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EFFICIENT AND ECONOMIC USE OF WATER IN AGRICULTURE - POSSIBILITIES AND LIMITS

by

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The agricultural sector is coming under growing pressure to make more efficient use of water. It has been blamed to be the greatest water user and have the lowest water use efficiency and lowest output per unit of water used of all sectors. Especially irrigated agriculture, the greatest water user of all, has been made responsible for inefficient water use and land degradation. The following article attempts to outline ways and potentials of efficient agricultural water use. It considers some basic questions on the role and potentials of plants in this context and points out possible ways towards technical and system improvement. It becomes clear that agricultural water use efficiency considerations should no longer be reduced to the farm or system level but should rather be extended to the whole catchment. Generally speaking, a more holistic approach should be adopted to solve the growing intersectoral water conflicts that are driven by the increasing scarcity of water resources.

In the past agricultural research and practice only dealt with the subject of water for purposes of optimising water management to satisfy the plant water needs. It is only in recent times that the effects of agricultural activity on water resources have been studied in the context of intersectoral water management and have consequently become a matter of public concern. This is due in particular to the increasing pollution of groundwater resources with agrochemicals. In areas of water scarcity the competition between different sectors of water users is (i. e. between agriculture, municipalities, trade, industry, nature conservation etc.) increasingly attracting public attention. Meanwhile it is clear that agricultural practice and research will in future no longer be exclusively geared to the task of optimising the water supply of crops. There is much rather a need to curb agricultural water consumption for the benefit of other sectors by, for example, reallocating water originally designated for plant production to the supply of the population with drinking and domestic water.

Irrigation farming, in particular, will find itself confronted with serious challenges during the next few decades. On the one hand, irrigated agriculture is the only way of securing the increase in food and fibre production for meeting essential needs in terms of food and clothing. On the other hand, irrigation farming is more and more having to compete with other interests for dwindling resources in water. The situation is aggravated by the steady decline of financial resources and growing cost of modernising existing and constructing new irrigation systems. All this, finally, is taking place in a political and social environment which takes a very critical stance on irrigation.

The agricultural sector will have to take on this challenge. It will have to use its water resources more sparingly, minimise the environmental impact of its water consumption, and submit to constant self-monitoring in the form of eco-auditing. This leads to the

question of how water actually can at all be saved in the agricultural sector and whether the water saved can finally be diverted to the benefit other users.

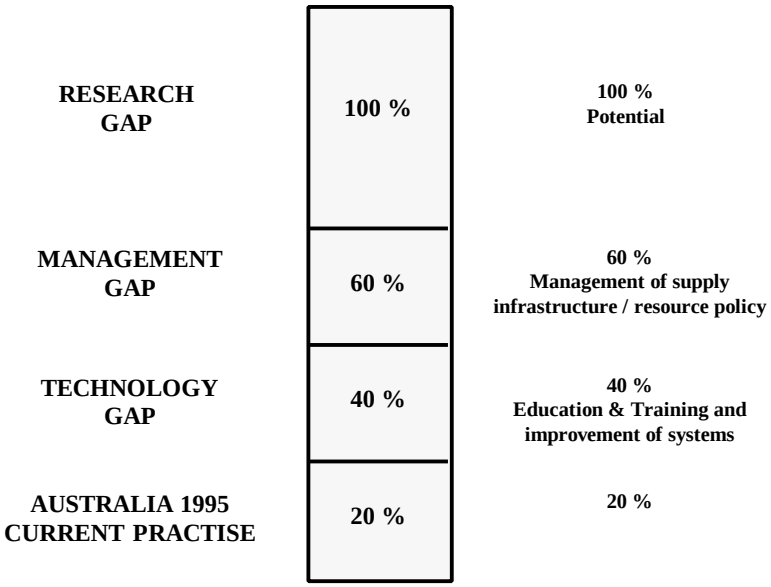

Fig. 1 Possibilities for better exploiting of production potentials in Australia according to estimates by Cape (1995) (source: adapted from Cape, 1995).

Are our crop plants water squanderers?

