visit in the Western Galilee i) Efficient use of water and fertilizers in greenhouses (reverse osmosis, water and nutrient recycle, rain water collection, irrigation water treatment) - Shefer Nurseries, Kfar Bialik ii) Avocado tree irrigation monitoring research, Kibutz Rosh Hanikra iii) Management aspects of avocado and banana (net houses, soil mulching, irrigation and salinity field monitoring, water qualities and more), Koren Valley, Western Galilee.	The Technion, Haifa	Professor Avi Shaviv

Israel (Cont)	23-25th February	Site visits – • Centre for Desert Research, Ben Gurion University • Central and Northern Arava Research and Development – Greenhouse vegetable research station • Kibbutz Yot Vitah • SDA Spice – herb/spice producers & manufacturers • Banana/Mango plantations (Galilee) • Kibbutz Yifkah – Netafim training and research centre and factory (drippers, lay flat pipes – low pressure)	Netafim	Mr Dubi Raz

UK	1st – 3rd March	• Presentation to Masters students (Advanced Irrigation)
		• Meetings with
		  ○ Dr Tim Hess (Reader in Water Management) – Water footprinting
		  ○ Dr Ian Holman (Senior Lecturer) – Impacts of climate change
		  ○ Dr Adrian Williams (Principal Research Fellow in Operational Research in Natural Resources) – Carbon footprinting
		• Visit to The Fens region – irrigation and drainage
			Cranfield University	Dr Jerry Knox

	4th March	• Meeting with Professor Pete Smith, University of Aberdeen	University of Aberdeen	Professor Pete Smith
USA	9th March	• Discussion with Mike Shannon, Bob Farved	USDA	Mr Mike Shannon
	11th March	• Discussion with Professor David Pimentel	Cornell University	Professor David Pimentel
	15th March	California Farm Water Coalition/ Agricultural Water Management Council	California Farm Water Coalition	Mike Wade
	16th March	• Center for Irrigation Technology, California State University, Fresno (Dr. David Zoldoske) • City of Firebaugh (Jose Ramirez, City Manager) • Stamoules Produce (Chuck Dees, Manager)	Various	Various
	17th March	• Errotabere Farms (Dan Errotabere) • Wheeler Ridge-Maricopa Water Storage District (Bill Taube, General Manager)	Various	Various

3 Turkey

3.1 Irrigation industry

Turkey is unique in the world market, in that it is one of the few countries that are self-sufficient in food production. The agricultural sector has been Turkey's largest sector in terms of employment, and a major contributor to the country's Gross National Product, although by 2007 this had declined to 11%. Almost 20% of Turkey's arable land area of 28 million hectares is currently irrigated (5.28 million hectares), and there is scope to further irrigate 3.22 million hectares. Turkey's water activities have been comprehensively planned since the 1950s. Currently, water management policies are directed towards satisfying the growing demand for domestic water supply, achieving food security, generation of energy and environmental conservation. Integrated regional development projects are an important aspect of Turkey's water resource management, including the Southeastern Anatolia Project (GAP), Eastern Anatolia Project (DAP) and Konya Plain Project (KOP).

Irrigation accounts for 74% (34 billion m^3) of total surface water use; this proportion is expected to decline to 64% (72 billion m^3) by 2023. Most surface irrigation networks are operated and maintained by Water User Organisations. In addition to this, groundwater use by irrigation is 55% of the total allocation (6.77 billion m^3). Groundwater irrigation is provided by irrigation cooperatives, and all irrigation schemes are constructed by the government. Investment costs are refunded within 15 years by farmers, free of interest. Groundwater is allocated to farmers free of charge.

Major irrigated crop production in recent years includes maize, cereals, cotton, fruit and vegetables. Approximately 92% of irrigation is carried out using surface irrigation methods such as furrow, with the remainder using drip and sprinkler. The State Hydraulic Works department identifies that gravity irrigation investment is cheaper than pumping irrigation investments, and also specifies the financial burden of pumping costs for farmers as a problem; thus gravity irrigation is the preferred option.

Key water resource issues in Turkey include:

- The threat of water scarcity due to climate change
- Extreme weather events such as droughts and floods
- Improvement of water infrastructure and irrigation facilities

- Integrated water and energy management for sustainable development – the need to invest in hydropower
- Transboundary water management – transboundary waters constitute 40% of Turkey's water potential.

This information is taken from the Turkey Water Report (General Directorate of State Hydraulic Works, 2009a) and the Water and DSI report (General Directorate of State Hydraulic Works, 2009b).

3.2 Observations

3.2.1 Agricultural energy consumption

3.2.1.1 Previous studies

One of the motivations for selecting Turkey as a country to visit was several publications I had read regarding agricultural energy consumption, at the farm and country level, including the following publications:

- Canakci, M., Topakci, M., Akinci, I., & Ozmerzi, A. (2005). Energy Use Pattern of Some Field Crops and Vegetable Production: Case Study for Antalya Region, Turkey. *Energy Conversion and Management, 46*(4), 655-666.
- Erdal, G., Esungun, K., Erdal, H., & Gunduz, O. (2007). Energy use and economical analysis of sugar beet production in Tokat province of Turkey. *Energy, 32*, 35-41.
- Esungun, K., Erdal, G., Gunduz, O., & Erdal, H. (2007). An economic analysis and energy use in stake-tomato production in Tokat province of Turkey. *Renewable Energy, 32*, 1873-1881.
- Hatirli, S. A., Ozkan, B., & Fert, C. (2006). Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy, 31*, 427-438.
- Ozkan, B., Akcaoz, H., & Fert, C. (2004). Energy input-output analysis in Turkish agriculture. *Renewable Energy, 29*, 39-51.
- Ozkan, B., Fert, C., & Karadeniz, C. F. (2007). Energy and cost analysis for greenhouse and open-field grape production. *Energy, 32*, 1500-1504.
- Sayin, C., Mencet, M. N., & Ozkan, B. (2005). Assessing of energy policies based on

Turkish agriculture: current status and some implications. *Energy Policy, 33*, 2361-2373.

Unfortunately none of the researchers were available for me to visit. However, discussions with Dr Bilal Hussein and Dr Ramazan Topak from Selcuk University, who are also working in this area, were fruitful.

3.2.1.2 Current research into energy in irrigation

Dr Ramazan Topak from Selcuk University has been undertaking a large study of direct energy use in irrigation in the Konya closed basin area. The Konya closed basin is 14% of the total cultivated area of Turkey; it is also the driest area in Turkey. The water potential of this region is 2.5% of Turkey's total potential water supply. Thus, there is a high cultivated area but low water availability. Average rainfall is 323 mm per year, with an autumn/winter rainfall dominant pattern. Rainfall is low during the production period. Winter cereals are exposed to agricultural drought and must be irrigated. All arable land in the area is suitable for irrigation. There is currently 550 000 ha irrigated in the region. The small average farm size of 5 ha is a problem; however water availability is the biggest issue facing the region. Sprinkler irrigation is the most common irrigation method. Field studies show that application efficiency for sprinkler irrigation systems is 83%. The University projects that 80% of tubewells used are associated with sprinkler systems. There are some surface irrigation systems, as well as some drip on vineyards, orchards and recently introduced into field crops. The average total efficiency is 73%.

