Improving the productivity of irrigated agriculture

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The need for irrigation

Irrigation agriculture requires massive amounts of water. For example, to produce 1Kg of wool in the MIA requires 62,000 Kg of water; 1 Kg of beef, 42,000 Kg, and 1 Kg of wheat, 2,000 Kg (38). The cheapest and most economic way to provide these inputs of water is by natural rainfall, a fact well documented by economists such as Davidson (22). But such rainfed systems in semi-arid areas are likely to be highly variable in output and periodic crop failures can cause major food shortages. Therefore it is not surprising that as the world population has increased from 1700 million in 1900 to 4,000 million in 1976, the world irrigated area has increased at a faster rate, from 10 million ha to 233 million ha (45).

Australian agriculture cannot isolate itself from international demands for food. As the world population doubles in the next 40 years (59),expanded production from irrigation will be essential for meeting these demands and avoiding the devastations of famine. Despite the importance of irrigation in world food production large area schemes over 10,000 ha have seldom been economic (16).

It is hard to justify, in economic terms, the expansion of irrigation in Australia from 50,000 ha to 1,500,000 ha in the period from 1900 to 1980, which has resulted in Australia having 0.105 ha of irrigated area per head of population compared with .084 ha in the USA, .042 ha in the USSR and .101 ha in mainland China (29). Irrigation development in Australia has resulted largely from Government initiatives to achieve secondary benefits such as regional development, employment creation, favourable balance of payments, drought insurance, national security, recreational value of water storages and an adjunct to hydro-electricity generation. Irrigation agriculture now represents a significant national investment, producing about 14% of the gross value of agricultural output from 0.3% of the land in rural holdings or 4% of the land that is cultivated for crops and sown pastures. It is also a major source for high-value products such as fresh and processed vegetables, cotton, citrus, grapes, tobacco and sugar.

Irrigation agriculture, and the infrastructure supporting it, represents a valuable national resource, using 77% of all water used in Australia (89). The efficiency with which this resource is being conserved and utilized must be of vital national concern. However, other than the economic studies such as that of Davidson (23) little attention has been paid to this topic. We use the term efficiency to refer to the input/output relationships of irrigated agriculture. Three concepts of efficiency are important and inter-related:

- economic efficiency, - dealing with the costs and returns of irrigated agriculture.
- irrigation efficiency, the ratio of the volume of water available for irrigation to the volume finally used in biological production (evapotranspiration).
- biological efficiency, the level of biological production generated from irrigation and other inputs.

We also use the term productivity to refer to the level of biological production being achieved from irrigation. Provision of irrigation theoretically removes water as a constraint to biological production, but owing to inefficiencies, production may fall far short of its potential. Therefore the level of biological production resulting from the provision of irrigation is fundamental to an understanding of the efficiency of irrigated agriculture.

Historical factors influencing productivity

The initial demands for irrigation followed the severe droughts of the 19th century; the primary concern was to stabilize pastoral production. This fact, and the dominance of the grazing industries in the rural

economy until the 1970's, led to an emphasis on irrigated pastures and low-cost forms of gravity irrigation, particularly in Victoria and New South Wales (Table 1). In the selection of sites for large area irrigation developments, the need to utilize gravity has largely taken precedence over the suitability of soils for intensive, high output agriculture. Thus the flat, alluvial, low-permeability, sodic soils of the Riverina Plain have provided the basis for much of our irrigation agriculture. With the exception of rice, most of these soils have proved unsuitable for intensive irrigation agriculture (64). To sustain large irrigation developments expensive water storages have been needed to regulate river flow, owing to the large variability in continental rainfall.

Table I Irrigation area and methods for the major irrigation states of Australia. 1975/76 (7).

	Total Irrigated Area Mha	% Area Irrigated Pastures	% Area Furrow/Flood Irrigation
Victoria	.56	87	89
New South Wales	. 6	47	84
Queensland	.19	12	42

As a consequence of these historical factors the returns from irrigated agriculture have been insufficient to service the associated high capital costs. Prices of water have been fixed to cover annual operating expenses and typically farmers have not been charged for the capital costs incurred by irrigation authorities (6, 23, 37). For these reasons little direct economic incentive has existed for the efficient use of water. With the emerging awareness of the value of water as a limited resource, and its misuse a cause of environmental degradation, it is now imperative to examine the major inefficiencies of irrigation agriculture (87).

