The Sustainable Use of Water Resources for Agriculture and Horticulture

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Abstract
Irrigation is required to ensure that agriculture and horticulture is profitable in many of the drier parts of Australia and New Zealand. Recent OECD figures for New Zealand reveal a large increase in the volume and depth equivalent of irrigation water being used. Analysis of these data suggests that there is room to reduce the depth of water used on our irrigated farms. We discuss how this might be achieved. Using irrigation efficiency as a metric to guide this quest for sustainability is considered to be flawed for it only focuses within the farm gate. We report on an Australian programme of research called System Harmonisation which has created a framework to link irrigation water users with wider communities of interest. We first discuss how in New Zealand irrigation water is allocated, and how water use is reported, before presenting new toolkits that have been developed to enable growers to reduce the water footprint of their products. Reducing the water footprint of products will ensure shelf access of food and fibre products in supermarkets and will lead to premium pricing.

Key words
Ecosystem services, irrigation efficiency, water-use nomenclature, decision support tools

Introduction
The ecosystem services provided by soil and water are critical for human well-being. The Millennium Ecosystem Assessment (2005) classified ecosystem services into four types: supporting, provisioning, regulating and cultural services. For agriculture, in many cases the supporting services of soils are inadequate for sufficient provisioning of food and fibre. Increasingly, water and nutrients are needed to ensure economic levels of plant productivity. Irrigation and fertilizers are frequently used to overcome inadequate natural stocks of water and nutrients in the soil. It is estimated that irrigated agriculture covers some 260 million hectares of the earth's surface, such that this 17% of the world's cultivated lands can provide 40% of the global production of food and fibre (Fereres and Evans 2006). Irrigated agriculture consumes about three-quarters of the world's fresh water taken for human use. There are growing environmental pressures as a result of the quantity of irrigation water being taken to feed the world. Globally, about 175 million tonnes of nitrogen are taken up by crops, and synthetic fertilisers account for about 40% of this. Takahashi (2006) calculated that some 2 billion people, one-third of the world's population depend on synthetic nitrogenous fertilizers. Through the leakage of nitrates from the root-zone, these fertilizers, along with manures, are diminishing the quality of ground and surface waters. Sustainable use of water and optimal use of fertilizers in agriculture are imperatives if we are to ensure that all four types of ecosystem services are maintained across agricultural catchments.

The Comprehensive Assessment of Water Management in Agriculture (2007) set out to answer the global question of "Will there be enough water to grow food?" They concluded that it is possible to produce the food, but only if we act to improve water use in agriculture to meet the acute freshwater challenges over the coming 50 years". Highlights from this assessment have now been published in a special issue of the journal *Agricultural Water Management* (Clothier et al. 2010), and in the preface Dr Margaret Catley-Carson, of the International Water Management Institute wrote:

> "This is perhaps the most extraordinary recipe book ever produced: Take one world already being exhausted by 6 billion people. Find the ingredients to feed another 2 billion people. Add demand for more food, more animal feed, and more fuel. Use only the same amount of water the planet has had since creation. And don't forget to restore the environment that sustains us. Stir very gently."

The challenge is to develop sustainable irrigation practices in agriculture and horticulture (Glennon 2009). Our research focus has been on horticultural irrigation, and we will explore recent developments there and consider how they might foreshadow developments in agriculture. We describe here what future irrigation practices will entail: from irrigation allocation policies and procedures, through better irrigation scheduling and more effective application methods, to responding to the new shelf-access requirements of supermarkets and rising ‘green’ demands of consumers. However, before embarking on a discussion of these, it is worth assessing whether there is room for improving irrigation water use in Australia and New Zealand, and how the term “irrigation efficiency” is a flawed concept in the quest for sustainable use of water resources.