The importance of direct energy consumption and the motivation to study this is due to several factors, including the critical nature of irrigation in this region, a high proportion of direct energy consumption and high diesel prices. As rainfall is virtually non-existent during the crop production period, no irrigation means no yield. Direct energy consumption is very high compared to indirect energy consumption, and up to 65% of total energy inputs into crop production are associated with irrigation. Direct energy costs are expensive due to the highest diesel prices in Turkey. Electricity costs are lower than diesel (a trend in most areas of the world currently). Much of the work completed has looked at direct energy costs at the field scale under farmer's conditions.

Dr Topak's study compared different irrigation regimes: 25%, 50%, 75% and full irrigation.

The results from the study show that for full irrigation using a drip system the energy consumption is 52,000 MJ/ha, with irrigation accounting for 37 000 MJ/ha. There are opportunities to reduce energy use with pressurised systems if the correct operating pressure is selected, and also by controlling water application, since over irrigation leads to higher energy consumption. The solution to this is irrigation scheduling and proper management.

We discussed the problem of upscaling of local results due to high variability. Dr Topak's aim is to analyse the water and energy efficiency at the basin level (Konya), however the researchers stated that there was very little/no variability among field/cereal crop production throughout the region. There may be a problem with vegetable crops, but they generally exclude these from calculations. When I asked about the high variability that I found during my study (see Jackson et al., 2010) and how they would account for this, Dr Topak said that to be more accurate, more information must be known about a region when there is high variability. This is problematic in conditions where data collection is expensive. In their experience they feel that surveys are not a good way to collect data – direct measurements on farm are better, i.e. diesel consumption, average pressure etc. It is also essential to know the system well in general.

Figure 1 Discussions with Dr Bilal Acar and Dr Ramazan Topak at Selcuk University, Konya.

3.2.2 State of technology & importance of energy issues

For farmers and government employees, energy consumption is primarily being considered in terms of cost rather than physical energy use, or the impacts of this. In one way, this is a positive as it brings energy consumption to a common unit of understanding for farmers, state employees and researchers. In many of the projects that were presented, energy costs (in terms of pumping) were included. For example, in one trial comparing different irrigation methods for sunflower and maize crops, the cost of pumping was incorporated – and found that costs more than doubled with the use of drip. In another project, the costs of pumping using different water sources were compared. This estimated the cost of using groundwater (600 TL/ha), surface water (150 TL/ha) and small earth dams - local systems with small pumping systems - (50 TL/ha). Small, local systems were clearly optimal in terms of cost of pumping.

Typically in any research, it is common to concentrate on the most limiting factors; in Turkey, this is usually water, but where this is not restricted, fertiliser is a major cost to farmers. One staff member from Ankara University described a fertiliser trial where they had shown that farmers can reduce nitrogen by 25% and phosphorous by 50% and still maintain yields. From an energy perspective, this outcome also results in reducing energy inputs, as nitrogen fertiliser is a major energy input.

Another joint project being undertaken in the Thrace region between Turkey, Bulgaria and Greece is a scoping study to look at options for optimising water application; this also considers energy costs of the different options studied. The next step is to look at implementing some of the recommendations in these regions.

In a discussion at the workshop held at Nekim Kemal University, one of the presentations showed that the difference in net revenue for a sunflower crop using 0% and 100% irrigation was almost zero, but yield is almost double. The question was raised, why irrigate? The predominant view was that Turkey and the irrigation industry benefits in terms of revenue and increased food production, despite the loss of water and other possible unintended environmental problems. This again raises the question of irrigation in broader terms than just inputs and outputs.

Modernisation in terms of installation of pressurised systems and electricity costs of pumping are supported by the government. The government subsidises 50% of the cost of pressurised systems. Electricity for pumping is also subsidised (60% of full consumer price). The farms visited showed highly modernised drip irrigation systems for horticulture. However, according to local researchers, in practice in many cases, there is a lack of technical support and energy costs become a problem for farmers, and often they revert back to using surface systems because of these issues.

Most of Turkey's irrigation is undertaken using gravity fed systems, although sprinkler and drip are also used. Manufacturers of a portable Hose Reel Irrigation System with the capacity to irrigate up to 5 hectares at once stated that farmers react quickly to the adoption of this technology. More units are sold in a dry year, probably due to the portable nature of these machines, and the relatively low cost (up to $25,000).

In discussing the importance of energy costs to farmers, it was mentioned that while they are generally important, fertiliser and other costs are more important. The biggest problem facing farmers is uncertainty in market prices, and the difficulty in covering costs of production. None of the institutions spoken to were considering emissions from agriculture, although some expressed the desire to do so. This is an emerging area in Turkey, and there was acknowledgment from researchers that this will get more attention in years to come.


Figure 2 Presenting at the Irrigation and energy use workshop at Nekim Kemal University, Tekirdag (left); and visiting an irrigated farm (right).

4 Israel

4.1 Irrigation industry

Irrigation is synonymous with Israel: scarce water resources and the pressure for food security have driven Israel to have a highly technical, water efficient agricultural industry. Israel's varied climatic, topographical and soil conditions (from sub-tropical in the north to arid in the central and southern regions) make it possible to grow a wide range of agricultural produce. At least 60% of the country is defined as arid or semi-arid. Rain only falls between November and April, with uneven distribution of yearly precipitation, historically raging from 700mm in the north to less than 50mm in the south. About two-thirds of Israel's field crops are grown on un-irrigated land. These rain-fed crops include wheat for grain and silage, hay, legumes for seeds and safflower for oil. The remainder is summer crops such as cotton, sunflowers, chickpeas, green peas, beans, corn, groundnuts and watermelon for seeds, mostly irrigated. The amount of irrigated farmland is approximately 182,000 ha out of a total area under cultivation of approximately 440,000 ha.

While agriculture today represents a low 2.4% of the Gross Domestic Product and four percent of exports, agriculture has grown in absolute terms and played an important part in Israel's economy for over five decades. Agricultural output in 2000 was worth about $3.3 billion, of which 20% was exported.

In some areas, such as the Arava and the Jordan Valleys, agriculture provides almost the sole means of livelihood for the population. In 2000, approximately 72,000 people were involved in farming, constituting about 1.7 percent of the country's workforce. In monetary terms, Israel produces almost 70% of its food requirements. It imports sugar, coffee and cocoa and much of its grains, oilseeds, meat and fish. However, these imports are partially offset by exports of fresh agricultural produce and processed foods. Today, just under a fifth of the income of Israel's farmers derives from the export of fresh produce, including such products as flowers, avocados, vegetables that are out of season elsewhere, and certain exotic fruits grown exclusively for export. In addition, some 442,000 tons of fruit and vegetables – 16% percent of the entire crop - were sold to factories for processing and export in 2000.

Water saving has been a priority since the establishment of Israel; saving water, finding new sources and making optimal use of scarce land still characterize the country's agriculture.

The country has eight major and several small-to-medium-sized companies producing irrigation and filtration equipment. Israeli engineers and agriculturalists created the revolutionary drip system, and continue to be world leaders in this technology today.

To overcome regional imbalances in water availability, most of the country's freshwater sources have been joined into the National Water Carrier, an integrated network of pumping stations, reservoirs, canals and pipelines which transfers water from the north, where most of the sources are, to the agricultural areas of the semi-arid south.