A major problem in the development of irrigated agriculture is the almost exclusive focus on the construction of the water delivery subsystem to the exclusion of the on-farm problems of efficient water use (86). This preoccupation with 'hardware' results from a single-discipline approach to water management (97). One discipline cannot hope to solve the complex physical, chemical, biological, economic and sociological problems involved (86).

These emphases must now change as our principle water resources, particularly in the Murray-Darling basin, become fully committed and demands increase for the more efficient use of existing water resources and for the reversal of land and water quality degradation. A good example of the benefits to be gained from this change in emphasis comes from Israel where, from 1959 to 1975, the amount of agricultural production per unit of water increased by 221% (4). In addition, the amount of irrigated land has increased from 105,000 to 225,000 ha while the amount of water used has decreased from 8.0 Ml/ha to 5.5 M1/ha in the period 1956 to 1978. Such changes are possible where the political will, economic incentives and relevant research exist.

The inefficiencies of irrigation agriculture

a. Irrigation inefficiencies

Major causes of inefficiency result from a failure to make effective use of water for evapotranspiration due to losses en route to the root zone. Bos and Nugteren (14) found from world survey data for large irrigation areas, similar to and including Australian ones, that about 20% of the water was lost between the dam and the irrigation area. A further 30% of the remaining water was lost while being distributed within the irrigation area to farms and a further 40% of the remaining volume was lost within the farm during the application process. Therefore only about 34% of the volume of water originally released from the dam is finally used in evapotranspiration. Losses within the river system can be justified by the need to recharge underlying aquifers. However, the other losses are largely detrimental. These result from unlined channels, and from irrigation methods that lead to excessive drainage and/or excessive surface

runoff into permeable areas. Some drainage through the soil profile is necessary in semi-arid areas to leach salts below the root zone. However, van der Lelii (42) estimated that deep drainage under rice in southern NSW was often twenty times that required for adequate leaching.

Some low efficiency values may be more real than apparent as the drainage effluent can be reclaimed and reused, and, as water tables rise, saturation of the subsoil minimises deep percolation losses. Thus some contemporary studies on Australian irrigation efficiencies (43) may be masking the intrinsic inefficiencies of existing systems.

The short term economic costs of irrigation inefficiencies are substantial. Water is wasted, irrigable land goes unirrigated and potential income is lost. Water derived from more efficient irrigation systems is often cheaper than deriving this water from building more dams (100, 30). The longer term economic and environmental costs are less obvious but will become apparent through high water tables, loss of production due to land salinization and degradation of water quality due to the salt loading of rivers. Should the proposed drainage solutions to these longer-term problems (58, 33) fail also to reduce accessions to the water tables, costly and environmentally damaging problems of disposing of all the effluent may result (26).

Given the widespread evidence of substantial irrigation inefficiencies, there is a disturbing lack of published studies on these inefficiencies and their cost to the nation, despite a recent ICID Seminar on this topic (43). State water management authorities could be fearful of legal action if deficiencies in the design of irrigation systems was proven to be a major cause of salinization losses by farmers, but this in itself cannot explain the neglect of this subject. It appears that the preoccupation with the 'hardware' of delivery structures in water resources development has created a major blind spot leading to the neglect of on- and off-farm management issues. This is still evident from recent NSW Water Resources Commission literature (e.g. 74, 102), where no attention is given to the possibilities afforded by new technologies for the more efficient on-farm management of water. Unfortunately agricultural scientists have also failed to address these same problems.

b. Biological inefficiencies.

