Water Use Efficiency

A study into Water Use Efficiency in Irrigation

A report for NUFFIELD AUSTRALIA FARMING SCHOLARS

by Andrew Watson

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Foreword

A steadily worsening drought, declining allocation from surface water sources, a tightening terms of trade for cotton production, convoluted yet steadily advancing State and Federal Water Policy development disputes and savage bore water allocation cutbacks set the scene for a decision on Nuffield study topics. In trying to set this study topic, I focussed on the single tenet of this issue I could manage at property level- Farm Water Use Efficiency.

Our family farming operation has for many years concentrated on improving all our efficiencies, fiscal, social and environmental. However, the Cotton Industry Best Management Practices (BMP) program brought a concerted focus for us on water; how we used it, how we stored it and what quality was it? My family management team and I have looked at other operations, cotton farming or otherwise, all over Australia in an effort to bring positive change to this aspect of our operation. In recent years, alongside others in our industry, our farm took ideas for soil moisture-metering capacitance probes from the wine-grape industry, electro-magnetic soil surveys from the geology sector, and aerial infra-red plant imagery from possibly the armed services, in order to gain greater production from our most limited resource- water.

The award of the Nuffield farming Scholarship for 2006 meant I was able to expand this research to other parts of the world. There were two basic criteria for the directions I headed: firstly, I wanted to see how other developed and therefore probably wealthy nations with similar climate conditions were dealing with this issue; and secondly, I was interested in how lesser developed nations with lower capital and technology bases, again in similar climatic situations, were handling the thorny topic of productive water use.

This trip enabled me to see and understand multi-species cropping systems, alternative irrigation techniques, new and ancient farming systems, and to look at emerging bio-technological advances. Some of the systems will be appropriate to our farming operation, and some will be appropriate to other operations with different circumstances in Australia.

Acknowledgments

I am deeply grateful to the Sidney Myer Fund and Nuffield Australia for this chance to experience such an enormous breadth of differing approaches to what I find quite similar problems faced by farmers world-wide.

I would also like to sincerely thank my family: father and mother, John and Robyn, and brother Peter and his wife, Georgia, for making it possible for me to be away from the farm for the period of the scholarship.

I am also extremely grateful to the many, many people from many nations who were prepared to share their experiences and knowledge with me on what I must admit was almost an exhausting range of topics surrounding the issues facing successful farming in the world today.

Contents

Executive Summary

Australia has some of the most advanced Water Use Efficiency farming systems in the world, and our arid environment has demanded we have some of the most advanced Water Policies and Regulations. However, water scarcity is being recognised as a burgeoning problem by scientists in many parts of the world, but the banner is yet to be taken up by policy makers.

The major findings of my study are:

- More developed nations like the US and Germany are focussing on technological advances like bio-technology, more advanced measuring techniques, and more efficient irrigation systems;
- Lesser developed nations rely on farming systems like multi-species cropping that focus on their strength of low labour costs, but which also manage climate variability well;
- Budgeting on ideas like combining irrigation systems such as Overhead Spray and Furrow Irrigation show low return on investment;
- The Water Use Efficiency in the Australian Cotton Industry is the best in the world, with many other countries' industry unable to even measure their usage, let alone calculate efficiency;
- Australian Water Policy, with its focus on realistic and achievable management of both supply and demand, is more advanced than most places in the world.

Introduction

The background behind the original idea for my topic, Water Use Efficiency in Irrigation, is fairly simple- I am an irrigation farmer in northern NSW with a rapidly declining water resource base. In recent years the lack of significant rainfall in our river system based storage dam catchments has meant lower annual extraction levels; and new science in the management of underground water sources, suggesting over allocation of many Australian aquifers has seen legislated reductions in entitlements for many users. With tightening margins, most farmers in recent years have been moving toward developing their land resource to the maximum limit afforded by their water constraint. Therefore, the current reductions in the water resource have caused a significant under-utilisation of the land asset and, longer term, the stranding of some developed irrigation assets.

The Nuffield experience has given me the opportunity to research alternate ideas on cropping systems in both dryland and irrigated farming management systems, and to apply costings to identify if these will be of benefit to Australian agriculture and to my own agricultural enterprise. These ideas include the use of perennial tree crop species mixed in with an annual species based systems, different irrigation systems and bio-technologies.

The initial direction I looked at in planning my tour was to see whether other countries had advanced research in the area where Australian Water Use Efficiency research was heading- technical measurement and control of the current irrigation models to achieve the greatest product yield with the least volume of water. I concentrated on areas in the world where similar climatic conditions exist. Additionally, I focussed on irrigated cotton as it is an industry where I have some knowledge and contacts around the world. Much of the work being done in Australia and around the world on Water Use Efficiency in Irrigation is being researched by Universities at project or PHD level. I have attempted to refine the information I was able to collect down to a level at which it is able to be understood and implemented at a farm management level. At times, there seemed to be a significant distance between outcomes suggested by research projects and common practice at the farming level.