The average consumption of water by agricultural production in Australia (Table 1) serves as a good example to show that agricultural production, in itself, is extremely water-intensive. This is true regardless of whether plants are irrigated or can satisfy their water demand through natural precipitation. This high rate of water consumption per unit of dry matter produced is not restricted to crop plants but rather a characteristic of all plants including trees and naturally growing wild plants.

The greater part of the water consumed by cultivated plants is transpired into the atmosphere. This means that the water consumption of a crop is decisively governed by the evaporating capacity of the atmosphere, which can be expressed in terms of the suction force gradient and the resistances to diffusion in the system constituted by soil, plant, and atmosphere. The driving force behind this process is the high negative water potential, which is equivalent to the suction force or, in everyday language, the atmosphere's thirst for water. Even very damp air having a relative humidity of, for example, 95% creates a suction force in the air of -69 bar. The water is literally been wrenched from the plant by the surrounding air increasingly intense with lower humidity. Plants have very limited means by which to protect themselves against this suction force. Therefore a closure of the stomata, the most important counteractive response, will always result in al lowering of productivity. This transpiration behaviour suggests that in terms of litres of water per kilograms of dry matter produced the high water consumption of useful plants is quite inescapable.

Moreover, plants only lower their rate of transpiration when water availability is low. Plants to differing degrees have adaptation mechanisms at their disposal which allow them to cope with stress due to water scarcity. However, these mechanisms cannot wholly prevent productivity from decreasing under such conditions. Conversely, a plant that is in ample supply of water will make correspondingly "wasteful" use of that supply. This means that plants have no mechanisms of their own which could make a sustainable contribution of enhancing water use efficiency.

Table 1 Average water consumption of agricultural produce in Australia

agricultural product	water consumption
1 bottle of wine (Barossa Valley)	250 l
1 bottle of wine (Riverland)	450 l
1 l of orange juice	550 l
1 kg of alfalfa hay	600 l
1 l of milk	700 l
1 kg of rice	1.600 l
1 kg of cotton	2.200 l
source: Cape, J., 1995.	

The only way to increase water use efficiency in plants is through human manipulation such as breeding or the use of transpiration inhibitors. The potentials for increasing plant productivity is far from being used to the full, as can be seen in Fig. 1 for the example of Australia. If the productivity potential were used better, this would undoubtedly lead to a marked increase in water use efficiency. Fig. 1 also shows by what means this potential could be better exploited.

At present it is hardly possible to achieve higher yields under conditions of reduced transpiration. It remains to be seen whether and to what extent breeding can serve to improve the ratio of productivity to transpiration. The use of transpiration inhibitors is of dubious value, both ecologically and economically. Breeding, however, in the course of the past decades has led to the successful development of new varieties with an altered productivity to transpiration ratio. Certain genetically improved varieties, for example among the cereals, now yield considerably more grain even though their yield in terms of total plant mass has remained the same. This means that while the productivity to transpiration ratio has not increased with regard to the whole plant, it has considerably done so with regard to grain yield. Unfortunately the water thus saved can hardly be diverted to other water user sectors.

Efficiency increase through reductions in unproductive loss parameters

However, a crop consumes water not only through transpiration (T) but in considerable measure also through evaporation of water from the soil (E). The aggregate of these two quantities is termed evapotranspiration (ET). Productivity of water use should therefore not be referred to transpiration alone but to evapotranspiration. Furthermore, plants' efficiency in using precipitation and irrigation water also depends on "water

losses" through seepage and surface runoff. An assessment of the water use efficiency of a crop has therefore always to take into account the other losses caused by seepage and surface runoff.

Especially in times of water scarcity, growers will therefore aim at reducing the unproductive water losses incurred through seepage and surface runoff. This has the favourable side-effect of reducing soil erosion associated with water loss. From a more comprehensive viewpoint of water economy, however, measures to this end must not necessarily lead to an improved water use efficiency. This is because reduced seepage leads to reduced renewal of groundwater, while reduced surface runoff results in reduced water volume of flowing in water courses, this limiting their value to downstream users and impairing the water regimes of river-side meadows and wetland biotopes etc. Referred to units of cultivated land such measures of course will improve water use efficiency as a rule. However this does not automatically increase the amount of water available for non-agricultural sectors.