The biological yield problem is chronic (Table II). For pastures in northern Victoria the yield potential has been calculated at over five times the current level of production of perennial pastures (19). In the MIA (1978/79) the average yield of maize was 5.2 tonnes/ha. The best commercial crops yield 10 tonnes/ha while the potential yield of existing genotypes appears to be about 15 tonnes/ha. A similar story holds for other crops except rice. The problem of low yields is a major limiting factor to irrigation in the tropics. A review committee in 1978 concluded that "given the high costs structure of the Ord River Irrigation Area, significantly higher yields are required in comparison with most other Australian agricultural areas before farming can become profitable" (103). Sugar has however, been successfully irrigated in the tropics (1).

Table II Actual and potential farm yields of irrigated crops on the Ord River Scheme in Northern Australia, (Wright, personal communication) and the MIA, New South Wales, (NSW Water Resources Commission, personal communication).

	AVERAGE COMMERCIAL YIELDS	POTENTIAL* YIELDS
	Tonnes/ha	
ORD RIVER (1979/80)		
Sunflower	1.5	3.0
Sorghum	4.9	10.0
Maize	4.5	8.0
Rice, Summer Crop	5.5	5.5
Winter Crop	6.5	7.0
Wheat	2.2	5.8
Mung Beans	0.6	1.5
Soybeans	1.8	4.0
MIA (1978/79)		
Sunflower	1.5	3.0
Maize	5.2	12.0
Sorghum	5.0	10.0
Rice	6.1	8.0
Wheat	2.6	7.0
Soybeans	1.2	3.0

* Potential farm yields are a subjective estimate based on best farmer and experimental yields.

c. Economic inefficiencies.

It is beyond the scope of this paper to deal in depth with economic inefficiencies. However, it is evident to us that inefficiencies in use of water (60% wasted) and often low biological yields (50% of potential) must be major contributing factors to the economic inefficiency of irrigated agriculture. These factors combined with the low cost of water must inevitably lead to a misallocation of resources, as evidenced by excessive use of water, leading to high water tables, and its use on enterprises of low profitability or low water use efficiency (87, 69, 10). One example of this in the MIA is that 85% of the water is used on rice, the crop with the highest gross margin/h but potentially the lowest gross margin/M1 of water. Where water is the major limiting factor, its use on the more water-efficient enterprises (gross margin/M1) would, depending on relative fixed costs, tend towards the maximisation of national benefits.

The effect of these various inefficiencies on the value of output from irrigated agriculture is evident from a comparison with Israel and comparable areas in the USA (Table III). This low value of output is often associated with low yields and with wide use of water on low-value enterprises. It is therefore important that the factors causing low biological yields in our irrigated agriculture are examined.

Table III Comparison of the gross value of irrigated output per unit area between Australia and comparable climatic areas in California, USA and Israel.

	GROSS VALUE OF OUTPUT	
	PER UNIT AREA	PER UNIT OF WATER DELIVERED
	A$/ha	A$/Ml
Victoria (1978/79)	676	106
New South Wales (1978/79)	726	
Queensland (1978/79)	1256	181
Yolo County (California 79/80)	1559	
Tulare County (Calif. 79/80)	3944	
Israel (1977)	9139	1370

Sources of Information:
From Annual Reports of State Water Resources Commissions and Blainey (personal communication) in New South Wales.
From Agricultural Crop Reports in California. Irrinews No. 13 (1978) for Israeli data. Exchange rate used, US $1.00 = A$1.00.

Causes of low biological yields

It is often assumed that lack of water is the most important factor limiting crop yields in semi-arid Australia. It therefore comes as a surprise that the addition of water to a soil does not inevitably lead to dramatic increases in crop yield. For example, maize has a national average yield of 2.5 tonnes/ha. Irrigation in the MIA raises this to 5.2 tonnes/ha through the use of water, higher nutrient inputs (particularly nitrogen), higher plant populations and better overall agronomy. However, the best farmers are getting yields in excess of 10 tonnes/ha and top experimental yields are around 15 tonnes/ha. These top yields represent the current genotype potential. However, their remains an unexploited environmental potential of 20 tonnes/ha due to an important but often unexploited attribute of irrigation agriculture.