Water-use metrics: A national comparison

The OECD has just published its report on “Sustainable Management of Water Resources in Agriculture’ under the auspices of their Joint Working Party on Agriculture and the Environment (OECD 2010). Figures are provided in this report on changes over the last decade of total agricultural water use, and the changed area of irrigated land (Figure 1)

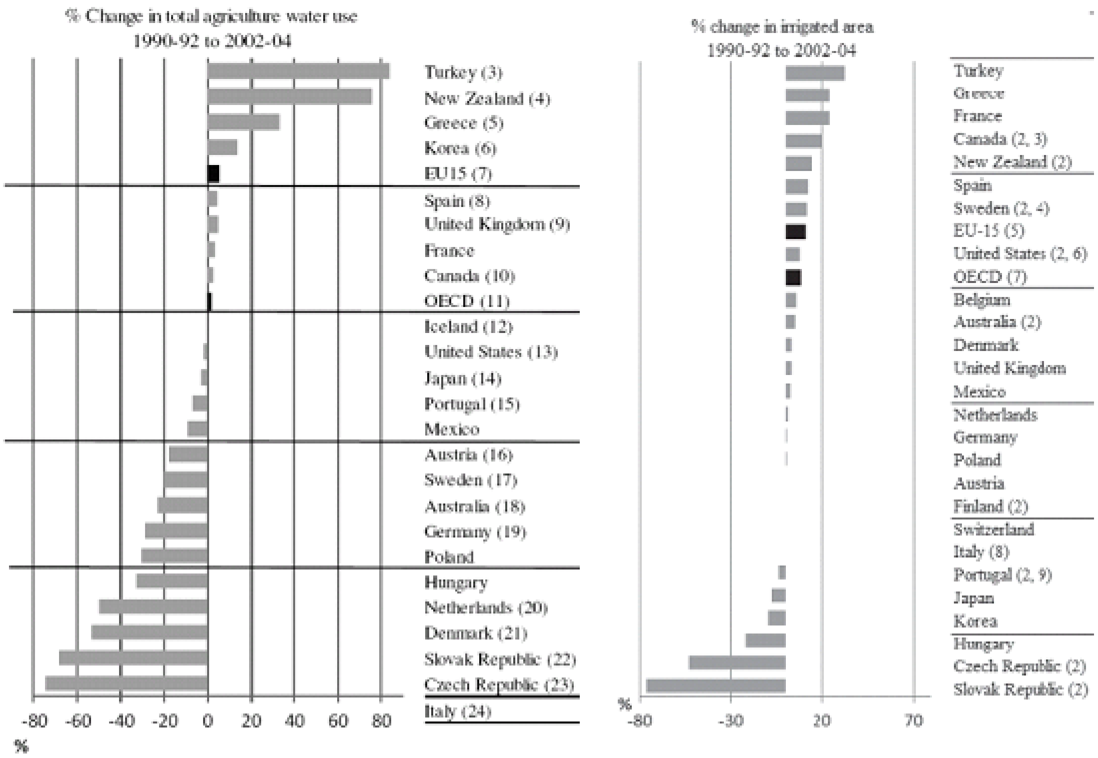


Figure 1. The decadal (1990-2002 to 2002-2004) % change in agricultural water use by country (left) and the decadal % change in irrigated land area (right) (OECD 2010).

From Figure 1, it can be seen that New Zealand ranks near the top in both water-use change and irrigated land area change. The change in land area will have been a result of the expansion in irrigated viticulture, but primarily as a result of the growth of irrigated dairying in the South Island

These data can be used to compute the depth-equivalent (mm/yr) use of water in irrigation. The New Zealand ‘decadal’ change relates to the years 1999 and 2006 for water use, and 1985 to 2003 for land area. Over the ‘decade’, the water used for agriculture rose 76% from 1280 to 2254 Mm^3. Yet, the land area only went up 15%, from 250 to 285 kha. Thus the equivalent depth of irrigation, on average for New Zealand, rose from 512 mm in 1999 to 790.9 mm in 2006 – a 54% rise. Meanwhile, in Australia, the use of water in agriculture went down from 13,384 to 10,310 Mm^3, whereas the irrigated area grew from 2,380 to 2,497 kha. The depth equivalent use of water dropped from 562 to 413 mm – a 27% drop. Australia would seem to be using irrigation water more parsimoniously a decade later. This could be due to the 10-year drought and water shortages, as well as different water pricing, economic instruments, and policy changes. It could also be a result of the environmental and production consequences in Australia of past over-watering, notably due to duplex soils and water-logging, plus groundwater encroachment and root-zone salinity. Further analysis of these data would be interesting.

