AGRICULTURE, WATER AND CATCHMENT MANAGEMENT

By

Dr John Williams[1]

Aapresid Congress 2010, Argentina

Summary

Water use and its management are fundamental to productive and sustainable agriculture. Innovative water management in both rain-fed and irrigated agriculture requires hydro-ecological knowledge and practice at a range of physical scales from that of the soil profile to the paddock, to the farm, to the catchment and often the river basin. The flows of water, nutrient and salt are first understood and managed within the soil profile and root zone; then the regolith and thus the surface and groundwater systems flow within the river valley and ultimately, the catchment. Many of the difficulties experienced in agriculture result from a failure to connect the behaviour of water on the farm to the hydro-ecological behaviour of the landscape and catchment. Water management on the farm and water management for the catchment must be linked, aligned and integrated. Further, it must be understood against the climate variability and the expected impact of climate change. Sustainable agricultural production whether fed by rainfall alone or under irrigation, must be able to manage climate variability and be aligned with the capacity of the water resources to supply under this variability. Food security will require that the allocation of water resources is sustainable and within the capacity of healthy rivers and groundwater systems to supply. This paper sets down some of the principles for farm water management and water resource planning which may be of value to the way ahead for Argentina.

1. Background and matters of principle

Soil-plant-atmosphere function is central to agro-ecosystem function and ultimately the ecological sustainability of the landscape, catchment or river basin. Agriculture is about actively managing agricultural ecosystems in a sustainable way to yield food and fibre. The soil is not only a critical part of the agro-ecosystem but the soil profile encompasses many ecosystems, the biodiversity of which is the engine room of agriculture. The soil ecology not only supplies water and nutrient but also stores valuable carbon energy supply that drives a seething foundry in which matter and energy are in constant flux as it provides the support services for ecosystem primary production. A rich mix of mineral particles, biota, organic matter, gases, water and nutrients, soil constitutes a self-regulating biological factory essential for initiation and maintenance of life and particularly, the food and fibre for civilisation. Organisms in soil recycle residues, converting them to nutrients and other compounds, thereby providing the primary cleaning and recycling function for ecosystems.

[1] Commissioner, NSW Natural Resources Commission, Sydney Australia. Email: john.williams@nrc.nsw.gov.au
Director, John Williams Scientific Services Pty Ltd, Canberra Australia. Email: jwil3940@bigpond.net.au
Founding Member, Wentworth Group of Concerned Scientists, Australia. Website: www.wentworthgroup.org

Soil/plant interactions determine the partitioning of rainfall, snowmelt or irrigation into overland flow, infiltration, storage, deep drainage and, in turn, groundwater recharge. The way soil accepts, stores and transmits water and associated solute, strongly influences the nature of rivers, springs, lakes and wetlands. This critical role of soil/plant interaction in ecosystem and landscape function has rarely been the focus of soil science and agronomy. Much of both disciplines have been directed to serving a single production focus in agriculture. This is reflected in the fact that most soil science and agronomy departments at our Universities have been historically married to agriculture, with only fleeting connections with ecology and the earth sciences. Few have been formally associated with ecology, ecosystem studies or earth science; although a trend towards association with natural resource management is common around the world.

In the move towards ecologically sustainable development over the past two decades, there has been a clear recognition that this single, very narrow focus on agricultural production has led to degradation of the natural resource and the environment. There is now increasing awareness (Williams 2005) that ecologically sustainable land and water management requires a shift to an ecological approach that studies agricultural production in the agro-ecosystem in which it is cast and its place within the broader landscape. Soil/plant interaction and function are fundamental to ecosystem health and environmental quality. It is therefore imperative that the soil science and agronomy community moves its attention to increasing knowledge and understanding of these life-sustaining processes in the soil, the catchment and the landscape. The challenge before agricultural scientists is to direct their thinking and effort to the processes in the soil/plant system that are critical to a better understanding of ecosystem function as a basis for more sustainable management of the planet's land and water resources. In this way, soil science and agronomy can play a key role in providing the scientific knowledge urgently required for more sustainable management of our ecosystems in the landscapes across the globe.