In semi-arid rainfed agriculture, the length of growing season for photosynthesis is primarily determined by rainfall. However with irrigation this constraint is removed and the primary limitation becomes temperature. For example, the potential growing season for maize in the MIA when mean temperatures exceed 15$^{?}$C is about 200 days. Current late-maturing cultivars of maize reach physiological maturity within 140 days if planted early; therefore a significant part of the growing season is still unutilized for photosynthesis. It is postulated that utilization of this additional growing season could raise the potential yield of existing cultivars from 15 to 20 tonnes/ha. This possibility is particularly evident in sunflowers (35, 92).

More important, however, is the discrepancy between actual and genotype potential yields (5.2 v 15 tonnes/ha). A major cause of this discrepancy appears to be associated with root-zone limitations (19), with agronomic and socio/economic factors of secondary importance.

a. Root zone limitations

The ideal situations for surface irrigation -youthful, deep, undifferentiated and permeable soils with rapid natural drainage -are generally absent in Australian irrigation areas. The Australian landscape is old, flat and well- weathered. Fine-textured soils predominate in the major irrigation areas, occurring widely on flood plains where flat topography intensifies the problems of poor internal drainage. Limited areas of coarser-textured soils do occur. However, the major part of our irrigation water is used on fine-textured soils and the following discussion will concentrate on these.

Soil factors limiting the growth of tree crops on an irrigated fine- textured soil, typical of those that predominate in northern Victoria (66), have been identified as:

- a shallow A horizon low in organic matter, high in silt and prone to slaking on wetting, creating problems of water entry,
- a B horizon low in permeability with a saturated hydraulic conductivity below 2 mm day ,
- an air-filled porosity below 5 percent at -0.01 MPa suction,
- bulk densities of 1.5 gcm^3 in the surface soil and 1.6 gcm^3 in the subsoil, and
- a high mechanical resistance to root penetration on drying (11).

A high level of organic matter and associated biological activity appears to be important for maintaining a stable aggregate structure on these soils (12, 90). Many of these soils when subjected to frequent and intensive cultivation deteriorate in structure (31). Organic matter added to the soil by plant growth, and the resultant products of biological activity, can often stabilise aggregates susceptible to disruption due to irrigation. This disruption is associated with rapid wetting or reduction in electrolyte content of the soil solution (81, 12). In addition, extremes of wetness followed by dryness of the surface soil under conventional systems of flood irrigation appear to be antagonistic to the maintenance of high levels of biological activity, particularly earthworms (90). Prolonged drying accelerate: soil mineralization (13), and on soils of low permeability subsequent flooding may induce anaerobiosis and high losses of nitrogen due to denitrification (Melhuish, personal communication).

Some soils of fine texture characteristically crack on drying and swell on wetting. This has a major effect on infiltration characteristics, with an initial rapid entry rate into the cracks (201 and subsequent decline to low values as the cracks close (0.1 to 1 mm day). Under flood irrigation it is common for over 80 percent of the water to enter the soil within the first half-hour (57, 63, 72). Subsequent ponding of the water may lead to low air- filled porosity (101, 66, 18), creating the basis for low soil oxygen content following flood irrigation (57).

These soils when wet are also predisposed to structural degradation by cultivation. Chan (17) noted that these soils, after five years of intensive cotton production, were showing signs of structural degradation, particularly in the 0.2-0.4 m layer. McGarry (61) found that when virgin soil before sowing was cultivated wet rather than dry, significant depressions in the subsequent growth of cotton occurred, associated with the formation of large massive prismatic peds and loss of meta-voids.

Loveday (50) found a positive relationship between the water entry capacity of a range of fine-textured soils on the Riverina Plain at the initial autumn watering of subterranean clover pastures and their subsequent production. The level of water entry capacity was related to the degree of cracking. It was postulated that this capacity is controlled by a 'throttle' (a zone of low hydraulic conductivity) in the upper B horizon where clay is at a maximum, electrolyte levels are at a minimum and appreciable exchangeable sodium and magnesium is present (53). Addition of gypsum resulted in an _1 increase in the infiltration rate under long-term ponding from .7 mm day¯' to 3.5 mm day^1, due to a reduction in the dispersion and swelling of clay between the 0.25 and 0.55 m depth (60). The low permeability and porosity of these soils under irrigation may be further exacerbated (73, 85) by significant falls of rain (68). The bad effects of such high-quality water on soil permeability may be offset by the lower leaching requirement required to maintain a favourable salt balance in the root zone.