The total average annual potential of renewable water amounts to some 1,800 GL, of which about 95% is already exploited and used for domestic consumption and irrigation. About 80% of the water potential is in the north of the country and only 20% in the south. Israel's main freshwater resources are: Lake Kinneret - the Sea of Galilee, the Coastal Aquifer - along the coastal plain of the Mediterranean Sea, and the Mountain Aquifer - under the central north-south (Carmel) mountain range. Additional smaller regional resources are located in the Upper Galilee, Western Galilee, Beit Shean Valley, Jordan Valley, the Dead Sea Rift, the Negev and the Arava. The long-term average quantity of replenishable water from major water resources amounts to about 1,800 GL per year. Reclaimed wastewater effluent, intercepted runoff and artificial recharge and desalination are also widely used water sources.

Table 1 Long term potential of renewable water

Resource	**Replenishable Quantities (MCM/year)**
The Coastal Aquifer	320
The Mountain Aquifer	370
Lake Kinneret	700
Additional Regional Resources	410
Total Average	**1,800**

In addition to surface water resources, the national water company Mekorot has also developed the following water supply options:

- **Deep wells** at depths of 1,500 meters and more. Approximately 1,040 water wells currently pump water throughout Israel, half of which are operated by Mekorot. Of these, 150 wells are used for recharging purposes, while the remainder are used as water sources.
- **Rehabilitation of old wells** through the use of state-of-the-art engineering techniques, a process that costs 20% as much as drilling new wells.
- **Wastewater treatment and reclamation** through advanced treatment methods. Mekorot operates 8 water treatment plants with a daily flow of 500 ML (186 GL per year). Following treatment, water is routed to one of nine effluent reclamation plants. These plants desalinate the water and/or insert it into the soil for tertiary treatment and to recharge the aquifer, generating 206 GL of effluent water per year.
- **Creating usable water through the desalination of brackish water, seawater and treated wastewater.** Mekorot operates 31 reverse osmosis (RO) and electro dialysis (ED) desalination plants throughout Israel with a daily treatment capacity of nearly 1 GL. Through an ambitious building program, Mekorot intends to increase desalination production by 2010 to nearly 200 GL per year, including 100 GL to be desalinated from sea water, 77 GL from brackish water and 13 GL from secondary effluents and wastewater.
- **Artificial recharge of groundwater** at recharge plants located throughout the country, including Shafdan, Shikma, Menashe rivers, Nachshonim and five reservoirs south of the Dead Sea. Artificial recharge of Israel's Coastal Aquifer serves to restore higher groundwater levels to counteract further intrusion of sea water and to counteract withdrawals.

This information is taken from:
http://www.mfa.gov.il/MFA/Facts+About+Israel/Economy/Focus+on+Israel-+Israel-s+Agriculture+in+the+21st.htm.

http://whttp://www.moag.gov.il/agri/files/agriculture/index.html

ww.mekorot.co.il/Eng/Activities/Pages/WaterResourcesManagement.aspx

4.2 Observations

4.2.1 Current agricultural practices

Israeli agriculture is highly technologically advanced, precisely managed and reliant on irrigation. In terms of access to water, irrigators do not own water rights; they have the opportunity to use it indefinitely as long as it is used "productively". Access can be cut back if it is not used. Water is used efficiently because it is scarce and expensive. Through discussions with local industry leaders, they identified the biggest problems facing farmers in Israel as being:

1. Lack of labour availability; internal/domestic labour is scarce, and most farm labourers are recruited from Thailand – this makes farmers reliant on immigration policy, which has been cut back lately;
2. Land and water availability; and
3. Market pressures.

Energy intensity in irrigation is not a matter of energy for pumping, since water is delivered pressurised to farmers either from the national water grid (sourced from the Sea of Galilee), recycled water or from groundwater. The government owns and distributes all water, and the pressure it is delivered at varies but is mostly around 4 - 5 atmospheres (400 - 500 kPa). Energy intensity is embedded in the highly mechanised nature of agricultural production. For example, equipment used for irrigation (drip lines etc), use of plastics as mulch and covering, heating and equipment for green/net houses (Figure 3). However there are strategies to combat this, for example Netafim offers recycling of all driplines and then sells the next batch to farmers at a cheaper rate. In terms of country scale emissions, agricultural emissions are just 3% of the national total. Farmers are not thinking about controlling emissions or the impacts of this, but at the ministry level they are. At this stage the discussion is around targets in line with OECD/EU averages.

Figure 3 Plastic tunnels for tomato production in the Arava region (left), and a state of the art greenhouse in the Upper Galilee (right).

Fertiliser appears to be closely monitored; for example, at one Kibbutz they were using weekly petiole testing of potatoes to determine nitrogen fertiliser use. This was also used in greenhouses visited. This offers an opportunity to reduce energy use by optimising uptake by plants and preventing leaching; nitrogen fertiliser is often a major energy cost, due to the energy intensive process by which it is manufactured, so any reduction in waste of nitrogen fertiliser will also save energy. Emissions can also be reduced by optimally applying nitrogen, through a reduction in nitrogen lost as nitrous oxide.

There is a need to look at energy productivity of Israeli agriculture in comparison to other situations; while energy inputs appear to be high, yields are also high as. No studies of energy use in Israeli agriculture could be found.

4.2.2 Irrigation research

At the Technion, I met with researchers in the Department of Engineering. No one is working on irrigation directly, but they are involved with applied research which is linked indirectly to irrigation, and see their role as more to advance knowledge of aspects of irrigation e.g. soil physics, the movement and behaviour of fertiliser in soils, water movement in the root zone etc. The researchers work closely with industry to solve problems using applied science to understand systems. For example, with the increasing use of waste water, they have studied the reactions of reclaimed wastewater on soil properties and plant interactions.

In terms of emissions, there is some research into emissions of N_2O from streams, shallow groundwater and from agricultural inputs. However, again this is at the process stage, for example looking at how to evaluate sources and processes of N_2O and which microbial processes are affected. To do this, they are using isotopic based tools, merging soil physical processes with data monitoring. There is also work comparing irrigation with wastewater and fresh water, fertilisers/organic/non-organic production methods and different soils. To do this they are using long pass Fourier Transfer Infra Red (FTIR) to quantify CO_2/N_2O emissions.

Other research is being undertaken using spatial and spectral data to identify salinity stress in vegetation. It is hoped that this will result in appropriate irrigation depending on suitable soil types, and improve irrigation scheduling/cycling. This research combined thermal data with spatial and spectral data. It helped to identify areas of stress to isolate areas to further investigate using ground based methods.

At the Central and Northern Arava Research and Development station, research into greenhouse vegetable production is being undertaken. In this desert region, water resources are extremely scarce (230 m^3/day per farm) and farmers are also working with some of the worst quality ground water in Israel (2.8 – 3.5 EC). Peppers, tomatoes, melons, vegetables and cut flowers are produced in net or plastic greenhouses. These produce high quality fruit and vegetables in winter for export to EU markets. In terms of research impacting on water and energy management, trials include:

- LED lights to reduce energy costs
- Fertiliser type (Ammonium Nitrate vs Urea) to see if N quality has an impact on yield productivity and product shelf life (this could also affect energy use)
- Biological controls and spraying – thrips are resistant to pesticide use now – next year farmers will use biological control as it is more effective (i.e. for peppers)
- Trials being done to demonstrate the suitability of irrigating at night. Currently farmers are only irrigating during the day and are reluctant to try night irrigation.