"New water" for agricultural production

The continued decline in renewable fresh water resources has stimulated the search for water resources which have not been utilised until now and appear accessible. One such resource is fast running-off precipitation water which is not naturally been hold back. Further more the use of sewage water, industrial effluents and desalinised brackish water is looked at as being another source for the increase of useable water.

In many dry regions the revival of historical water harvesting techniques is now being considered as a possible way of alleviating water scarcity (Prinz, 1996). The term water harvesting is understood to mean the collection of surface runoff and its use for irrigated crops production under dry and arid site conditions. In addition it allows a drinking water supply for humans and their livestock. In some cases special measures are taken to increase the runoff to "water harvesting areas". These measures generally improve precipitation water use efficiency as they allow to hold back, collect, and hence render usefully the fast running-off fraction of precipitation water that otherwise would have been lost. Whether water harvesting measures are able to improve the water use efficiency of the entire catchment area will depend on the conditions of the individual case. Thus, excessive water retention in the upper part of a catchment area can impair the water supply of the lower part and put its users at risk of suffering water shortage. If the potential unit productivity of water is higher in the lower region, then this will also results in considerable economic losses to the catchment area as a whole. Of course it can just as well be the other way round. In assessing the potential contribution of water harvesting techniques to improving the water and food supply Rosegrant (1997) states that "...given the limited areas where such methods appear feasible and the small amounts of water that can be captured, water harvesting techniques are unlikely to have a significant impact on global food production and water scarcity."

In some countries (e.g., Germany) wastewater utilisation has been practised successfully for more than 100 years. The health risks involved in this can be reduced considerably by an appropriate management. The range of possible uses depends above all on the features of the site in question and the prevailing economic and sociocultural conditions. At present some 500,000 hectare, i. e., 0.2% of the world's irrigated land are supplied with sewage water.

Though this area is certain to increase in the coming years, it will altogether hardly exceed 1% of the world's total irrigated land.

"New water" through desalinisation of seawater or brackish water is at present receiving great attention. Although technical developments have progressed very rapidly in this area during the past decades, desalinisation is still a very expensive process with costs ranging from 1.00 to 2.00 US$ per cubic meter. Desalinised water is too expensive to be used for irrigation. Even if the cost of the desalinisation process is may be reduced in future, it remains unlikely that seawater or brackish water will ever be used for irrigation purposes to a greater extend.

Economic use of water through modern irrigation techniques?

Irrigated agriculture consumes some 80% of the world's developed water resources. In conjunction with the generally very poor rate of utilisation of traditional surface irrigation methods, which range around 40%, this is continually provoking demands to improve irrigation efficiency by the use of modern technology. Such demands appear all the more justified as, for example, sprinkler irrigation permits a rate of utilisation of 70 to 80% and that of drip irrigation even reaches efficiencies of more than 90%. This could lead one to conclude that in principle more than half the water currently used for irrigation could be saved through the use of modern irrigation techniques. However, economic use of water is only partly a question of the technique applied. It depends to a far greater extent on the management of water deployment and application and on the technical, economic, and socio-cultural framework conditions. For example, Hagan (1994) in a study on the Jordan valley (Jordan) found that the rate of water use efficiency reached 70% in the case of furrow irrigation and only 42% to 56% in that of drip irrigation. These differences were attributable to the respective framework conditions of the cases under study. Those farms which used surface irrigation had to cope with extreme water shortages and were therefore compelled to use their supply as efficiently as possible in order to secure a minimum income. By contrast, farms which used drip irrigation were in ample supply of water and grew crops with a high market value. Their low cost of water and high gross earnings relieved them of the need to use their water efficiently and acted as an invitation to squander.