I have looked at the research into comparing different water application techniques such as Overhead Spray systems, Sub-surface Irrigation (SDI) and Furrow irrigation. Specifically, I have focussed on these comparisons on heavy clay soils based on two premises: firstly, there is much proof existing that Overhead sprays and SDI systems will significantly improve Water Use Efficiency on lighter, sandier and freely draining soil; and secondly, the majority of Australian cotton is grown on heavier, higher clay content soils.

The basic outcomes of my experience were that Australia and its irrigation industries are world leaders in research into Water Application and Management techniques and Farming Systems work in this field. Additionally, Australian Water Policy development is significantly advanced over most other countries that I visited.

However, in more wealthy countries where there is enough market share to generate research funding, like America and Germany, there is significant world-leading advances in capitally intensive research areas like overhead spraying systems and bio-technologies.

Thus I feel there are a number of technologies coming in the next few years which will greatly benefit the Australian irrigation industries, and which will fit within our farming systems very well.

Irrigation models in cotton in Australia

There are a number of techniques for irrigating cotton in Australia. These include furrow irrigation, overhead spray technologies, sub-surface and surface drip and some bay or field flooding arrangements. These have a large range of development costs, water usage figures and management difficulties associated with them, as well as a number of variations on each theme. A number of research organizations have been focused on researching Water Use Efficiency of irrigation of Australia including NSW Agriculture, Cotton Research and Development Corporation through the Australian Cotton Research Institute, and the Irrigation Association of Australia, as well as number of commercial entities including Aqua-tech Consulting in Narrabri.

An estimated 80-90% of Australian cotton is irrigated using the furrow flooding method. This technique dominates on the heavier cracking clay soils of northern NSW and southern QLD and uses over the bank syphons to direct water from the channels to the furrows. The main variation on this technique is 'through the bank piping', essentially a labour saving device to irrigate a large number of rows at once, which is declining in popularity as irrigation uniformity is being found to be a significant profit driver. Included in this technique is a variety of row spacings from 30 inch to 2 metre beds. This method is generally considered to have the cheapest development costs as earthen supply channels are used and land is formed by lazer-leveling to hold a constant slope.

Overhead boom-type spraying systems are gaining in popularity as they have a reputation of using significantly less water than flooding systems. This includes pivot- and lateral-move systems. Pivots systems are pipe fed directly from a bore and lateral moves are self-powered and usually draw from channels but hose-drag systems also exist. There are many different variations on the actual water delivery spray systems used, including overhead spray, LEPAS and hose/sock drag techniques with almost as many opinions as to which are better systems. However, reportedly there is a yield penalty associated with some of these systems, as well as a very high economy of scale cliff to surmount.

Sub-surface drip is employed in some areas where the soil type is so light or sandy that it is probably uneconomic to water with any other method. Water use with this system is substantially reduced but the investment costs are very high and ongoing with reasonably regular drip-tape replacement.

Another system gaining credence is a technique of flooding the entire field to a very shallow depth in a very sort time frame, and then emptying it very quickly to reduce any water logging effects. Generally the fields will be lazer-leveled from the middle of the fields down to each end, much like the crowning of a road, and a bank placed all the way around. Water is let into the area covering the field up to the highest point in the centre, then drained out quickly to the ends of the field down each levelled slope, into possibly the next field. The labour input to this system is minimal, and the establishment costs are fairly comparable to standard furrow irrigating. Some disadvantages surround the inability to either 'water up' or flush a field of young cotton as covering the young plants or seeds with water for too long will kill them, and there are some questions on how much water-logging actually occurs.

A very small amount of cotton is check-bank flood irrigated, and this is declining because of the same issues outlined in the above scenario. I am unaware of any cotton in Australia being irrigated with spray-gun systems, K-line systems or with rolling or hand-laid aluminium pipe spray techniques.

Australia has many systems of irrigation, with the majority focussed on suiting the land forms and soil types that they are based in. Economics will continue to drive changes in the future.

Defining Water Use Efficiency

From a farming point of view, water use efficiency is a measure of two factors, the amount of water applied to a field relative to the yield of the field, and the amount of water that is lost (or gained) in storage and transfer of the water from its source to the field.

Traditionally in Australia the pumps pumping water from the river or bores are metered, however, most delivery systems from farm water storages or tail-water return systems are not, as well as any run-off into such tail-water storages. There are difficulties in measuring how much water is leaking downwards or out of channels and storages, or below the root zone in the field.

On the positive side, evaporation is able to be measured and more complicated measuring devices have meant that most of the above measurements are able to be estimated to a reasonable accuracy.