Now we examine whether the rise in the depth equivalent use of irrigation water in New Zealand is justifiable. It is possible to assess this by considering what water would be needed for irrigated pasture in one of New Zealand's driest parts – Canterbury. The growth of irrigated dairying there is the prime reason for the change in the country's agricultural water-use statistics. The average rainfall at, say Lincoln, over 2005/06 was 717 mm, whereas as it was just 600 mm over 1998/99. The average there is 640 mm. Is the use of 791 mm of irrigation water on a free-draining soil in Canterbury really needed? To gauge this we have used Plant & Food Research's SPASMO (Soil Plant Atmosphere System Model) to assess the stochastic distribution of irrigation needs for pasture (Green et al. 2010) over the period 1972-2002. We have considered grass growing on a generic very light soil (Trevor Webb, pers. comm.) near Lincoln.

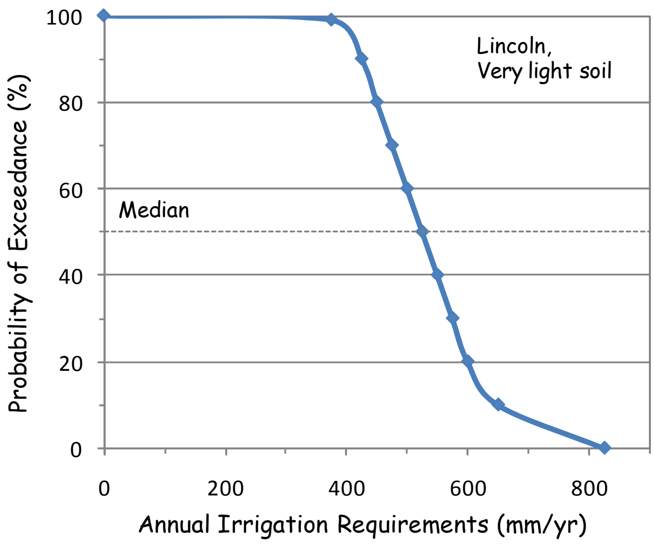


Figure 2. The SPASMO-modelled need for irrigation of pasture at Lincoln.

So the median need for irrigation in one of New Zealand's driest regions, on a very free-draining soil, is just 525 mm – assuming 100% effective application. In 2006, the average application of depth of water actually used, the OECD suggests, is 791 mm. Such an amount of irrigation would have only been required in the driest two years of the 37 years modelled for this dry region. That our national average usage is 791 mm thus suggests there is much room for improvement. It would seem that water use by irrigation is over and above that which is needed to ensure full pasture production. Also, there is likely to be, as a result, higher drainage rates from the base of the rootzone. It is tempting to say that irrigation needs to become more 'efficient'.

Irrigation efficiency: A flawed concept

The International Commission on Irrigation and Drainage (ICID) has recently adopted a set of definitions for water use that purposefully avoid use of the word 'efficiency'. Perry (2007), in his paper on "Efficient irrigation; Inefficient Communication; Flawed Recommendations", noted that "… the current nomenclature related to how irrigation interacts with hydrology – particularly terms such as efficiency and loss – produces confusing results for planners and policymakers. Even irrigation professionals use various terms interchangeably". He adds that an "… increase in efficiency means that consumption by crops is increased, thus higher efficiency can be expected to cause higher consumption, [and] that efficiency, unrelated to context can cause wrong decisions to be made economically, hydrologically and ecologically". Perry (2007), and the ICID, suggest that the following terms be used:

Water Use – Any deliberate application of water to a specified purpose.

All *Water Use* goes into:

1. Changes in storage (positive or negative)
2. Consumed fraction
    a. Beneficial consumption
    b. Non-beneficial consumption
3. Non-consumed fraction
    a. Recoverable fraction
    b. Non-recoverable fraction

Perry (2007) concludes by stating that this terminology is consistent with hydrology, and enables clear discussion amongst stakeholders on the benefits and costs of all water uses, in general, and for irrigation in particular. Water use efficiency only focuses on one side of the equation - the benefits to the user. Efficient irrigation can be hydrologically unsustainable, as Glennon (2002) notes in his book "Water Follies".