Although the irrigated soils of Australia have limited deficiencies of many nutrients (65), these can be rectified by fertilisers. Of importance are the effects of irrigation on nutrient availability. Prolonged anaerobiosis under rice can cause severe phosphorus deficiency in subsequent row crops (98, 99). In addition, soil anaerobiosis may have a significant effect on losses of nitrogen by denitrification. Realisation of the biological potential of irrigated agriculture will require high nutrient inputs, particularly nitrogen (81). Nitrogen transformations in flood-irrigated soils are vitally important since they are related to the turnover of soil organic matter, which serves as a sink for oxygen and a source of polysaccharides for intermicro-aggregate bonding. Soil organic matter is both a sink and source of nitrate for crop growth. Nitrogen fertilizers are costly, highly labile and need to be applied as a supplement to the nitrogen derived from soil organic matter. Because of the labile nature of nitrogen and the high requirements for high crop yields, lack of nitrogen could often be a significant root zone limitation to crop yields under irrigation.

The foregoing evidence suggests that major root zone factors could be limiting crop yields on surface-irrigated fine-textured soils. The mechanisms whereby these Factors operate on root function and growth are not clear. in any intermittent irrigation system the ability of root systems to explore an adequate soil volume is important. A major impediment to root growth is high soil strength (88). The high bulk densities of many Australian soils indicate that, as the soil dries, soil strength could be an important factor. In grey cracking clay soils it is commonly observed that roots preferentially develop along the slickensides that characterise the meta-voids of this soil (61), giving rise to a non-uniform micro-distribution of roots. On the other hand, the high clay content and low soil strength of these soils at high water content makes them susceptible to plastic deformation and degradation if cultivated too wet or subject to treading by animals (52). In addition to physical restrictions to root growth, root extension is highly sensitive to the oxygen content of soil air (41). At low oxygen content (< 3 percent) roots may age prematurely and lose their permeability (39), thus creating a requirement for new roots. In addition low oxygen content due to transient waterlogging may induce adaptations through the formation of aerenchyma and stimulation of adventitious roots (47). Sub-optimal root zone conditions may well stimulate root growth at the expense of aerial growth, leading to the observation of very high root length densities in the soil (87) in comparison with similar crops grown on more permeable soils (79).

It is likely that low soil oxygen levels will also inhibit root function, since the absorption and translocation of inorganic nutrients by roots of plants in solution culture are almost immediately inhibited when oxygen supplies become inadequate for aerobic respiration (40). Thus, following temporary waterlogging (25), ion uptake max be more inhibited that dry matter synthesis in the short term. In addition, low soil oxygen level can cause the accumulation of phytotoxic compounds in the soil, decreased production of gibberellins and cytokinins by roots and increased susceptibility to disease (15). Under low soil oxygen conditions, mesophytic plants adapt through metabolic, anatomical and morphological changes, which in most cases only ensure survival (47).

Irrigation agriculture in the future

Mark Twain is said to have remarked that he was concerned about the future, because that was where he was going to spend the rest of his life. A good way to get a fix on the future is to look at presently underused technology (77). The future of irrigation may well depend on our ability to integrate this mass of underused technology into new systems that are able to realize the biological potential of irrigation systems. To achieve this, changes in the following aspects of irrigation are foreseen as necessary:

- improvement in the agronomic management of crops using existing methods of tillage and irrigation
- Improvement in the surface stability and sub-surface permeability of soils to make them more suitable for irrigation, by using appropriate ameliorative, drainage, tillage and rotational practices (19)
- breeding crop varieties able to exploit the long growing seasons of irrigation areas, and resistant to diseases associated with systems of intensive irrigation culture
- use of more precise techniques of soil water and nutrient management to optimise water, oxygen and nutrient conditions within the root zone
- a greater use of irrigation water on soils that are better suited biologically for irrigation,

a. Agronomic management.