4.2.3 Technological advances

Most farms in Israel are very small and are dedicated to intensive nursery/vegetable production. Broadacre crops tend to be grown on kibbutz or big farms. Often farm sizes are now not big enough to earn a decent income.

A number of greenhouses and net houses were visited, including Shefer Nurseries in the Western Galilee. This is an excellent example of efficient use of water and fertilisers in ornamental greenhouses. Water application rates are approximately 1.5mm/day. In winter, their water source is 100% from rainwater collected from the roof area of the greenhouses. In summer, when rainfall is scarce, they use reverse osmosis to purify water, due to the need for very high quality water for most varieties produced. Water quality of that water delivered by the government has improved significantly in the last 1-2 years. Water prices are a small part of the total annual budget as they are so efficient. In fact, the cooling system uses more water than irrigation of plants. Water costs around 7-8 NIS/m^3 (equivalent to AU$2.25/$m^3$) (pressurised and with all treatments, fertiliser etc included). The nursery is a totally closed system, including water and nutrient recycling. Recycled water is treated using biofiltration (80% effective) and thermal sterilisation (100% effective). Dr Anat Lowengart (from the Ministry of Agriculture Extension Service) emphasised that Shefer Nurseries are a good example of growers adopting new technology and using extension officers only when they have a problem they cannot solve themselves

Avocado and banana research sites and productive farms were visited in the Western Galilee. At Kibbutz Rosh Hanikra, Dr Amos Noor and Yaron Weissmark are conducting avocado tree irrigation monitoring research. They are measuring eight water stress indicators to determine their ability to withstand a reduction in water application. The project is funded by grower industry groups. Similarly in the Koren Valley, trials into management of avocado and banana using nets, soil mulching, irrigation, salinity field monitoring and variable water quality are being undertaken. Bananas grown under netting have higher yields, lower water use and better fruit quality. In the Galilee region, field scale water savings are around 10% under nets (due to a more humid, subtropical climate). In the Jordan Valley however, water savings are around 30%. Yields are improved in both regions.

Low pressure, low flow (0.6 l/hr) drip systems (LPS) developed by Netafim have the potential to revolutionise water and energy management. These systems operate at between 2.5 – 8m head, and can be used in broad acre crops. LPS system (assumed operating pressure 5m) uses 13% energy compared to conventionally operated drip systems (assumed operating pressure of 40m) (Figure 4 and Figure 5). One limitation of LPS is that they require good quality water or energy for filtering, depending on water quality. Netafim are working on the development of low/no energy filters, and have floating in line filters and other options. However, it does mean that these systems will not be suitable everywhere – although it gives options for reducing energy and water use in certain situations. Netafim's new low pressure drip systems will not lead to saved energy costs within Israel due to the need in many cases here to reduce pressure before these systems can be used, but they do offer a chance to reduce water use, increase yields and crop quality and reduce fertiliser use.

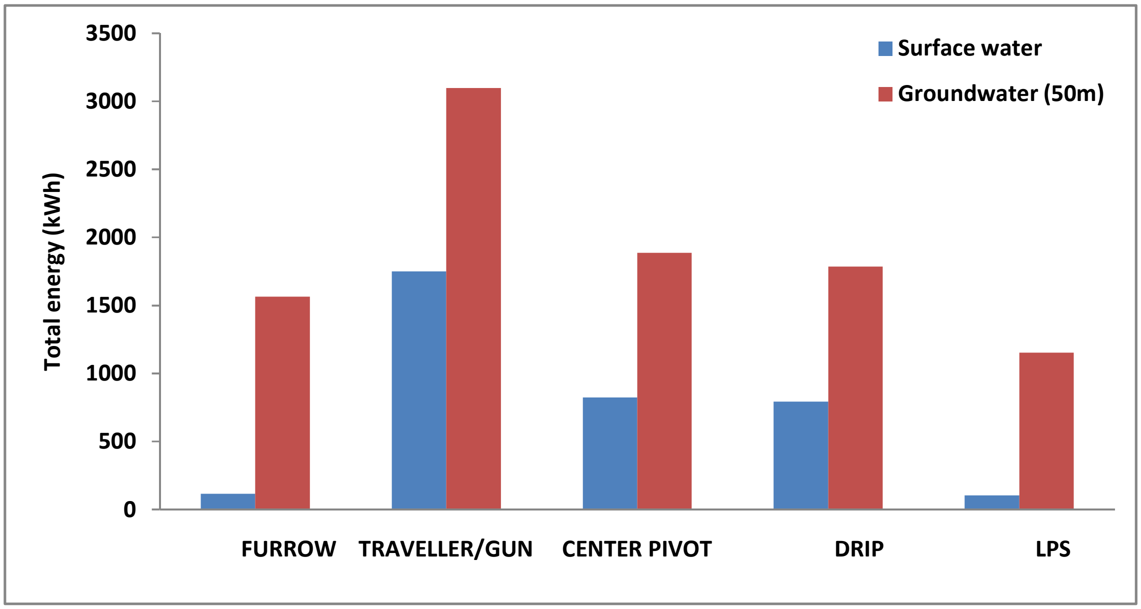

Figure 4 Energy use for different irrigation methods, including Low Pressure Drip (LPS).

Figure 5 Low Pressure Drip System at Kibbutz Yot Vita, near Eilat.

One of the biggest Kibbutzim visited was Kibbutz Yot Vita, near Eilat. This Kibbutz has 300 members and comprises of 100 ha of intensive agriculture, a greenhouse, date orchard, dairy and dairy processing factory. Most grain and fodder for the dairy is imported from the north of the country. Most of the irrigation is undertaken using drip (including low pressure drip), although they also have two centre pivots that use sewage water from Eilat, just used to grow pasture for feed – simply because they need to use the water (Figure 6). Dairy biogas is used to fuel the dairy operation.

Figure 6 Centre pivot at Kibbutz Yot Vita, near Eilat.

5 United Kingdom

5.1 Irrigation industry

The UK irrigation industry represents a very small proportion of total water use in the country; water use for irrigated agriculture represents only 2% of all water use. Despite this small proportion of water used, irrigated agriculture is economically very important, contributing 20% of total crop value. Over the last 20 years, there have been significant changes in the composition of the crops irrigated. The proportion of irrigation on pastures, sugar beet and cereals has declined, and in contrast there has been an increase in irrigation of high value crops, particularly potatoes and vegetables for human consumption. In 2005, irrigated horticultural crops accounted for 74% of the total irrigated area, and 86% of the total volume of irrigation water applied. Of these, potatoes and vegetables are the main irrigated crops, accounting for 70% of water use; in 2008 around 106,000 ha of potatoes and a similar area of vegetables were irrigated (Figure 7) (DEFRA, 2009).