Research on-farm

Our farm has been involved in a cotton industry field research project for the last three years to analyse the effectiveness of a number of computer programs in advancing water use efficiency in cotton growing. We have been using a computer program called Hydro-logic which models cotton plant water requirements based on a number of measurements like plant growth stage versus a calculated optimum stage, daily temperatures, rainfall and humidity, and capacitance probe soil water measurements, to predict irrigation timings. The second major program we are trialling is a commercial program called Water-Trac. This program measures the water balance from around the farm, including storage levels, channel seepage and evaporation, and field applied water and run-off.

The two computer programs allow us to get a very complete picture of where our water resource is going on the farm. As we know how much water is evaporating each day, and have estimates of how much deep drainage we have in field, dam and channels, we are able to assess just how much water the cotton plant is actually using.

The next step we have taken is to assess where the major inefficiencies are; whether they are in leaking storages or evaporation, and to change management systems to reduce losses. We have done electro-magnetic surveys of our dams and some of our larger channels to assess the porosity of the soil where water might be leaking and have spent significant capital re-lining and compacting dam floors. We also manage the water in our storages so that it stays there for the shortest length of time possible, to minimise seepage and evaporation. Thus we do not attempt to hold over water from year to year, but will plan to irrigate another winter crop with the water. Also, we will irrigate fallow soil to store the water in the profile for a future crop to be planted rather than attempt to store the water until the next cotton crop is planted. The program is remarkably similar to the concept of ‘response cropping’ in the dryland scenario, where we will plant and irrigate a winter crop if we have sufficient water left over from summer, rather than hold the water until next summer- and potentially lose a significant portion of it.

Figure 1: Water-Trac furrow water measuring devices in a planted cotton field.

In terms of field water use efficiency, we have done electro-magnetic surveys of all the major soil types in our irrigation fields and through the Water Trac program, we have been assessing the best way to furrow irrigate them. The general best practice has been to push more water down each furrow for a shorter time, to minimise deep drainage and reduce plant waterlogging. Traditionally 12 to 24 hour water shifts were used, but now we are finding if we reduce this shift length to 8 or 6 hour shifts we can save water as well as reduce waterlogging stress on the plants. The fields are also assessed for uneven height or constant slope by data-logging by tractors fitted with GPS receivers. This has enabled us to decide whether fields need re-levelling to ensure uniform water application.

The research into water use efficiency in Australian is quite extensive and has been driven by necessity of declining allocations from surface water sources, tightening terms of trade for farming production and a steadily worsening drought.

Multi-species Dryland/Irrigated production

Tree crops interspersed with annual crops in high moisture availability times.

In this section I will attempt to budget the concept of farming a Multi-species perennial and annual combination system in the style of farming in the dryer parts of Spain and Morocco. The very basis of this type of system is a perennial tree crop planted at widely spaced intervals and annual crops will be planted in-between when the water is available either in the soil in a dryland environment or stored for irrigation. The tree crops would be harvested even in dry times due to their extensive root systems making the most of available moisture, and the annual crops would use the water in the wet years or seasons that is excess to requirements of the perennials.

Figure 2:
Left- Olive Trees amongst Lucerne

Right- Stone Fruit inter-sown with Barley and Corn


The systems that I saw in Morocco were based on a very dry environment that stretched out into the Sahara desert that had access, when available, to irrigation water from snow-fed dams in the mountains down narrow river valleys. The perennial crops were predominantly Olive trees and Date Palms with the latter becoming the dominant species the further the valleys progressed into the desert environment. The main annual crop was bread wheat that would be hand sown and flood irrigated in small hand-dug bay systems. However, in some areas with greater water reliability, lucerne would be grown for hay production and others would have vegetable crops such as cauliflower or maize. The irrigation varied from flood irrigation to hand-moved spray lines to some surface drip systems.

Water off-takes from the rivers ranged from automated pump stations in some government funded areas, but were mainly small rock weirs to divert water into concrete lined or earthen channels which ran parallel to the river until the water reached small areas of fertile soil amongst the largely rock and sand of the more distant desert valleys.

The Spanish farming systems seem to benefit from a more highly reliable irrigation water source and be focused on open paddock cropping. However, there was a very interesting Tree Crop/Grazing system termed the 'Dehesa' grazing model. The system comprised non-irrigated grazing country incorporating 'Holm' acorn trees at a density of 250 trees per hectare. Cattle would be grazed under the trees for 9 months until autumn (October to December), when they would be taken off to alternate pastures.

Figure 3: Retinta Cattle grazing under Holm Acorn Trees in Spain

Iberian (black) pigs would then be let into these pastures to feed on the acorns which would fall from the trees for the next three months. The pigs would be supplementary fed on pellets for the balance of the year. Outputs from the system would be vealer cattle to a feedlot market, and 18 month old pigs to slaughter and subsequent hanging for 3 years to produce a highly specialised ham product. The advantage of this system is the pig meat is selling into a very high priced niche market in Spain where acorn-fed ham is sold anywhere up to €100 (Euros) per kilogram.