System harmonisation

In Australia, between 2006 and 2010, the CRC for Irrigation Futures (CRC IF) facilitated discussions on irrigation between the many different stakeholders involved in water use. These discussions have been recently published by Bristow and Stubbs (2010) in a book entitled "Reinventing Irrigation Catchments: The System Harmonisation Story". Through its System Harmonisation (SH) programme, the CRC IF sought to deliver a whole new approach to better integrating and improving the research and practice of irrigation within a catchment context. The SH programme focussed on five catchments, one of which was in Western Sydney where the project was entitled WISER – Water and Irrigation Strategy Enhancement through Regional Partnership. WISER sought to develop a shared vision for water to address pressures on water coming from peri-urban growth, from the irrigation requirements of Sydney's 'food bowl', and from the needs to maintain the health of the Hawkesbury-Nepean River.

Bristow and Stubbs (2007) discuss the SH programme across the five catchments under five headings: environment, science, irrigators, leadership and collaboration, plus business and economics. They conclude that the SH approach to irrigation provides a platform for the future, and in particular they stress the need for leadership, collaboration, and partnerships with the wide range of stakeholders.

We will now discuss the sustainable use of water for irrigation from the perspective of three groups of stakeholders: regulators and the public, the growers and farmers, and the consumers.

Irrigation allocation and transparent monitoring

In New Zealand, under the Resources Management Act (1991), a resource consent is required to take water from any lake, river, or aquifer. Irrigation consents are issued by Regional Councils and include specification of the amount of water allocated for irrigation of a specific crop at a location. The SPASMO modelling used to produce Figure 2 is presently used to allocate water consents by the Regional Councils of Northland, Hawke's Bay, Greater Wellington, Manawatu-Wanganui, and Marlborough. Recently, the front-end of the SPASMO model has been enhanced to increase user-friendliness and assist the drive to sustainable allocation of water to agriculture (Figure 3).

The consent applicant selects information on their crop and soil conditions, and then selects the nearest climate station to provide the 30 year weather record. The tool then provides information on the water balance, plus seasonal and monthly irrigation requirements at three levels of exceedance: at the median (50% of the time), the 1:5 (80% of the time) and 1:10 (90%) year highs. On the right-hand side, the consents

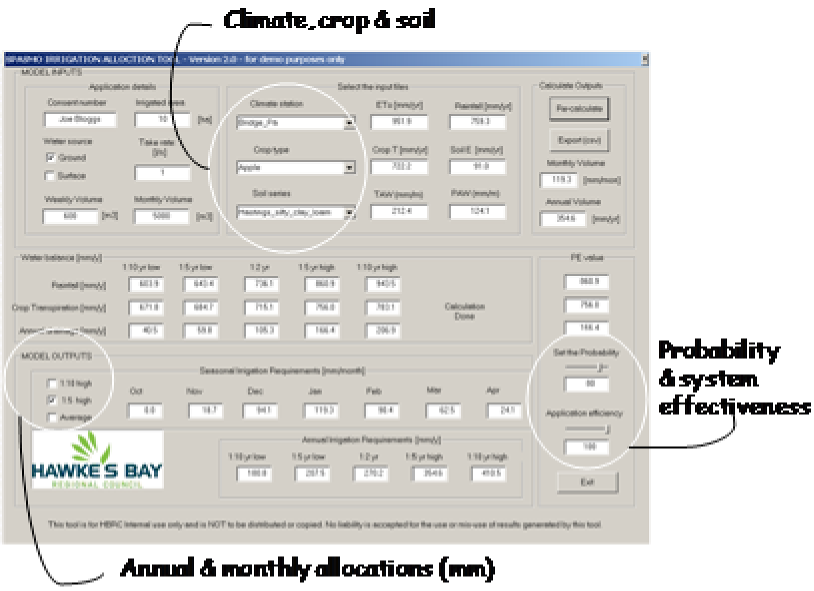
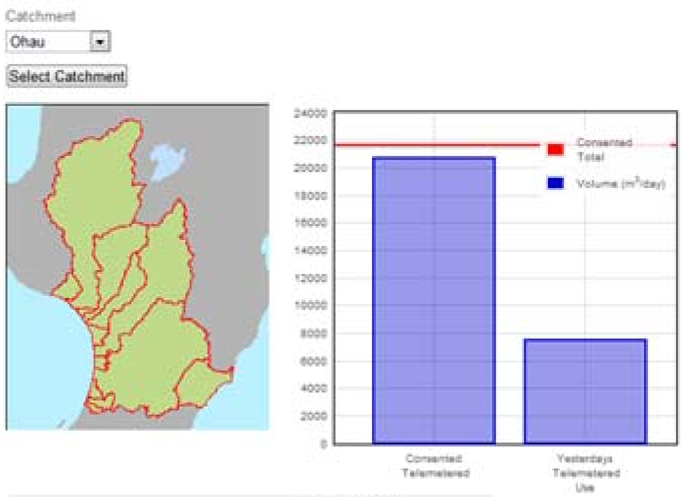