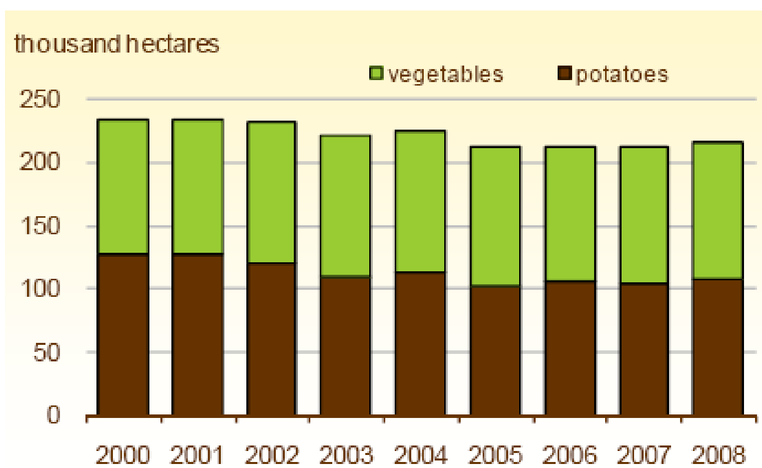

Figure 7 Area of potatoes and vegetables irrigated, 2000 – 08 (DEFRA, 2009).

Agricultural abstractions have decreased by 48% during the period 1995 – 2007 (Figure 8). Approximately 95% of irrigation water for agriculture is abstracted from surface (54%) and ground (41%) water (DEFRA, 2009). Rainguns are the most commonly used irrigation method.

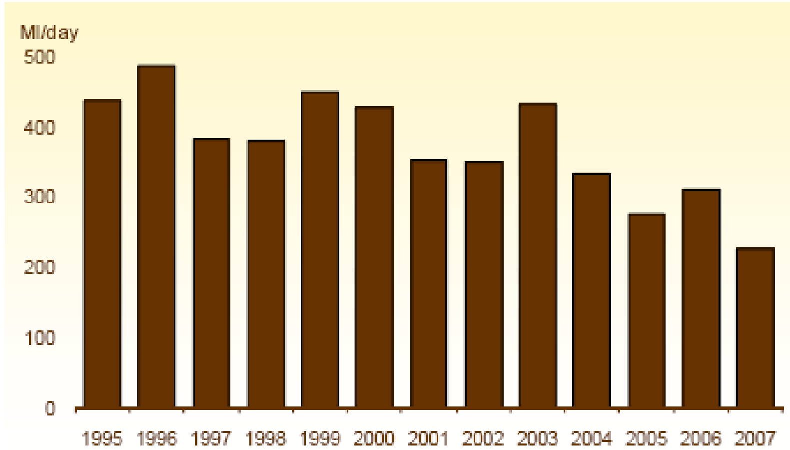

Figure 8 Licensed water abstracted for irrigation, 1995 – 2007 (DEFRA, 2009).

5.2 *Observations*

5.2.1 Climate change

At Cranfield University, I met with Dr Ian Holman, who is researching the integrated assessment of the effects of future changes on natural resource management. These include cross sectoral interactions and impacts, including climate and socio-economic aspects of agriculture. Studies show that in the UK, agriculture is more sensitive to the economic environment, and is relatively insensitive to climate. However, while this applies to agriculture in general, irrigation is more sensitive as water resources are highly affected by climate change. Part of the complexity in assessing irrigation and climate change is that water availability and water allocation are determined by social values.

Dr Holman is interested in the impact of climate change on irrigated agriculture and how adaptation will occur. There will need to be cash inputs to change infrastructure and production systems. There is a need to manage landscapes gradually, and to plan for transitions so that ecological processes can adapt to climate change. Maintaining species in response to climate change may be untenable in some circumstances. To help adaptation, non climate pressures should be reduced. Payments for Ecosystem Services are an option, but is it right to create a market for something that is traditionally free?

5.2.2 Carbon accounting & carbon sequestration

Professor Pete Smith at the University of Aberdeen was the Convening Lead Author of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, Mitigation volume, Chapter 8 (2004 - 2007), and has published work on energy intensities and GHG emission mitigation in agriculture. Irrigation included as a sequestration option due to the opportunity to increase productivity. However, in most cases energy costs don't cancel out improved organic matter and productivity. There are energy costs associated with applying water, including GHG costs and embedded costs. Methane is probably a small component of flooding (aside from rice production, which is often permanently flooded). However, N_2O emissions might be much better under drip (Kallenbach *et al.,* 2010).

I discussed with Professor Smith his views on including or excluding agriculture from emissions accounting/trading schemes. If it is left out, it's hard to give people incentives to change, because it is not accounted for. But if it is kept in and used to 'squeeze' producers, it could bring the industry down. On a global level, there is a need for accounting, but it needs to be managed carefully. Most developed countries already have country level agricultural emissions. Accounting for bulk N is not accurate, as shown in accounting systems e.g. precision farming. In his opinion, Australia has one of the best carbon accounting systems (NCAS), the result of spending $12m per year from the early 2000s as opposed to £300K pounds in the UK.

In terms of mitigating carbon emissions, Professor Smith thinks we need to look at the biggest sources of emissions and try to get people to move towards lower emissions. Even small changes can make a big difference; all the 0.5% add up. We need to 'decarbonise' in the next 20-25 years. Options include microgeneration of fuel – 5/7 emissions come from fossil fuels. There is no time for nuclear development. Renewables are deployable now, and big investments are needed now. Changing economics will force a change. In agriculture, the reuse of mineral N and organic manures is essential, and can be forced by costs of N. Boosting soil organic matter (carbon) has other benefits apart from carbon sequestration. The problems with this are that it is time limited, reversible and easily lost. If we only have 20 years to make a change, carbon sequestration is not a wide scale solution – we cannot rely on this. Carbon sequestration should be seen as a co-benefit rather than the driver. Farmers are already being paid for carbon sequestration on the voluntary market – but it is not the only solution.

Dr Adrian Williams at Cranfield University undertakes agricultural systems based Life Cycle Analysis, combining indicators for human health and resource consumption. He has worked on projects at the national scale for the Department of Environment, Food and Rural Affairs (DEFRA), looking at ten main field crops to compare those produced in the UK with imports (Williams *et al.,* 2008). We discussed methods of upscaling, and ways of breaking down systems into biophysical components, i.e. soil texture, rainfall zones. Also need to look at a range of activities, rather than just one aspect of a system. Variations in machinery use (such as found in Australia) are not a problem in the UK – there is more homogenous use. Any variation is taken from DEFRA's farm business survey. This starts with financial aspects and incorporates energy interests – but with more of an aim at direct energy. Indirect energy has now also been added. People use this information for carbon footprinting, but there is a danger that this will miss finer points. There is a need to maintain diversity of understanding.

Dr Williams described a new project for the Committee on Climate Change regarding soil carbon. This project explores consumption at the country level (UK), based on commodities consumed, and the impacts of scenarios for reducing emissions within the UK. For example, a large reduction in the production of meat products within the UK would free up arable land in the UK, but would have impacts elsewhere. There is a need to examine the effects of this – what would replace livestock production, and what would the impacts be? There are also implications for land use change from imported crops. For example, there can be a shift in international trade, i.e. organic soy is imported into the UK from China, but China then needs to fulfil its soy requirements, and imports conventionally produced soy for their needs from Brazil. Thus, there is not a net increase in organic production – and the carbon impacts of this change in production due to trade influences. For example, organic, low energy food products have a high land requirement, thereby increasing land pressures.