The significant difference these systems have in contrast to Australia is the availability of a cheap source of labour. Any system in Australia would have to be adapted to be highly mechanised to allow for Australia's high cost of labour. Additionally, the intensity of irrigation in the Moroccan system seemed to negate the 'edge' effect that seems to prevail in Australian broad-acre cropping system where the crop is planted up against a tree line. The pasture growth in the Spanish system also showed no indication of the trees using all the moisture and denying the pasture opportunity to grow. The rainfall is winter dominant (September to March), and I saw the system in late summer (September), so I am not sure whether this has any impact or not.

A number of both dryland and irrigated systems will be analysed, and a number of major assumptions will need to be employed. The models will assume the proposed systems will be transplanted onto existing flood irrigation land in Australia, reducing the need for some development costs such as irrigation systems which will be considered as sunk costs.

The tree crops or perennials to be considered as examples are:

- Olive trees at 119 trees per hectare
- Jojoba bushes at 357 bushes per hectare

Olive Trees inter-sown with Wheat

Olives are considered here because there is an established market in Australia for the oil and fruit and most of the growing processes are able to be mechanised. The budget assumptions are listed below.

The assumptions being made for these budgets are:

- that Establishment costs are amortised over 10 years,
- all the irrigation head works and channels are functional and considered as sunk costs,
- planting in the Olive/Wheat Combination would be in row widths of 14 metres to mechanise growing of the annual crop,
- trees rows would allow 90% of the area to be planted to wheat,
- irrigation scheduling would mean survival watering of the Olives in a dry year, and complete furrow irrigation of both crops if water was available
- Wheat and Olives Budgets taken from NSW DPI farm budgets: http://www.agric.nsw.gov.au

Figure 3

Olives for Oil Production vs. Olive/Wheat Combination				
	Olive	Olive/Wheat	Wheat	
	Production	Production	Production	
	250 trees/ha	119 trees/ha		
Income (Olives)	$ 10,989	$ 5,231		per ha
Gross Margin (Wheat)		$ 208		per ha
Less Variable Costs (Olives)	$ 8,000	$ 3,808		per ha
Gross Margin	**$ 2,989**	**$ 1,423**	**$ 231**	per ha
Less Amortized Capital Costs/Establishment Costs (Olives)	$ 541	$ 290		per ha
Business Return	**$ 2,448**	**$ 924**	**$ 231**	per ha

The proposed system of a combination of Olives and Irrigated Wheat shows a Business Return of 38% of a full Olive production system, but will return more than 400% of a straight Irrigated Wheat crop, given a full water scenario. The idea of the Combination system is that in a dry year with limited or no irrigation water, the perennial olive crop could still show a harvestable yield. More research will be required to understand whether the drop in yield expected by an Olive crop with less than optimal water would show a positive business return after variable costs are taken out.

The Wheat crop would show a zero return as it would not be planted in a completely dry year, but there would be less risk as no variable costs would be outlaid. The author's experience suggests, however, that the natural optimism of a farmer would mean that a wheat crop would be planted in most years in hope of rain, thereby increasing the risk by incurring a good portion of the variable costs up front. The edge effect will have some bearing on the obtainable yield in the annual crop as well, meaning the budget could vary downwards from the above scenario.

"…Mixing trees and crops introduce the problem of competition for light, water and nutrients. Tree/crop combinations (agroforestry) will only be profitable if the value of tree products and any benefits from shelter exceed the value of displaced crops and decline in crop yield through competition.

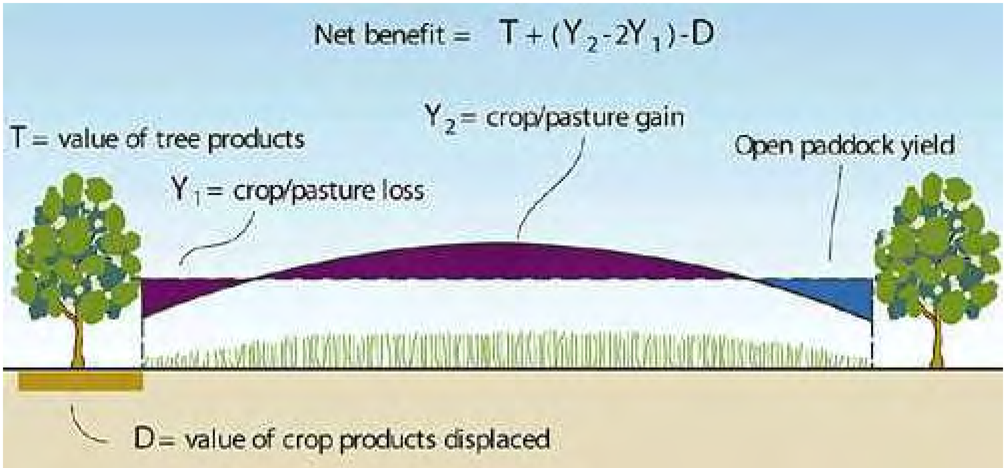

Figure 19. The net benefit of tree belts is a combination of the value of the tree product plus yield enhancement due to shelter less the area of land displaced and the crop lost to competition