Figure 3. The interactive SPASMO-based decision support tool for developing a resource consent to take water for irrigation (amended from Green et al. 2010).

officer and the applicant can jointly explore the impact of choosing a different probability level of exceedance, and they can also examine the impact of a change in the effectiveness of the irrigation system. Both the officer and the applicant are thus aware of the year-to-year and seasonal risks, and the imperative for increasing application effectiveness. Before issuing consents, the Regional Councils have already assessed what environmental flows are required by the local hydrological systems, and the sum of consents in a water management zone cannot exceed these. The public are increasingly asking for information about the performance of consent holders. Under the RMA (1991) regulations that have just been passed in August 2010 all Regional Councils will have to measure and report water-takes greater than 5 l/s within 6 years, and for water-takes greater than 20 l/s these must be monitored within 2 years. One Regional Council in New Zealand, Horizons Regional Council, already publicly reports catchment water use (m^3/day) in near real-time, since they presently require major water takes to be metered and telemetered. Nearly 90% of water-takes, by volume, are currently metered by Horizons. The web site showing water takes in a catchment in the Horizons region is presented in Figure 4. On the left is the catchment limit for consents, and the currently telemetered volume (here 96%), along with the sum of yesterday's water use by all consent holders (here 36% of the total).



Zone	Latest Flow (m^3/s)	Volume (m^3/day) Consented Total	Consented Telemetered	Yesterdays Telemetered Use
Ohau		21680	20730	7534
Catchment total	-	21680	20730	7534

Figure 4. The web-reporting by Horizons Regional Council of the near real-time performance of all water-take consent holders in a catchment.

Through this telemetered monitoring, Horizons Regional Council is enabling transparent reporting of the performance of irrigation-consent holders. Individual consent holders have access to real-time information about their water use. The Regional Council receives an alert should the water take exceed the consent. Through public scrutiny and regulatory oversight, irrigation consent holders are encouraged to use the minimum amount of water to achieve economic production. This monitoring and visible reporting provides a strong driver for agricultural water users to use water sustainably.

Scheduling and minimising water use

Sustainable allocation of irrigation water is a necessary, but not sufficient condition for increasing the sustainability of water-use in irrigation. Real-time management of water on the farm, and the appropriate use of good application devices are also imperatives. Through new knowledge, available even in real-time and analysed on-line, also in real-time, it is now possible to schedule irrigation to minimise water use. In Australia's CRC IF, there were two research programmes; the SH project, and one called 'Irrigation Toolkits to Improve Enterprise Performance. We now describe the irrigation toolkits that we have been developing for horticulture in New Zealand to reduce irrigation water use.