It is a demanding journey to build an agriculture that is sustainable so that our grandchildren have the rivers, land and oceans which have the same or better capacity to supply food and fibre as they do for our generation. The challenge is to build agro-ecosystems that generate wealth from food and fibre products and which have within them flows of water, nutrient and carbon that are well-matched to the flows that can be accommodated in hydro-geochemical cycles of the continent (Williams 2005). Matching the flow of water in the agro-ecosystem and matching that flow to the flows that operated in the landscape prior to agriculture, is one sustainability principle which will be the focus of this paper.

2. Water and agriculture at the soil profile and in the paddock

The way forward has required scientific capacity to measure, model and predict the flows of water, nutrient and carbon in our agro-ecosystems and relate these to the flows occurring in the landscape. This coupling of paddock to catchments and ultimately river basin continues to stretch scientific knowledge and capacity, but progress has been made.

In Figure 1, the one dimensional water balance for an agro-ecosystem is illustrated. The flow of water to be managed in agriculture is depicted by each arrow.

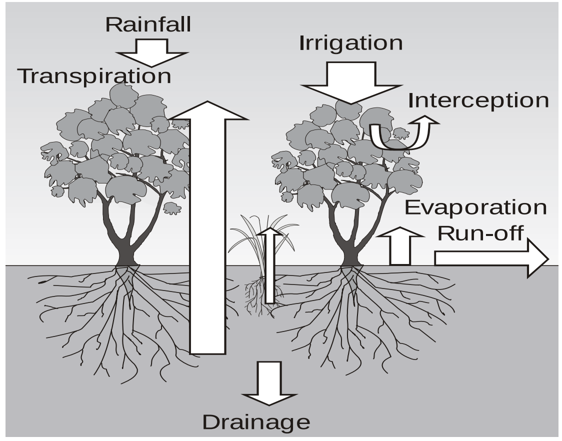


Figure 1: One dimensional water balance

The flow beneath the root zone, the deep drainage or leakage, is the critical flow to manage in terms of soil acidification, salinisation and for water and nutrient transport to rivers, groundwater and wetlands. The horizontal flow in overland flow or subsurface flows is important again to rivers and groundwater and the transport of sediment of nutrient, pesticide and salt to these natural resource bodies. The magnitude of these terms in the water balance for dryland cropping in the southern wheat-belt of Australia based on measurement and simulation modelling is set down in Table 1. It serves to illustrate the profound influence that crop type and rotation can have on the average water use (ET) and the average movement of water and with it nutrient, pesticide and salt beyond the agro-ecosystem into the landscape and catchment. The question before us is: How does the flow under the agro-ecosystem compare with the flows which evolved over many hundreds of thousands of years in the genesis of the landscape's hydro-geochemical cycles?

Table 1. Comparison of simulated average annual water balances in a Red Kandosol at Wagga Wagga (1973-1996) for the scenarios of continuous wheat, lucerne fodder crop and a three year lucerne/wheat rotation

System	Rain (mm)	Runoff (mm)	ET (mm)	Drainage at 4m (mm)	Drainage at 1m (mm)
Wheat	611	15	411	185	223
Rotate	611	15	507	89	181
Lucerne	611	15	579	25	134

(Source: Dunin et al. 1999)

Averages are not always what we need to consider in examining water flow in the ecosystem. Climatic variability is most important in Australia and is also important in Argentina. Expressing variability as a probability based on historical data is a first step forward. This is explored for the same systems examined in Table 1. In Figure 2, the variability of the annual deep drainage of the water balance is simulated for 23 years. It demonstrates that the deep drainage varies greatly for each part of the wheat/lucerne rotation, lucerne fodder crop and for continuous wheat.

Furthermore, the variation is determined by the sequence in the cropping rotation interacting with the rainfall variability to create a very large variation in the movement of water beneath the root zone.