Source: Redrawn from Lefroy EC and Scott PR (1994). Alley farming: new vision for western Australian farmland. ***Western Australian Journal of Agriculture*** **35: 119-126**

…"(CSIRO- Land & Water Australia 2000)

My major concern with the outcomes of the above budgets is there isn't adequate reflection of the risks in the Australian climate. As with the potential for the Murray River in 2007, there may be zero allocation of water for the Olive trees, meaning the yield may not cover variable costs, let alone capital repayments. The annual crop situation, however, would not incur any costs in a zero allocation year as a farmer would not plant.

Jojoba Oil inter-sown with Wheat

Jojoba Trees for oil production inter-sown with a cereal such as wheat shows some potential under this arrangement with the expectation that a positive Gross Margin could still be obtainable in a zero water situation from the very drought tolerant Jojoba plants. The figures from the table below show the business return on the Combination cropping system to return 98% greater than the Wheat alone model in a full water scenario. The Jojoba Trees alone would return 4 times greater than this again so maybe the focus of my efforts should be to try this as an enterprise.

Figure 4

Jojoba for Oil Production				
	Jojoba Trees Only	Jojoba Tree/Wheat Combination	Wheat Only	
	trees/ha	trees/ha		
	1312	357		
Income(Jojoba)	$ 16,216	$ 4,412		per ha
Gross Margin (Wheat)		$ 208	$ 231	per ha
Less Variable Costs (Jojoba)	$ 5,299	$ 1,442		per ha
Gross Margin	$ 10,917	$ 2,971	$ 231	per ha
Less Amortized Capital Costs/Establishment Costs (Jojoba)	$2,626	$715		per ha
Business Return	**$ 8,291**	**$ 2,256**	$ 231	per ha

There are broader issues surrounding Jojoba, with the size of the market in Australia being very small and extremely vulnerable to excess supply, and there is little research I have found as to whether irrigation will have a positive effect on yield. Additionally, the labour component issue of harvest is a problem, as is finding or establishing an oil processing plant in an economically suitable distance.

The brief analyses of multi-species cropping detailed above highlights the financial advantages of growing a single species focussed on maximising its return. The multi-species system has the disadvantage of management decisions and will invariably favour one crop to the detriment of the other. I feel that this style of system would be unlikely to succeed in the current economic environment in Australia.

Consideration of a combination of Different Irrigation Systems for Cotton

The research into water use efficiency that we have carried out on my farm in Australia into furrow irrigation has shown that one of the biggest water use periods is the first irrigation or irrigations. This is caused by the relative difficulty in only applying enough water to cover plant need. The farm water use figures for the past 5 years suggest up to 30% of annual pumped water use can be taken up by the first furrow irrigation.

I wanted to look at the economies of a combination of two different types of irrigation, focussed on attempting to apply the right amount of water to cotton at different stages of its growth. Understanding from above that furrow irrigation will put on too much water in the early stages of plant growth, and Overhead spray systems are unable to keep up with peak plant demand later in the season unless prohibitively expensive, I looked at combining the two. As well, I researched some US data to consider using a combination of drip irrigation and furrow irrigation.

Combination of Overhead Spray with Furrow Irrigation

While in the US and Canada I visited a number of Overhead Spray Manufacturers including Valmont Irrigation ("Valley" irrigation systems) and Vanden Bussche Irrigation. I was interested in a style of Linear Move Irrigator that was relatively small, but easily able to be end-towed to different parts of the farm after it had applied one pass of water. The idea was the Linear Move Irrigator would be used to apply the first and possible second irrigations on a series of cotton fields, and then the balance of the season furrow irrigation would be used.

In order to justify the cost of not only the machine itself, but also including the entire related infrastructure, it was felt the machine needed to be specified to deliver 25mm/day/hectare meaning 100 acres or 40 hectares could be watered in one pass in 24 hours. The machine would then be moved endways to the adjoining fields and run down them and so on. Assuming 6-10 hours were required to move the machine between fields; 400 hectares could be watered in 14 days. This would suit our planting profile and the amount of water applied would be sufficient to germinate seed or for seedling cotton irrigation. This application rate is double that of the current Australian specified machines in the cotton industry; however we worked on the assumption that to get over sufficient area in the watering cycle, we needed to do this in one pass.