In Australia, nitrogen fertilisers are approaching 30% of the variable costs in intensive crop production; 75% of all nitrogen fertilisers used in south-eastern Australia are used on irrigated crops (Muirhead, personal communication). Given the cost and importance of this nutrient in achieving high yields, research is needed to develop application techniques that minimise losses of nitrogen and maximise crop responses to nitrogen fertiliser. Such techniques need to be complemented by an understanding of the physiologica effects of nitrogen insufficiency at different stages of crop growth. This knowledge combined with a quick sap test for the N status of the crop (84, 21) could be used to schedule the application of nitrogen fertiliser through the irrigation water.

Other aspects of agronomic management, such as row spacing, plant population and seeding time are obviously important, but benefits from their manipulation are constrained by other more significant limiting factors.

b. Soil management.

Despite the difficulties of maintaining the physical fertility of irrigated soils the only facet to have received detailed attention has been the use of ameliorants, particularly gypsum (52, 83). The benefits of gypsum have been variable on many red-brown earths, where surface slaking due to the high silt content of the A horizon is the main problem. On these soils a long-term program of deep tillage and stubble incorporation to increase the clay and organic matter content of the surface A horizon is probably needed. However, any of these soils still have a major problem of low sub-surface permeability...)

Recent work at the Tatura Irrigation Research Centre in northern Victoria has attempted to integrate a number of these approaches to achieve complete profile modification (66). This involves improved drainage of the A horizon by deep ripping of the impermeable B horizon with injection of gypsum to stabilize aggregates. This is then followed by management of irrigation and cultivation that aims to build up organic matter and maintain biological activity to improve surface soil structure. This management involves:

- minimal cultivation and use of herbicides for weed control,
- slow wetting up of the soil from the base of furrows to minimise slaking,
- development of a surface mulch to stimulate biological activity and provide protection against rain drops, and
- frequent irrigations to keep soil water tensions above -0.03 MPa.

Such systems of profile modification have given threefold increases in yields of lucerne. Cockroft and Martin (19) express optimism that these management techniques will lead to a realisation of sustained higher crop yields under more intensive systems of cropping. The scientific basis for these approaches to improve soil macro-porosity and structural stability is well supported by work on gypsum (57), on stubble retention (36) and on minimal tillage (34, 80). The silent revolution of minimal tillage may prove to be vital if soil degradation associated with conventional tillage and water management is to be reversed, but the full benefits from improved soil physical fertility may only be realised when it is combined with more controlled systems of water application.

c. Soil water management.

To maximise plant productivity soil water within the root zone needs to be managed between two limits (70),

- <u>upper limit-</u> to ensure an adequate diffusion rate of oxygen to roots for their growth and function
- <u>lower limit-</u> to ensure that soil strength is low enough for root growth and soil hydraulic conductivity adequate for water and nutrient uptake.

These two limits have not been defined for our major irrigation soils or used as biological criteria for the design and operation of irrigation systems. Engineering criteria, commonly used on their own, often do not allow the full biological potential of the system to be expressed. Our traditional systems of flood irrigation offer only crude control over soil water, often creating conditions of excessive wetness and dryness at the terminal ends of the irrigation cycle. In these systems only the frequency of application can be controlled, whereas for optimisation of the root zone the quantity applied and its placement are also important.; New developments in surface and pressure- based irrigation offer this control. Therefore a major question to be resolved is whether these developments in association with appropriate soil management can overcome the major root-zone limitations inherent in current systems.

- surface irrigation

The advent of laser technology for levelling land to uniform grades is leading to the redesign of many surface irrigation systems (82). Resultant improvements in biological production have yet to be documented. 'On layered soils, concern has been expressed at the possible problems associated with the exposure of the B horizon by land levelling operations.