5.2.3 Water accounting

Dr Tim Hess at Cranfield University is conducting research into water footprinting. The main aim of this is to refine water footprinting to take into account the *impact* of using water, not just the *amount* of water used. That is, the impacts of water use in time, space and source. Water footprinting takes into account the differences between blue (surface and groundwater resources - irrigation), green (rainfall/soil moisture) and grey (polluted) water associated with the production of any good or service. This approach gives a stress related water footprint, and accounts for the impact of production from, for example, rainfed versus irrigated crops, or crops produced in water scarce regions compared to those produced where water is abundant. Producing a single number is meaningless unless we take into account the impact of that water used, which is the advantage of the water footprinting approach.

When the water footprint of crops is examined, some studies take into account inputs, but this works out to be 99% of water attributed to the growing process. There are major differences for livestock systems – where using feed (irrigated or dryland) or grazing systems (irrigated or dryland). Water footprinting is done from a top down approach on a national scale, with flows on a national basis. In terms of accounting for variability, the methods used assume the average method of production, multiplied by the quantity of crop produced/area.

Ultimately, there are impacts on consumers from carbon and water footprinting that should be considered. Supermarkets are using these indicators as a marketing tool to increase profits; ultimately, supermarkets dictate what will be produced, and increasingly in the UK, the methods by which they are produced. For example, up to 60% of the irrigated area in the UK is scheduled using scientific (objective) approaches (Hess *et al.*, 2009). Is this because of the high value crops or because many supermarket QA processes require this as a component of the process? Figure 9 shows an example of some of the supermarket programs that farms are accredited with. People want carbon footprinting now, and they want it with no errors – in reality, you get a value with an error band around it. A rating may be better than a single number. There are potential legal constraints related to carbon footprinting. Methods are needed for estimating the uncertainty related to these numbers. Consumers range from informed to uninformed, but for a lot of people their consumer preferences will still come down to price. Professor Pete Smith thinks that consumers are becoming better educated, and carbon labelling is a benefit that will change behaviour as it becomes more common and better understood.

Figure 9 A farm sign in The Fens area; the symbols at the bottom of the sign are all different programs that this farm is accredited with.

5.3 Field visits

Along with Dr Jerry Knox, I visited Holme Fen, which is land that was reclaimed in the 1850s (previously 2nd largest lake in UK). It is now highly productive agricultural land; soils have very high organic matter and are uniform and very fertile. Major crops produced are field crops (wheat etc.), potatoes, onions and spring onions. Crops give good yields and are of good quality. Fields are drained in winter by a series of drains, which eventually drain via large channels into the sea, where they are pumped at low tide. In summer, drains are blocked and used to sub-irrigate fields (see Figure 10).

Figure 10 A typical landscape in "The Fens". In summer, these drains are blocked and used to sub-irrigate the neighbouring fields.

6 USA

6.1 Irrigation industry

In 2008 the US had a total irrigated area of 54.9 million acres (22.2 million hectares) in 2008, an increase of 4.6% over the previous 5 years. The total quantity of water applied also increased by 5%, up to 91.2 million acre feet (112,493.5 GL). The major irrigated states are Nebraska, California, Texas, Arkansas and Idaho. There is excellent, comprehensive information available from the 2008 Farm and Ranch Irrigation Survey (USDA, 2008), including information on crop water use, irrigation method, decision making by irrigators and energy use. Figure 11 shows the area and quantity of water applied from groundwater and surface water. Groundwater is the dominant water source, accounting for over 53% of total water use.

	2008	2003	% Change
Ground Water			
Acres Irrigated	36.2 million	32.3 million	+12
Acre-feet Applied	48.5 million	43.5 million	+12
On-farm Water			
Acres Irrigated	8.8 million	7.2 million	+22
Acre-feet Applied	13.8 million	11.7 million	+17
Off-farm Water			
Acres Irrigated	13.1 million	13.8 million	-6
Acre-feet Applied	29.0 million	31.6 million	-8

Figure 11 Water source, 2003 and 2008

Given that groundwater is the dominant irrigation water source, it is likely that the cost of pumping will add significantly to costs. The above mentioned survey reports water expenses per acre for groundwater as $60.9, and surface water as $36.13. This may explain why in the 5 years between 2003 - 2008, almost 75,000 farms made changes to their irrigation equipment or management practices that reduced energy use and/or conserved water. Around 46% reported a reduction in energy costs and 59% a reduction in the amount of water applied. Figure 12 shows that electricity is the biggest energy expense for irrigation pumping, followed by diesel fuel and natural gas. The level of information available for irrigation in the US is far greater than anything available in Australia, and indeed many other countries.

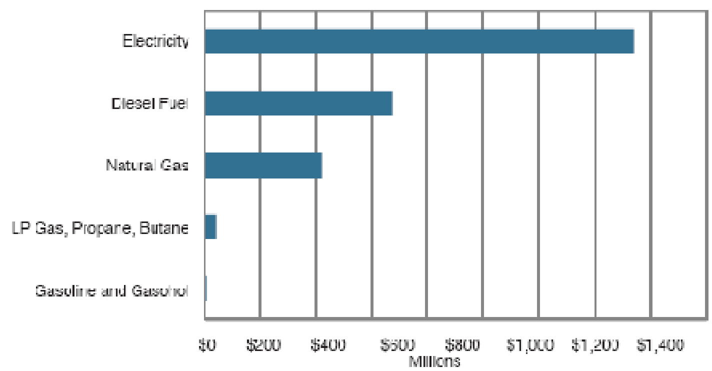

Figure 12 Energy expenses for irrigation pumps, 2008 (total 2.68 billion)

6.2 Observations

6.2.1 Energy and carbon in agriculture – Professor David Pimentel

Professor David Pimentel from Cornell University is the pioneer of studies into energy in ecosystems and agriculture. His career has developed from entomology, but he also developed an interest in energy and biofuels. In 1968 he was part of a National Panel to identify what would be the major problems facing agriculture over the next 25 years. Professor Pimentel suggested energy, and all others on the panel disagreed. He then went on to set up a Masters program in ecology and then in environmental policy. Along with his Masters students, in 1970 he wrote the first paper on energy in agriculture. This took 3 years to get published in *Science*, but when it did it coincided with the oil crisis of the 1970s, and prompted further research into this subject which he continues today.

Figure 13 With Professor David Pimentel at Cornell University.

Professor Pimentel agrees that irrigation is essential, but questions whether all crops currently irrigated necessary. We need to think about what types of crops should we be irrigating and where. For example, lettuce is irrigated in California and then transported to the east coast – this is intensive in terms of water and energy; for an energy output of 400 calories/head of lettuce, it requires 4000 calories for transport. In Nebraska, irrigated corn uses three times as much energy as non-irrigated corn. Irrigating high yielding (in terms of energy) grain crops may be suitable, or irrigating to save crops in times of drought to maintain production. However, this would eliminate the possibility of investing in high tech irrigation systems and complex water delivery and access systems if irrigation was going to be spontaneous – it would not be economically feasible. Gravity fed irrigation systems still have a place, given the energy intensity of pressurised systems.

Changing consumer preferences is also important in terms of the energy used for crop production and storage. For example, in the US, most people eat twice as much as the body requires (kcal), including twice as much protein which is energy intensive and emissions intensive. There is a need to go back to locally produced, seasonal food.