Figure 5: Overhead Spray System over Maize in Spain

To put this amount of water in perspective, usually we would expect to apply between 4.5 and 8.5 MGL/ha over an average of 6 irrigation cycles each season using furrow irrigation, depending on rainfall received. We would expect in a dry soil profile situation, to apply 100-150mm/day/hectare using furrow irrigation for the early irrigations, and lessor amounts on a shorter cycle time later in the season. Given 100mm/ha equates to 1 Megalitre/ha, using the overhead irrigator for the first irrigation, I would hope to save 1.0MGL/ha each season. Cost estimates for a Linear Move Irrigator with a hose drag attachment would be AUD $100,000, however the related infrastructure such as pumping and piping systems and moving powerlines and storage dams would amount to five times this cost. The estimated related savings of 1.0MGL/ha/ann over 400 hectares with an average temporary transfer water price of $100/MGL would only mean a saving of $40,000/annum. Assuming current interest costs, this means a +15 year repayment phase, which I consider a bit long for machinery purchase. However, for an operation without the limitations of powerlines and limited space, this may be an alternative worth considering. Also, if the current drought continues, the temporary water price will remain at over double the above estimation, meaning this proposal should be reviewed.

Combination of Deep-buried Drip Tape with Furrow Irrigation

One of the major problems with drip irrigation in the majority of the cotton areas in Australia is the unsuitability of the soil type to this technology. The cracking black and grey clay which predominate in the industry do, as their name suggests, crack wide open and tend to pull the drip tape or tube apart. One suggestion from an English water scientist with irrigation contacts in California was consideration of deep-buried drip tape to counter-act the shallow cracking tendencies of clay soils. We were able to source some research in testing of deep-buried drip-tape but the concept has not been fully explored.

I believe deep burying the drip tape at 60-80 cm below the surface could reduce the damage caused to the tape from being pulled apart by the cracking soils. Traditionally drip tape is buried around 20cm. Provision of moisture at depths of 60-80cm will also suit tap-rooted plants like cotton later in their season as the roots reach that depth, and will leave open the top area 30-40cm of the profile to always be dry enough to soak up rainfall.

One area where this system would not gain in efficiency would be in the period from establishment to when the plant root would reach the wetting zone of the drip-tape. The crop would need to be watered via an alternative method, presumably furrow irrigated.

However, many questions remain: will the efficiencies gained later season from the drip irrigation offset the higher water use from the early season furrow irrigation; as the Nitrogen fertilizer is placed in the top 20-30cm of soil, would the concentration of the root zone around the water source at 60-80cm mean this fertilizer is not fully utilized; and would the higher cost of deep-burying tape this deep in clay soils be offset by water efficiency gains?

It seems in this area I have come back from my Nuffield study tour with a whole new raft of ideas to prove or disprove on my own farm, but I guess that is the Nuffield experience.

Bio-Technologies

The cotton industry in Australia is the only large scale commercial agricultural industry able to employ Genetic Modifications under to current State legislated moratoria on Genetically Modified Crops. Over the last 11 years on our farm at Boggabri, we have been growing cotton that has been bio-engineered to tolerate Glyphosate herbicide (e.g. Roundup©) and to resist major insect pests. However, despite not initially trying to use this technology to increase water-use efficiency we have been able to achieve some water savings. Additionally, there is research in the US aimed at developing genetic modification in cotton and other crops, to sustain greater water stress tolerance with equivalent yield, or to achieve greater yields with the same amount of water.

In talking about unexpected water use efficiency gains from current technology, some background in cotton production techniques is needed here. Historically, seed bed preparation and weed control have been the focus of pre-plant farming operations. The soil will be farmed in order to produce a reasonably fine tilth, shaped into furrow and hill/bed formations to allow water to be run down the furrows while keeping the area to be seeded high enough so it doesn't become inundated.

Another purpose of pre-plant cultivation was to incorporate residual herbicides to combat weeds. The introduction of the Roundup Ready© trait in cotton has meant we are able to do away with the need for pre-planted residual herbicides to be incorporated just prior to planting. This in turn has meant we are able to form and fertilize the seed bed area much earlier, up to 3-4 months in advance, leaving a greatly increased period of time for rainfall to provide planting moisture. Even if we have to brush away dry soil to plant into deep moisture, this still means we can establish the crop without needing to pre-irrigate or water-up in a high percentage of years, thus potentially saving a significant amount of irrigation water.

The Bio-tech company Monsanto Limited has a current program to develop Water-Stress Tolerance in Cotton and Maize. Whilst in the US I was able to meet with the project managers and discuss the project aims and expected outcomes. It is not expected that this new trait will be commercially available in cotton in Australia until 2013, after it has proven both the technology works and it is safe. However, I am looking forward to volunteering to trial these products as I see the project goals of either 20% water use drop for the same yield or 10% yield increase for the same water use as being of great value to the Australian farmer.

There are many questions that will arise over the development of this product, which I will follow with keen interest. Will the plant tolerate combination of heat stress and water stress; will it be better at handling less water over the entire season, or just at one part of the season; will less water affect fibre quality; and what will Monsanto charge us for the technology?