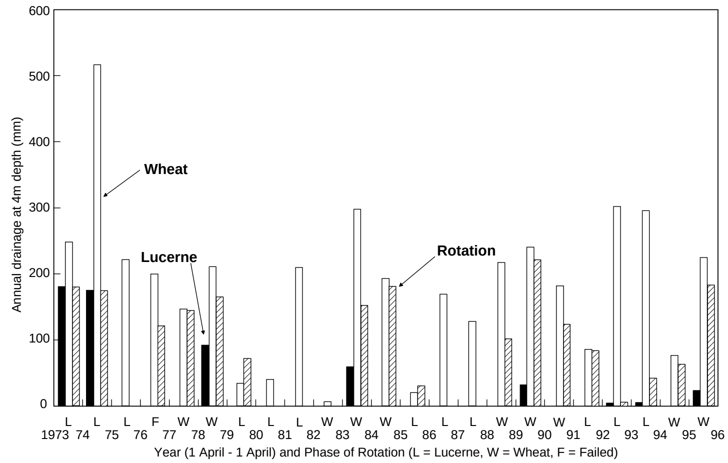


Figure 2: Comparison of simulated annual deep drainage (mm) at 4m in a Red Kandosol at Wagga Wagga (1973-1996) for the scenarios of continuous wheat, lucerne fodder crop and a three year lucerne/wheat rotation. (Source: Dunin et al. 1999).

The data shows that under continuous wheat cropping in Australia, a relatively large amount of water and associated nutrient escapes beneath the root zone. These valuable resources are not captured in the fodder or the grain. It is wealth forgone. So not only is the resource lost but that resource loss contributes to the primary causes for salinity, acidification and in some instances, stream and groundwater pollution. This points to the Australian irony that whilst our cereal productivity is constrained by lack of water and nutrients, the fundamental cause of much of our land degradation is an excess of water and loss of nutrients at key periods of the year!

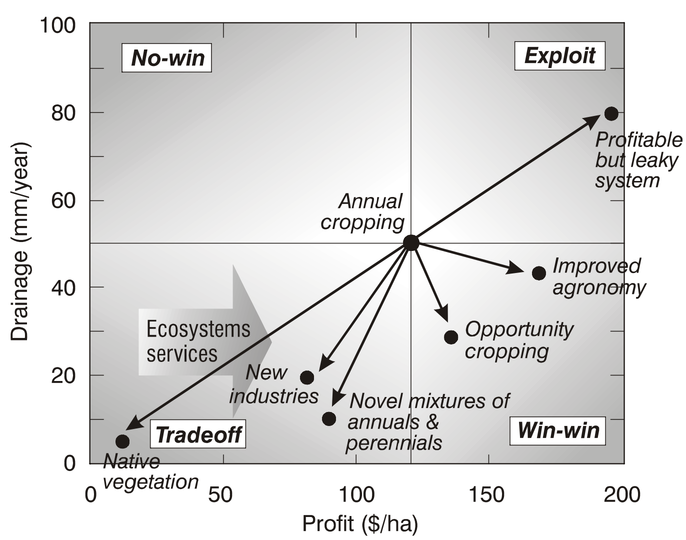


Figure 3: The profit–drainage matrix. Most of our farming system options that reduce deep drainage leakage also reduce profitability and are in the trade-off quarter. Very few farming system options reduce leakage and also increase profitability. The importance of economic benefit from sale of ecosystem services is illustrated. (Source: Williams and Gascoigne 2003).

The search for profitable farming systems that have leakage rates similar to native vegetation is in its infancy. Brian Keating (CSIRO Sustainable Agriculture Flagship) introduced a simple diagram in Figure 3 that is helpful in understanding that moving from our relatively profitable but leaky annual crops to other farming options usually require a trade-off. Most systems that have reduced leakage are also less profitable. To date, there are few options that sit in the win-win quarter of Figure 3. The challenge before us is to build more systems that fall in this win-win quarter.

These are some of the issues of concern in southern Australia. Are they relevant to Argentina? The principle of understanding the interaction between rainfall variability and farming systems in terms of the water balance will be very similar. The terms in the water balance that matter may be very different but the science and concepts will be the same.

Understanding the impact of farming practice and particularly conservation or minimum till cropping on the water balance is critical. To understand this against the climate variability will be most important. Over 20 years ago, Bristow et al. (1986) demonstrated how conservation tillage with mulch retention can shift, quite dramatically, the water balance. If the water is not transpired or evaporated then it must move to deep drainage. In their simulation of a season with 645mm rainfall, the bare soil would leak 97mm while the same soil under a residue mulch would leak 270mm.