Green et al. (2010) outline how Plant & Food Research and HortPlus are collaborating to develop *CropIR-Log*, a calculator for real-time scheduling of the irrigation of tree and vine crops. The 'Irrigation Calculator' is a software tool to help growers, or their consultants, schedule their irrigation using local values of evapotranspiration and rainfall that are accessed via a web-based interface. The *CropIR-Log* tool utilizes local soil properties as well as calibrated crop-factors for apples, kiwifruit, summer fruit and wine grapes. Soil water measurement and on-line water-balance modelling allow fine-tuning. This provides growers with high quality recommendations about when and how much to irrigate. With these new software and hardware tools, growers can devise their irrigation scheduling in a way that can be benchmarked throughout the growing season, and used to report their use of water. The on-line front-end of *Crop IR-Log* is shown in Figure 5.

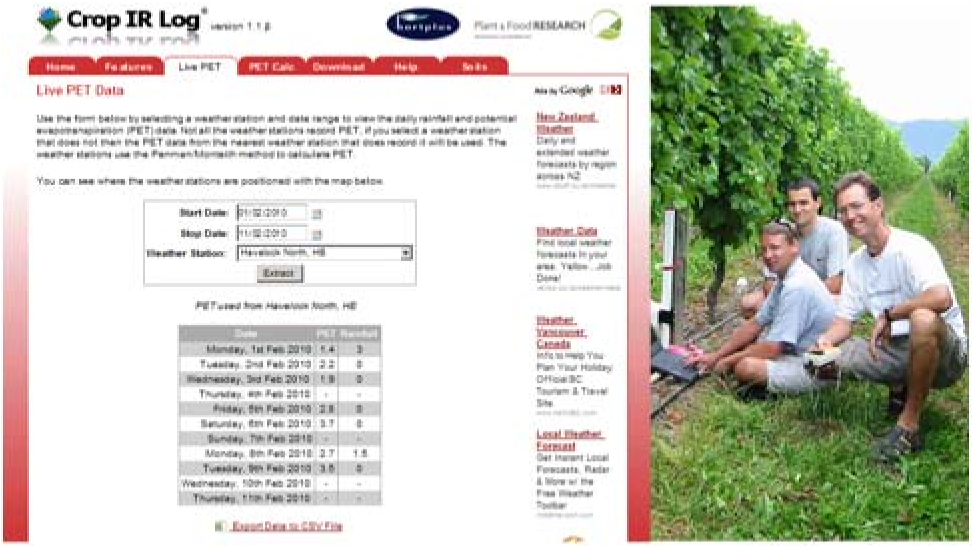


Figure 5. The front-end of Crop IR-Log, and on-line tool to schedule irrigation.

There are different challenges in pastoral agriculture in the quest to realise higher application effectiveness. Over 25 years ago, Clothier and Heiler (1983) observed that the pattern of soil wetting under different irrigation devices could be dependent upon the rate at which irrigation water was applied. The pattern of uniformity in the soil was much more a result of soil physical phenomena than of the spatial pattern of application engineered for the device (Figure 6). The uniformity coefficient of the latter could be designed to be high, but because of preferential soil-water flow processes in the root-zone, the efficacy of soil wetting seemed to be quite low. Observations today still seem to suggest that the wetting effectiveness, even under modern devices, leaves much room for improvement (Dr Tony Daveron and Dan Bloomer, pers. comms). Maybe this helps to explain why so much more irrigation water has been used in New Zealand over the last decade (Figure 1). The ineffectiveness of rootzone wetting under certain devices means that more water must be applied to bring the soil up to the required storage. New devices for real-time monitoring of soil water, along with precision technologies, based on GPS and robotic technologies, offer great prospects for better tactical application of water.

Whereas Clothier and Heiler (1983) focussed on the interactions between surface ponding, macropores and preferential flow, recent work has revealed that the surface phenomenon of hydrophobicity, also known as soil water repellency, creates conditions that lead to low effectiveness of soil wetting, both under rain-fed and irrigated agriculture.