I have a belief that the other genetic modification mentioned above in cotton, the inclusion of the BT gene to kill insect that predate on cotton has impacted, at least indirectly, on the water use efficiency in cotton over the last 5 years. While under optimum conditions, the BT gene does not directly lead the cotton plant to yield higher than conventional varieties, the reduction in insect management requirements has meant we can now focus on plant nutrition and optimising water application. I believe this has contributed greatly to our average farm cotton yield increase of over 30% in the last five years. Basically, we now have the time to concentrate on these issues and fine-tune our management of such.

Bio-technology is one of the tools we can use to manage various management issues. It has proven to have broader positive applications when used as part of an integrated farming system as detailed above. I am hopeful that future will bring safer and environmentally beneficial advances in this area.

Cover Cropping cotton models

One of the study areas I was unable to fulfil to my satisfaction was to look at cotton farming systems which used a sprayed out cereal crop residue as a 'cover crop' into which cotton is planted. However, I was able to access a fair deal of information from the internet, and more recently from Australian trials.

Initially, cover cropping in the US was used for weed control of plants that had developed glyphosate resistance in the Roundup Ready cotton. The cereal crop residue would act like a garden-mulch in preventing weed seed germination. The specific weed most mentioned in much US literature is Mare's Tail, which had been a major constraint to US cotton growers.

While this cropping system will certainly have similar applications in Australia, I see further advantage in reducing soil-water evaporation in field, reducing wind and water erosion, and slowing water flow rates to increase infiltration in particular soil types. I have trialled this system over two years on my farm without much success. Some of the difficulties were: an inability to apply fertilizer post sowing; and the rapid breakdown of the wheat mulch permitting weed competition later in the cotton season.

Figure 5: Planting cotton into sprayed out wheat

One change over the last year has encouraged me to try again in this coming season is the release of the Genetically Modified Roundup Ready Flex© trait in cotton. Whereas the previous trait (Roundup Ready© Cotton) only permitted over the top Glyphosate herbicide spraying up until the emergence of the fifth true leaf of the cotton seedling, the new trait confers the ability of the cotton plant to resist the effects of the chemical all season. Thus, while keeping in mind the issue of encouraging Roundup resistance, we will be able to control weeds all season in the cotton crop. Another change that I will make as a result of my Nuffield experience will be to trial rice as the cereal cover crop due to the longevity of its stubble as mulch.

I will be focussing on using this system to address water infiltration problems I have with some of my soils, where at present we have to irrigate every 6-7 days as opposed to deeper cracking clay soils which last 12-14 days. There has been some reported success of this technique in Australian cotton industry press from a property at Narromine, NSW. Essentially, the stubble will act to slow the flow of water down, giving it time to soak further into these harder setting soils. This will mean extended intervals between irrigations, reducing the periods of waterlogging the plant will face, and hopefully lead to better yields and fibre quality.

Cover-cropping seems to be a tool which can overcome specific problems for different management scenarios. There are different examples in both the US and Australia which proves the farming system can work which encourages me to continue my trialling on my farm.

Economical Crop Water Use Requirement Measurement Techniques

There was some very interesting work being done at the University of Hohenheim near Stuttgart, Germany. Some of the work parallels the work being done in Australia in Computer Modelling of Plant Water Use requirements. However, the research was focussed on providing cheaper plant analysis tools than we have today.

Some of the tools we use at the moment to assess plant water requirements are reasonably expensive. One example is our Soil Moisture probes, which transmit soil moisture content information every 15 minutes to a web-based computer system for graphical interpretation. These probes and associated software cost around $4,000 per unit which we use to cover a 40-50 hectare/unit. Another style of water measurement is stem-collar arrangements which measure and transmit plant stem thickness records regularly, and cost in the same order. Broader scale tools also used are aerial infra-red photography to analyse the plant colour spectrum for colour changes that indicate plant moisture stress. As this needs to be done at regular intervals the cost can add up to be quite significant.

The basis of the research being carried out in the University of Hohenheim is to see if an inexpensive hand-held infra-red tool, similar to the unit in most modern mobile phones, to measure the colour of the plant, would provide enough information to be an effective management tool. The most concerning issue for the researchers is the limited colour spectrum of such units. This work is being tied in with plant water use computer modelling similar to the Hydrologic model mentioned earlier in this paper.

I will be watching to see if anything comes from this work as anything that helps to reduce our cost base will be of great interest to our farm.

Water Policy

Development of Australian water policy is significantly ahead of any of the countries where I was able to talk to the policy makers. The most basic difference I see in the drivers for water policy development is the understanding, or lack of, the finite availability of the resource, and the maturity of the governance structures. Amongst developed nations, Australia certainly has the most arid climate and most reason to develop sustainable water policy. The current drought has focussed the entire nation's attention on this process, and having seen some of the attitudes in other developed countries, I am happy to comment that our domestic water policy development is following generally realistic and appropriate directions.