Since then crop production models have evolved greatly. Currently, the use of crop simulation models like APSIM (McCown et al. 1996) can help a great deal. For example, it is a most useful tool for farmers to manage drought and climate variability and prepare for climate change. Such relationships show the importance of matching soil type and conservation farming to manage the rainfall variability. At this marginal location, the 50% probability on a loam soil yield is only 1 tonne per hectare per year while on a self-mulching clay soil it is nearly 3 tonnes per hectare per year. The relationship also points out that on the loam soil there is a 30% chance of obtaining zero yield while on the clay soil there is a 10% chance of a zero yield. Using simulation models like APSIM along with field measurement is proving useful in managing rainfall variability.

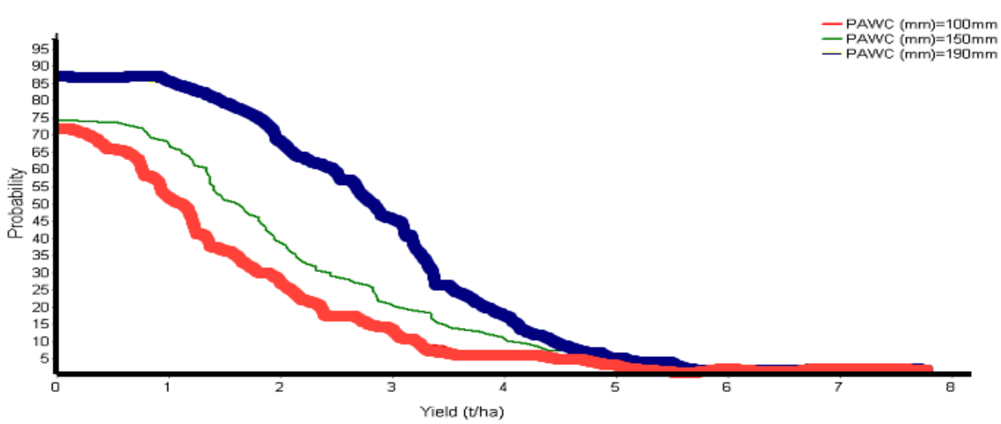
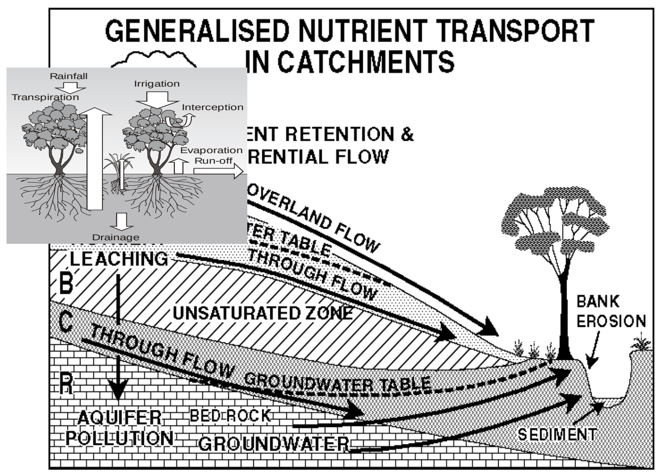


Figure 4: Illustration of the probability/yield relationship for wheat production in a marginal area of southern Australia as it is influenced by soil type.

3. Connecting the paddock water balance to the catchment

The issue of managing the water balance to capture the water and nutrient and at the same time seek to match these flows to those which operate in the landscape is a critical part of building sustainability. Soil processes, landscape function and productive agro-ecosystems must be integrated. No longer can agriculture flush and forget. In irrigated agriculture it is necessary to keep mobilised salt from accumulating in the root zone. To keep a healthy root zone for crops and trees usually about 10-15% of applied water must move beyond the root zone to flush the salt out of the root system. But where does the salt go? This flow of water and salt along with nutrient and pesticide must be managed by agriculture. Further, it must be managed with an understanding and engagement with management of the groundwater, river systems, wetlands and estuaries. All of these must be managed as a whole-of-system. Likewise, the water extraction for irrigated agriculture from groundwater or rivers must be matched to what the river needs to replenish itself or to support the ecological function of the river, wetland and estuary.



Williams, figure 2.

Figure 5: Water balance of agro-ecosystem determines water flows to and from agriculture which are connected to water flows in the landscape and catchment.