Deurer and Müller (2010) report that a survey of soils in the New Zealand carried out by Dr John Carter has shown over that 70% of the soils exhibit water repellency such that soil wetting is very patchy (Figure 6). They also report that in the Hawke's Bay under dryland conditions, soil rewetting by rains following summer drought resulted in what locals called dry-patch syndrome. This patchiness of wetting and pasture growth, as a result of hydrophobicity, resulted in a yearly loss of pasture yield of 35%, or 4 t/ha, with an economic loss of about $400 per hectare. The implications for irrigation are that since hydrophobicity only occurs once the soil's surface water content drops below a critical value, which is soil dependent, it would be prudent to ensure irrigation before this. Multi-criteria rules for determining when to irrigate would enable soil wetting of higher effectiveness. These rules could be used to justify the use of irrigation and demonstrate to consumers of primary products that local water resources have not been compromised by water use.

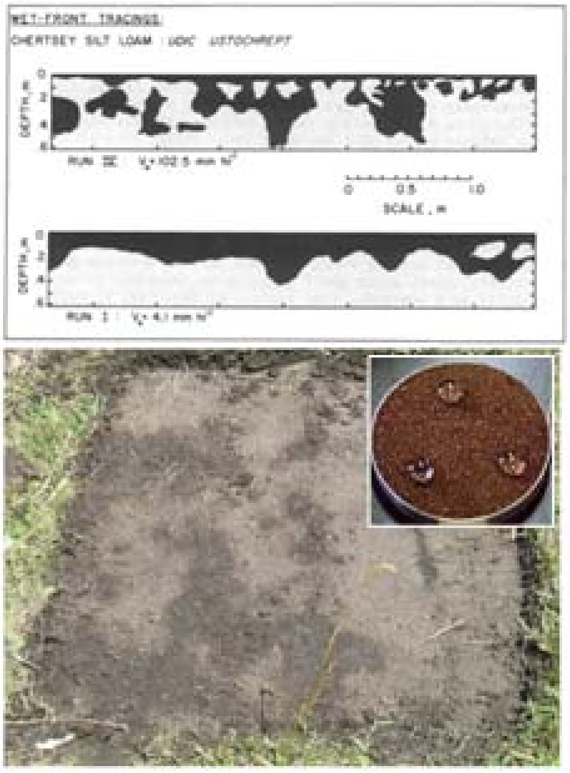


Figure 6. Top: Wet-front penetration under two rates of sprinkler irrigation (Clothier and Heiler, 1983). Bottom: Examples of water repellency and a soil-wetting pattern (Deurer and Müller, 2010)

Consumers and production footprints

According to Lubin and Esty (2010) 'sustainability' is an emerging business megatrend. These authors note that for businesses, there is a clear correlation between strong environmental, or sustainability performance, with superior financial returns. They suggest that "… value tied to the successful execution of a sustainability strategy – what we call an eco-premium – [is] a further signal of the emerging megatrend's strength". They conclude that 'winners' in this megatrend will be those who have the capacity to demonstrate sustainability. Irrigated agriculture and businesses producing irrigated food and fibre products should, if water is used sustainably, be winners. Certainly, there are increasing demands in the market place for products with a minimized water footprint, and this pressure is being channelled through the supermarket chains which sell the food and fibre products from irrigated agriculture.

Growing public concerns about the water footprint of primary products (Chapagain & Orr 2008), have led to moves to develop water footprinting labels on products, especially food (Segal and MacMillan, 2009), so that consumers can see how their purchasing choices affect the country-of-origin's natural capital stocks of water, which may have been affected by irrigation. In July 2009, the American-based supermarket chain Walmart announced plans to develop a worldwide sustainable product index. Walmart will provide its global suppliers with a survey of 15 questions on: Energy & Climate, Natural Resources, Material Efficiency, People & Community. Two relate to water use. Reporting the sustainability of water use along the supply chain of primary products will likely become a necessary condition to ensure shelf access in supermarket chains.

Conclusions

Our analysis of the latest OECD data on New Zealand's agricultural use of water suggests that there are opportunities to reduce the amount of water used by irrigated agriculture. We consider that this can be achieved through wiser allocation of water to irrigators, along with improving the on-farm use of this water by seeking better techniques and devices to apply water. Through quantification of the water footprint of products from irrigated agriculture and horticulture, farmers and growers will be able to secure shelf access in the market place and realize premium pricings.

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