Many Australian regulatory structures, like licensing of pumps and allocations, metering of pumping, and focus on environmental outcomes in river systems, are unheard of in many parts of the world, let alone being implemented. In the developed nations, the US example is fairly representative of what I saw around the world, with the scientists recognising the problems, but the users and the policy makers not seeing all of the issues so clearly.

One example is the Ogallala Aquifer, which underlies approximately 225,000 square miles in the Great Plains region of the US, particularly in the High Plains of Texas, New Mexico, Oklahoma, Kansas, Colorado, Mississippi and Nebraska. The depth of the aquifer from the surface of the land, and its rate of natural thickness, vary from region to region. The aquifer has long been a major source of water for agricultural, municipal, and industrial development. Use of the aquifer began in the early 20th century, and since World War II reliance on it has steadily increased. The extraction of this groundwater has now greatly surpassed the aquifer's rate of natural recharge. Some places overlying the aquifer have already exhausted their underground supply as a source of irrigation.

I visited a number of irrigation farmers in Mississippi and Nebraska and asked them about this underground water source. It was surprising how many comments were about how the "water table was dropping somewhere else, but that it wouldn't affect them". In most of these areas there were no meters on pumps, and the prevailing attitude seemed to be that the aquifer had always had enough water before, so it should do so now.

The Salinas Valley in California also seemed to typify another approach; that there would always be another source of water. This is a rich agricultural valley south of San Francisco which provides much of the vegetables for California and the US, with irrigated agriculture sourcing water from both underground and river sources.

The biggest problem facing the underground irrigators is the intrusion of salt water into the aquifer from the Pacific Ocean. This is thought to be occurring deep underground, with the high up-valley water extraction levels meaning the aquifer no longer has the pressure to force the encroaching sea water back at the bottom of the aquifer. Currently the bore water in a significant part of the lower aquifer is too salty to use for irrigation.

To the outsider, it would seem that regulation to reduce pumping levels would enable the aquifer to regain pressure and extrude the salt water back from traditional pumping areas. However, the main focus of research was focussed on finding 'new' water, such as re-cycled grey water or desalinated salt water. The Monterey Regional Water Pollution Control Agency was able to give us some comparable costs of agricultural water supply:

Figure 5

Water Type	**Cost in AUD/ML**
Desalinated Sea Water	$1500-3000
"Gulp-able" Recycled Grey Water (not potable water)	$300
Bore Water	$97

The Monterey authorities had taken the second option. This is in direct contrast to Australian policy which has recognized aquifer over-allocation and worked towards reducing the extraction levels of those aquifers.

Similarly, the main producer water body for the primary water supply for California, the Northern California Water Association, is pushing for 'new' water sources to be found for the rivers that supply water to not only San Francisco and Los Angeles, but almost all the irrigation in the San Joaquin Valley. With rapidly expanding population demanding greater water supply, and the threat of global warming reducing the holding ability of the main water storages, the snow-covered Sierra Nevada mountains, the focus is on increasing supply, rather than understanding its limitations and managing demand.

Of the lesser developed nations we saw, the problems in Morocco probably highlighted the underlying issues. While there had been significant investment in 'modern' water infrastructure projects like dams and delivery channels, the application of only one technology without further investment and environmental controls has left the projects less than successful.

The major dams in Morocco, for instance, had suffered 40% or more silt-fill through lack of erosion controls in their recharge areas, and increased irrigation development downriver without metered extraction controls has led to little or no water reaching to ends of rivers like The Draa. This, allied with the current drought in the region, has meant the desertification has claimed many former productive agricultural areas.

Thus, while I rail against the ponderous process of change in the Australian Water Policy scene, I am happy that it is proceeding towards realistic and achievable outcomes, despite the extreme pressures of the current drought.

Summary

The major findings I achieved on my Nuffield tour was to understand that Australian farming systems have some of the most advanced Water Use Efficiency techniques in the world; and our arid climate has demanded of Policy makers and resource users that we continue to develop the appropriate Water Policies and Regulations. There was recognition of world-wide water scarcity by the scientific community in many parts of the world, but not necessarily by the general voting public.

The significant outcome of my study was gaining an understanding of the following issues: more developed countries like Germany and the US are focussing on technological advances like bio-technology, more advanced measuring techniques, and more efficient irrigation systems; lesser developed nations are relying on farming systems that focus on their strength of low labour costs, but which also manage climate variability well; budgets on ideas like combining irrigation systems such as Overhead Spray and Furrow Irrigation show low return on investment; the Water Use Efficiency in the Australian Cotton Industry is the best in the world, with many other countries' industry unable to even measure their usage, let alone calculate efficiency and; Australian Water Policy, with its spotlight on realistic and achievable management of both supply and demand, is more advanced than most places in the world.

The longer I think about my Nuffield experience, the more I understand how the myriad of small changes, systems and techniques that I saw and experienced will shape my thinking and the development of agriculture in Australia in the future.

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