Professor Pimentel undertook a 22 year study with the Rodale Institute, comparing organic and conventional crops (corn and wheat). The conventional system was managed following recommendations by Penn State University. At the end of 22 years, the organic system had twice as much soil organic matter as the conventional system. In a drought year, the organic system had 33% higher yields for corn and 50% for wheat. The energy use was 33% less in the organic system, but 30% more labour was required. On average over the 22 years, yields were the same for organic and conventional crops. Organic production offers the potential to make our soils more resistant to drought.

Professor Pimentel sees genetically modified (GM) crops as an opportunity, but is opposed to the types of GM research being undertaken at the moment (e.g. chemically tolerant plants). There may be opportunities to reduce energy consumption through certain types of GM – for example, he would like to see GM to make annual plants become perennial – in order to reduce the energy required for soil cultivation, sowing and embedded in seeds. However this would also have an effect on water use – what would the trade-offs be?

According to Professor Pimentel, looking to the future, we will run out of oil. This will challenge the way we use water and produce crops. Pumping for irrigation on a wide scale may not be viable; thus food production will move to more suitable climatic zones. Transporting food and water will be a problem. This will cause major changes to agricultural production, and consumer preferences will have to change. In short, water and energy are the two items that will 'upset' US agriculture.

Dr David Zoldoske is the Director of the Centre for Irrigation Technology at California State University in Fresno (CSU-F). This centre is involved in several interesting projects related to water, energy and emissions. In one experiment, they have used driplines to apply CO_2 to a crop canopy (tomatoes and peppers) in a plastic tunnel. Around 30-40 tonnes of CO_2 are applied over 45-60 days during the season after the canopy is established. The results are good, with yield increases of 65% observed. In the year that the experiment was undertaken, there were high levels of heat stress, therefore higher CO_2 levels helped the plants cope with this stress. In terms of the carbon balance, the CO_2 used is a high quality by-product of biomass use. No additional CO_2 is being generated as they are using a waste product and also sequestering more carbon due to increased yields.

6.2.2 Pump efficiency programs

CSU-F has developed and managed the Agricultural Pumping Efficiency Program. The program is for agricultural water pumpers using electricity or natural gas, to help reduce energy use and improve resource efficiency. The funding for the program comes from the Public Goods Charge that is paid by ratepayers under the California Public Utilities Commission. There are separate programs for electric and diesel pumpers due to the nature of the funding secured to date. Under the electric pumping program, around 20,000 tests on about 8,000 pumps have been performed. This covers a lot of the big motors and or pumps with high hours. Big districts and city pumps already pay close attention to pump efficiency. 1 million kWh per month of new savings have been generated through improved pumping. This offers huge potential for energy savings across the state.

Part of the driver for assessing diesel pumps is pollution reduction, in particular reductions in N_2O and particulate matter (less than 10 micro m). This reduction in pollution is due to improved efficiency. So far there have been two pilot programs for diesel pumpers that have been highly effective, but funding has ended. For the funding body, the interest has shifted to fuel substitution, filtering etc. The results from the pilot programs show overall efficiencies of 17-18%; this was able to be improved by 67%. This resulted in a reduction on average of NOx emissions by 3.4 tonnes. It was also favourable in economics – with fuel bill halved in many cases. Diesel pumps are estimated to make up around 10% of the state's irrigation pumps, mainly used in isolated areas where access to electricity is poor.

6.2.3 Water and renewable energy – the biofuel debate

I met with Mike Shannon at the USDA in Beltsville, Maryland, who is the National Program Leader for Water Availability and Watershed Management. As part of this department's operations, it undertakes conservation assessments, looking at water availability and water quality, and assessing risks to the natural resource base. A resource conservation assessment is undertaken every 10-20 years. Economic issues are still what is pressuring farmers. In terms of irrigation, pumping costs are a major driver. Variable rate pumps should be used to take advantage of low rate, low energy options.

Along with Bob Farved from the Biofuels and Renewable Feedstocks program, we discussed the development of this industry in the US and the ways in which it interacts with the water sector. At this stage there is an aim to develop dryland crops to reduce dependence and impact of biofuels on water resources. Along with new crops, sorghum is being considered as it is relatively drought tolerant. There is no research being undertaken to support corn based oils, and they are sticking to native species as much as possible. There is pressure to work on species such as Miscanthus (Giant Reed) – but the invasive nature of this crop is a risk, and the research is trying to minimise this risk (especially due to the fact that research is funded by the public sector). The limitation for biofuel production is ultimately water, and there is concern about the biofuel-energy-water nexus – they are trying to build models to get an idea of capacities and limitations. There are a number of production options to meet biofuel production needs, and one option is to help farmers identify ways of developing local fuel options on/near farm systems.

Professor David Pimentel from Cornell University also discussed biofuel use in the US. He is openly opposed to current biofuel policies – US$23 billion subsidies for corn ethanol, and soybean biodiesel. This has increased food costs by around US$9 billion in addition to the subsidies (mainly through higher meat, milk and egg prices). His research indicates that biofuel production is energy negative (i.e. more energy is required in the process than is produced by the biofuels). Possibly the only energy "positive" crop for biofuels is algae. Analysis shows that the cost of production ranges from $0.2 - $9/l – their analysis suggests $1.8 which could make it feasible. Professor Pimentel would like to see diesel prices at around $10/l to encourage sustainable use of diesel fuel and also to make alternatives more viable.

6.2.4 Water tensions in California

Mike Wade from the California Farm Water Coalition (FWC) explained some of the pressures being experienced by irrigators in California, and also arranged several field visits for me. The FWC was formed in 1989 for education and public relations purposes, to try and address the negative publicity over agricultural water management. It is funded by dues (40c/ha) from irrigation councils. Mr Wade also works as part of the Agricultural Water Management Council (established in 1998), which works on water use efficiency projects, water management planning and deals at the district water supply level.

Water rights in California are a right to use, not a property right. The right to 'beneficial' use is defined by the state water code, and include appropriative, riparian and contract rights. The biggest problem facing irrigators currently are changing environmental regulations, including quality and environmental flows. There is not a water supply issue; there is a water legislation problem. Due to what are seen as environmental issues in the Delta region of the state, water allocations for irrigation have been cut to just 10% even in average climatic years. Agriculture is being blamed for decline in environmental sustainability, and pumps are turned off. This is affecting the west side of the San Joaquin Valley, with around 1 million acres affected. As an example, I visited the town of Firebaugh, who are facing huge social problems due to massive areas of land being retired because of a lack of water availability – up to 30,000 acres has been taken out or irrigated production in the area. There is a need to put plans into place so that actions can be taken in such situations.

An interesting point in terms of PR for the irrigation sector is defined as the 'hierarchy of credibility'. This essentially means that there are three levels of motivation for action – the highest level being the most credible to the general public:

1. The "right" thing to do – environmentalists have capitalised on this
2. Good for my bottom line – what farmers are saying
3. The law says I have to do it – least credible

Environmentalists are operating on a higher level of credibility than farmers, even though farmers are often doing things for the 'right' reasons as well. It is essential for farmers to promote this message.