Conventional irrigation methods offer little scope for reducing soil evaporation, one of the major water sinks implicated in irrigation systems. Subsoil irrigation methods, however, permit a marked reduction or even complete elimination of soil evaporation. Various subsoil irrigation methods have been experimented on in the past, in most cases with disappointing results. None were developed to technical maturity. In recent times there has been a resurgence in the promotion of subsoil irrigation and in efforts to make it a practicable alternative. A particularly noteworthy, technically very refined method is to be seen in subsurface drip irrigation (also known as SDI) (Lamm, 1995). If water resources continue to decline and the cost of water rises correspondingly, and given appropriately adapted management methods, this technique may yet become a serious alternative to conventional irrigation systems. Moreover, some simple irrigation techniques for arid regions have now also been developed for subsistence farming. These techniques are based on either the subsurface earthen drip pipe or the porous pitcher irrigation concept (Batchelor et al., 1996; Stein, 1994). It remains to be seen whether and to what extent these methods will be able to prevail.

Enhancing the economic efficiency of water utilisation

As explained above, the efficiency of water utilisation can be enhanced physically by reducing the amount of water consumed per unit of plant yield. Beside this, it is also possible under certain conditions to improve the economic efficiency of water utilisation. This can be brought about, amongst other ways, by reallocating water from an economically less productive application to one of greater economic value. This can mean, for example, irrigating plant stands with a high market value (vegetables, fruit) in place of ones with a low market value (vegetables, fruits) in place of ones with a low market value (forage plants, cereals)

One of the methods recommended as a means of improving the economic efficiency of water utilisation in irrigation farming is simply to curb the water supply. The basic idea behind this method, which is known as deficit irrigation, is to supply less water than would be needed to achieve maximum yield and accept the somewhat lower yield for the sake of avoiding the disproportionately high irrigation costs that would be required to saturate the plants' growth potential. In economic terms, cost reduction through deficit irrigation may be geared to maximising the financial profit per hectare or per cubic metre of water used.

Holistic approaches will be indispensable in the future

To date, assessment of water use efficiency has not taken account of the fate of the so-called unproductive losses, i. e., for example, the irrigation water that seeps into the groundwater and/or flows off aboveground via the drainage canal. Efficiency calculations have neglected the possibility that such water flows may be used by downstream consumers and so greatly improve the overall efficiency. On the other hand, they have also given too little consideration to the fact that water pollution can seriously impair water use efficiency for the catchment area as a whole because polluted water, if at all, will only be of limited use to downstream consumers.

Strictly speaking, losses in water are only unproductive if the water has irretrievably left the catchment area in either liquid or gaseous form or if it has become unfit for use. Thus, water that runs off an irrigation area aboveground or seeps into an aquifer, to name two examples, must not necessarily be lost in the physical sense so long as it can be recovered within the catchment area and reused. In assessing water savings a distinction must therefore be made between "real" and "theoretical" savings or improvements in efficiency (Seckler, 1996). For example, a farmer who succeeds in reducing seepage to groundwater and/or surface runoff to the draining canal by means of water saving techniques needn't necessarily be improving the water use efficiency of the catchment area as a whole, especially if the seepage water and surface runoff were previously used by downstream consumers. This example serves to show that there is little sense from the overall viewpoint of water economy in referring water use efficiency to an arbitrarily defined irrigation area or irrigation perimeter. Such investigations should always take account of what is happening in the water catchment area as a whole. This becomes the more important the scarcer the water and the greater the competition for the available water resource. Water consumers defending their interests within a catchment area must realise that the present and future problems of water utilisation can only be solved on the basis of an intersectoral water management conducted at the level of the catchment area. And farmers must awaken to the fact that they are only part of an integral whole.

Possible improvements towards efficient water use

Deliberations on how to improve water use efficiency should place a greater emphasis on catchment areas than they have done in the past. It is only at this superordinate level that real improvements in water use efficiency can be attained. Reduction of the rapid, so-called unstable runoff after heavy precipitation is undoubtedly the most effective measure for improving water use efficiency at the level of the catchment area. However, this is by no means the only possibility, others being

- production increase per unit of evaporated water;
- reduction of the proportion of water that flows into sinks where it is lost altogether;
- control of water pollution;
- reallocation of water resources from applications of less to ones of higher economic value;

In all these points agriculture is in position to make a decisive contribution to a more efficient and economic use of water. The task of agricultural research and consulting in this is to identify and point out sustainable measures that will work under local framework conditions.

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