In the USA the advent of laser technology has led to the use of dead level basins. These are combined with systems for high volume application, to give an even and rapid distribution of water (29). Flows of 1.5 Ml hr¯' are common so that 50 mm of water can be applied to a 10 ha bay in 3.3 hours. This method has not been evaluated experimentally in Australia, though a few high-volume discharge systems are in operation in northern NSW. However, the concept of using rapid application rates to minimize the duration of surface ponding is applicable. On the other hand, it is necessary, since heavy rains occur in many Australian irrigation areas, to determine the minimal slope required to give adequate surface drainage.

An important component of a controlled application system is the measurement of flow rate so that the amount of water applied can be regulated by adjusting the time of application. The traditional dethridge wheel is likely to be unsuitable for this purpose. Such measurement has been achieved in the USA by the use of broad crested weirs (78). These weirs permit accurate measurement of water delivered to individual bays and with modern electronic transducers provide the basis for the automatic opening and closing of gates (Replogle, personal communication). To handle the high-volume flows, large channels with special discharge structures to dissipate the kinetic energy of the water are needed (29).

An interesting development in surface irrigation in Australia has been (the development of high watertable systems for growing soybeans. High yields have been recorded by a farmer on the Riverina Plain where(soybeans have been grown on hills with a continuous flow of water maintained in every alternate furrow(2). Principles for such systems are well supported by recent research of Hunter *et* al. (42), and are the ultimate in high-frequency irrigation (76). However, they are (only likely to be suitable on soils of low permeability. These systems may optimise the root zone by creating a gradient in soil water levels in the hill, which permits roots to proliferate where conditions are optimal and may have application in conventional systems as a method for reducing soil anaerobiosis.

- pressure-based systems

Pressure-based systems for irrigating large areas have been developed in recent years. The centre-pivot system is widely used in the USA but its disadvantages are the need for high pressures and therefore high energy requirements, and its high discharge rate at the outer end which could create problems of ponding and runoff on soils of low permeability. To overcome these problems, lateral move systems have been developed (48). These have permitted the development of Low Energy Precision Applicator (LEPA) systems of irrigation (54). Such systems can traverse 1 ha of land for 1 K watt/hr of energy (0.17 litre/ha of diesel fuel), which compares with a tractor system spraying the same area using 1.8 litres/ha. The LEPA system uses one-tenth the energy of conventional sprinkler systems (54).

We foresee a situation where these systems could substitute for conventional farm equipment and be used to apply herbicides, soil ameliorants, fertilizers, pesticides and sow seed by fluid drilling. They would provide a basis for minimal tillage systems to minimize soil damage due to conventional tillage and wheel traffic (96). Nozzles and pressures can be selected that minimize damage on slaking soils (55).

These large scale pressure-based irrigation systems have been used in the commercial production of rice in the USA with significant economies in the use of water (24, 28). Recent evidence from our laboratory indicates that such systems of rice production are feasible in Australia.

In addition, trickle irrigation systems that permit an even higher level of control are now being widely used for the broad-area production of cotton in Israel with significant improvements in yield reported (3).

- irrigation scheduling

Irrigation scheduling advisory services (44) are not generally available in Australia because of a lack of demand by farmers. This situation may change as water becomes scarce and more expensive. More controlled systems of irrigation will require more accurate knowledge of crop water requirements to determine the timing and volume of application. Water use research in Australia has concentrated mainly on desired frequencies for the surface irrigation of pastures (65) and crops (89). Mechanistic studies using weighing lysimeters or energy balance methods have been used to develop crop water use models for cotton and soybeans for irrigation scheduling in the Namoi Valley of northern NSW (56). Owing to the probable contribution of high water tables to evapotranspiration in the intensive irrigation areas of south-eastern Australia, such studies may need to be complemented with other methods of measuring evapotranspiration Therefore to support future developments in controlled irrigation more detailed crop water use studies and the development of appropriate models for irrigation scheduling will be required 7 (62).

An interesting development in the application of modelling to irrigation agriculture has been the SIRATAK program developed for the cotton-growing areas of northern NSW. This computer-based model, designed to assist in makingtactical decisions for insect control, has recently been extended to include irrigation scheduling (75). The model is being run by a farmer- financed company in collaboration with Commonwealth and State research agencies. Such approaches could well develop further in the future as production from irrigation agriculture intensifies.