At the Wheeler Ridge-Maricopa Water Storage District, Bill Taube (General Manager) gave me some insights into some of the issues he faces along with other water district managers in the southern San Joaquin Valley. The supply issues due to environmental regulations are a serious issue in the region; farmers (and the supply company) pay for their full allocation of water whether it is delivered or not. Water costs for farmers range from $140 - $300 per acre feet ($113 - $243/ML). The range is due to geographical area, different bond areas and pumping lift. The challenges for the water supply company are to supply alternative water sources for their customers in a time of shortage (source water from federal water scheme, state water scheme, groundwater, aquifer storage and recovery system). Despite massive over-extraction of groundwater, Mr Taube believed that groundwater regulation was a bad idea, as each basin is unique and regulation tends to be one size fits all. He thinks there should be adjudication, not regulation. As an example of the tensions over water in California, this agency (in conjunction with others) is currently involved in 26 lawsuits.

Figure 14 The California Aqueduct.

6.2.5 Field visits

Mike Wade from the California Farm Water Coalition organised field visits to several irrigators in the Fresno region, as well as to the Wheeler Ridge-Maricopa Water Storage District in the southern San Joaquin Valley.

Stamoules Produce is a family run irrigation business. The farm area is 15,200 acres (6151 ha); some of this is double cropped per year, so annually they are irrigating 17,900 acres (7243 ha) in total each year. Crops produced include sweetcorn, peppers, melon and broccoli. Total water use is 37,500 acre feet per year (46,255 ML); water is at a premium in terms of cost and availability. Annual surface water allocation is 9,750 acre feet (12,026 ML). The balance is pumped or bought (in California there is no restriction on groundwater pumping). Water costs over $400/acre feet ($325/ML), making up 15% of total cost. Major energy costs are for cooling (pack house) and pumping (electricity costs for pumping are $160/acre foot ($130/ML)). The major expenses are labour, water and fertiliser.

All crops are pre-irrigated with sprinklers but then drip is used; this has been in operation for the past twelve years. The aim of this is to save water (30-40%) and improve production in terms of yield and quality. Economically, drip is sensible; if $1,000/acre is invested in drip, it is returned in one year. The company has rented some land with furrow, but if this is rented for more than 3 years they will convert to drip. For the high value crops produced, drip is relatively inexpensive. Irrigation is used as a vehicle to transport elements for plant growth – it is more than just getting the soil wet. The company sees drip as a good fit for their business. They have made it work, but have worked hard at doing that – to use drip successfully, they identify a need to have the right attitude, and drip has to fit the crop.

This company is a major operation and is using very advanced practices. An interesting technique being used is airjection – injecting air into buried driplines (under research at CSU-F). This technique is reported to give higher yields (30%), 50% more root mass, and maintain yields with poor quality water, and appears to be a simple riser inserted into the sub-main that adds air to the system (Figure 15).

Figure 15 "Airjection" at Stamoules Produce.

South of Fresno, I visited Errotabere Ranches. This farm has implemented drip on all land over the last 3 years. Before this they were using sprinkler and flood, but these systems were too inefficient. Energy costs were a consideration in the conversion. Water is delivered pressurised but they add extra pressure with booster pumps. Speed, labour management and efficiency/distribution uniformity has made drip a good proposition. Major crops are almonds, pistachios, pomegranates, garlic, tomatoes, garbanzo beans, cantaloupes and lettuce. Yields have increased with the use of drip, for example garlic yields have increased from 8 to 12.25 tonnes/acre using half the previous water use. Initially it was planned to use 1 year drip, but they are now moving towards 5-7 years.

Figure 16 Drip irrigation installed at Errotabere Ranch.

7 Lessons learnt & opportunities for Australia

One of the key findings from this travel opportunity was the chance to explore where different countries are placed in terms of

1. Considering energy and emissions in terms of irrigation, and
2. Assessing these aspects.

While each country and institution differs in its approach, it was revealed that there is a definite need to establish a better understanding of the energy and emission intensities of different crop production systems and the effects of irrigation method/water source on these intensities. This is particularly true given the pressures on fossil fuel resources, biofuel development and emission mitigation strategies under consideration. It is also confirmed that given the wide range of crop production systems found globally, and the different approaches taken to their management, the issue of up scaling variable local results is vital. This was discussed with several of the scientists I met, and the recommended options for incorporating variability into regional/global scales are:

- To be extremely careful to be specific as to which crop and region that is being discussed, including the irrigation technology being used.
- To ensure greater accuracy, more information must be known about a region when there is high variability. It is essential to know the system well in general, as well as to have comprehensive direct measurements on farm.

Looking at the use of different irrigation methods across the globe gives some options for adapting irrigation to a low energy future. For example, the use of low pressure drip systems can offer an opportunity to reduce water and energy use. There is also evidence to suggest that emissions are reduced with the use of drip irrigation (Kallenbach *et al.*, 2010). However, these systems clearly still have some limitations, for example the need for good quality water, and like any irrigation method, obviously require high standards of management to make them successful. It is important to recognise that there is no one size fits all approach.

Aside from pumping, nitrogen fertiliser use is a major component of energy consumption, and is also associated with nitrous oxide emissions. Closely matched nitrogen (and other) fertiliser application to plant nutritional requirements can optimise the use of nitrogen, ensuring that maximum benefit is derived from its application. This also prevents pollution of groundwater and surface water from leaching of fertilisers that are applied in the wrong quantities and at the wrong times.

The experience of the California Agricultural Pumping Efficiency Program shows that it is vital to look at all system components when considering irrigation. By ensuring that pumps, motors and irrigation systems are properly designed, installed and maintained, there are opportunities for water and energy savings. In California alone, this program has saved over 1 million kWh per month from the electric pumps that have been tested to date. Assessment of irrigation pumps in some parts of Australia has shown that up to 50% are performing poorly. A similar program to that developed in California, if implemented in Australia, could deliver electricity and diesel savings, reducing pumping costs for irrigators and reducing associated emissions.

Other key learnings included;

- The differences in scale between the countries visited. For example, Israel has just 182,000 ha of irrigated land, compared to 22.4 million ha in the USA. Along with total country size and resources, and governance/legislation differences, this question of scale raises questions about the feasibility of managing irrigation in such a high-tech was as Israel, on a bigger scale.

- The differences in the way water rights/legislation is structured was also an eye opener; unlike Australia, the countries visited had the right to use water for irrigation, but did not actually own the right as irrigators do here. In Israel, the government "owns" all water, including surface and groundwater. In California, there is no restriction on the use of groundwater. This has huge implications for over extraction, and there are problems with land subsidence and degraded water quality as a result. Despite this, groundwater regulation in terms of legislation was seen by some as a threat due to the different requirements for each region; legislation is seen as a "one size fits all approach" which would not account for this variability.

- The economic impact of water use – for example, in the UK, while irrigation is a very small portion of water use (2% of total), the difference in price between irrigated and non-irrigated strawberries is up to £3,000/ton. Thus the security of access to water at critical times is vital for these farmers.

The current global focus on water and food shortages in conjunction with rising energy costs and a drive to reduce emissions means that there is a requirement to understand these impacts on the irrigation sector. Strategic research in this area will be necessary in order to achieve a balance between meeting economic, social, environmental and legal obligations. A better understanding of these challenges will help with the development of strategies to adapt to changes brought about by a changing climate and related policies. This fellowship allowed me to interact with others around the world who are working on aspects of the energy-water nexus. Ultimately, it would be beneficial if these interactions and discussions could lead to options for the continued development of sustainable, vibrant agricultural communities through knowledge sharing and new science. Policies and practice for the irrigation industry must promote the production of food and fibre according to best-practice management with minimum impact to the environment.

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