In Figure 5, it is illustrated that agro-ecosystems are always connected to the large landscape. Understanding and managing these flows and linkages are the primary tasks of building sustainable farming systems. Farming does not end at the paddock or field. Agro-ecosystems are connected both upstream and downstream of the paddock or field. In Australia, tropical rainforest made way for sugarcane monoculture, semi-arid clay plains became irrigated croplands, and heathlands on sand plains were converted to wheat, canola and lupin fields. I understand there are strong similarities in Argentina. Natural ecosystems have been changed to agro-ecosystems with profound changes to the landscape, catchment flow and recycling of water, nutrient and carbon. Sustainable agriculture seeks to move these flows and cycles to be in harmony with landscape and catchment original flows and drainage capacities. In moving to more sustainable agriculture we are challenged to manage water in agriculture in an integrated way within catchment management.

4. Some of the water policy issues essential to sustainable agriculture

Productive agro-ecosystems are central to natural resource and catchment management. Agriculture and the management of land, water and biodiversity in the landscape and catchment must in the future be seen as one. Future catchment management is challenged with the task of integrating water resource use of rivers and groundwater systems with natural resource management of the ecological and biophysical functioning of the whole catchment and in which agriculture is pivotal. Currently in Australia, and in most countries I have examined, the water and natural resource management planning and actions in the catchment are usually conducted under parallel and disconnected management processes. For example, all Australian states and territories have planning processes for the management and sharing of surface water and groundwater resources through regulation and investment. Meanwhile, planning for the maintenance and improvement in the condition of land and water resources and ecosystems through investment incentives and regulation, particularly how vegetation management is conducted, is a disconnected process. Future catchment management will need to evolve so as to align and integrate these activities. Building sustainable agriculture will play a critical role by connecting and aligning the water flows to and from agriculture in such a way that it is compatible with the hydro-geochemical cycles and ecological functions of the landscape and catchment.

To address the fundamental problem in water resource trade-offs between agriculture, the environment and urban consumption, it is critical that catchment management evolve to integrate water sharing and natural resource management. Water in the agro-ecosystems that produce the food and fibre will need to be managed so that water resource use and natural resource management are effectively aligned and integrated with each other and also with the land use planning for urban and peri-urban planning. This will require large scale institutional change to bring these types of plans into one well-aligned process.

Each society, whether Australian or Argentinean, will be faced with a need for institutional and planning reform to better integrate agricultural water management into catchment management, in order to manage high climate variability and the anticipated impacts of climate change.

5. Conclusion

Our farming practices have rarely been designed, at the outset, to operate in harmony with the unique ecosystems in which they are cast. Progress towards ecologically sustainable agriculture as reflected in improved quality of the natural resource, can be best achieved when our agro-ecosystem and landscape functionality in which they operate match those operating in the native ecosystems and landscapes.

A key function of agriculture in the future will be to not only manage the agro-ecosystems so that they produce the food and fibre but also be an active part of catchment management and thereby provide ecosystem services for our urban societies through management of the landscape as a whole, its rivers, groundwater, wetlands and estuaries. The agriculture of the future (Williams 2005) will be paid not only for the goods it produces but will receive increasing remuneration for the services delivered through its management of healthy landscapes, rivers, wetlands and estuaries.

6. References

Bristow KL, Campbell G, Papendick R, Elliot L (1986). Simulation of heat and moisture transfer through a surface residue-soil system. *Agricultural and Forest Meteorology* **36**: 193-214.

Dunin FX, Williams J, Verburg K, Keating BA (1999). Can agricultural management emulate natural ecosystems in recharge control in south eastern Australia? *Agroforestry Systems* **45**: 343-364.

McCown RL, Hammer GL, Hargreaves JNG, Holzworth DP, Freebairn DM (1996). APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. *Agricultural Systems* **50**: 255-271.

Williams J, Gascoigne H (2003). Redesign of plant production systems for Australian landscapes. Proc. 11th Australian Agronomy Conference, Geelong, http://www.regional.org.au/au/asa/2003/i/4/williams.htm

Williams J (2005). Sustainable Agriculture in Australia: some ways forward. The Farrer Memorial Oration for 2005, Farrer Memorial Trust, Annual Report 2005, May 2006, Sydney, Australia, pp. 11-25. http://www.wentworthgroup.org/docs/Farrer_Oration_JWilliams.pdf