- benefits from more controlled systems of water application

It is anticipated that the main benefits on soils of low permeability would be a reduction in anaerobiosis, leading to improvements in crop yields, more efficient nutrient use (particularly nitrogen) and improvements in soil structure. In addition improved application efficiencies, a reduction in accessions of water to the watertable and therefore a reduction in requirements for drainage and saline effluent disposal would occur on the more permeable soils.

We can be encouraged by overseas experience. In the USA, the adoption of dead level basin technology in the Welton-Mohawk Irrigation District of 26,000 ha in Arizona, with an irrigation scheduling advisory service, is projected to increase application efficiencies from 56% to 80% with a 50% reduction in drainage flows (95). Such advantages could be highly relevant to many irrigation areas in southern Australia, with additional benefits from reduced anaerobiosis.

In Israel, the introduction of advanced distribution and application technology has resulted in 87% of the irrigated areas being sprinkler-irrigated, 10% with trickle and only 3% by gravity (compared with 77% in Australia). A result is a national application efficiency of 80% and no published evidence of major high water tables or drainage problems associated with the inefficiencies that afflict our major irrigation areas (4).

Research is needed in Australia to determine whether these techniques will offer significant advantages, particularly in overcoming the root zone limitations associated with traditional methods or irrigation on our fine- textured soils. We are encouraged by recent results from our laboratory, (Melhuish pers. comm.) where we studied the effects of time of ponding at each irrigation on the yield of sunflowers grown on a grey cracking clay soil. Yields declined linearly from 4.55 t/ha to 2.7 t/ha as the time of ponding increased from 1 to 48 hours. Loss of yield was 39 kg/ha for each hour of ponding.

Increasing control over water application will require additional energy, for capital and application purposes. Whether this will be compensated by additional energy output has yet to be determined. We have made these calculations for a range of situations using the approach and data of Leach (49), and if modest yield increases can be achieved our analysis indicate: that it will return more energy than is used.

d. Relocation of water to more productive soils.

If research and subsequent developments in soil and irrigation management fail to lead to a significant improvement in the efficiency with which water is used, then consideration should be given to research that could assist in redirecting this water to more productive soils. On the Riverina Plain, this would mean making more water available at the eastern rather than the western

region of the plain (64). With new pressure-based methods of water application, topographic features that so dominated early developments of large area irrigation would now be less restrictive. Legal changes would be needed so that water rights can be sold independently of land, thus enabling the more productive sectors of irrigation agriculture to gain access to more water.

Conclusions

- Wastage of water and low biological yields characterise much of our irrigated agriculture. They are the major causes of inefficiency and environmental degradation.
- This situation mainly results from an overemphasis on development of water resources at the expense of water resource management. This is a consequence of a narrow disciplinary approach to water. Broader multidisciplinary approaches are required if our irrigation resources are to be used efficiently.
- The focus of agronomists as evidenced by papers presented at this conference is too narrow and fails to identify, analyse and propose solutions to the major inefficiencies of irrigation agriculture. Systems-orientated scientists able to study and comprehend the complexities of irrigation agriculture are needed.
- Development of systems incorporating present under-used technology for soil, water and nutrient management could lead to a doubling of output from water resources currently committed to irrigated agriculture, through reducing the wastage of water and through higher crop yields.
- These developments need to be based on enlightened and innovative research into root-zone factors limiting biological yields. In addition broader studies to define and overcome the major irrigation inefficiencies of irrigated agriculture are vitally needed.
- Significant institutional changes in approach to the management of water will be needed if the potential national benefits from water devoted to irrigation are to be realised. The fragmentation of tasks for water resources management between a range of state instrumentalities has led to a neglect of vital areas of research and administration. This is particularly so in the area of on-farm management.
- Farmers should be rewarded for efficient water use. Therefore water should be priced at a level nearer its true marginal value and the subsidy afforded by the current low price of water replaced by an explicit subsidy to assist disadvantaged farmers.

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