Keynote Lecture

MORE YIELD WITH LESS WATER. HOW EFFICIENT CAN BE WATER CONSERVATION IN AGRICULTURE ?

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ABSTRACT

In rain-fed as well as in irrigated agriculture the urgency rises to implement water conservation measures, defining water conservation as "measures designed to promote **efficient use** of water and to **eliminate waste of water**". Besides supply side measures we have a wide variety of water **demand management measures**, which can be grouped into measures to **reduce losses**, and measures **to increase the efficiency** of water applied.

Pits, furrows, basins, bunds, ridges and terraces can be employed as useful to **minimise runoff** losses allowing better soil infiltration. **Evaporation** losses can be minimised by mulching and shading and the water storage capacity through incorporation of organic matter and deepening the root zone. To reduce **transpiration** wind breaks and improvement of shading of crops are being the most important techniques.

Other important water conservation methods are e.g. increasing the **efficiency of irrigation** water use, selecting best suited crops and cropping methods, and reducing the losses of stored water and improving the water availability. Efficiency increase in irrigation water can be accomplished e.g. by application of "supplemental", "deficit" or "surge" irrigation. Efficient irrigation methods like micro-sprinkler, trickle, or pitcher can be applied. **Losses** have to be avoided in conveyance (losses can be 30-50%), distribution and application. To achieve optimum water conservation & improved water use efficiency, education and training, public incentives, management of supply infrastructure, an optimised resource policy and further research are needed.

KEYWORDS

Water conservation, irrigation methods, water supply management, water demand management

INTRODUCTION

Water is already in many parts of the world a scarce commodity – and will be of even shorter supply in future: Due to an ever increasing world population, improving standard of living, irregularities caused by global climate change and growing water pollution, the world water problems aggravating day by day. Especially the drier parts of the tropics and subtropics, but also European countries, experience severe water supply problems – and agriculture will be hit hardest. **Agriculture** utilizes globally about 70 % of all the water managed by man, and about 80 % of the water used in the developing world (Prinz 2000). At the same time, the competition between the various sectors – agriculture, communities, industry, nature, becomes stiffer and agriculture will be the loser in the run for scarce water resources, as the output per unit water is of significantly lower value than in the other economic sectors. On the other hand, the need for more food asks also for more irrigation water, therefore we have to find ways of growing more food with less water (Agarwal 2001). But it is not only a problem of water quantity, but of quality due to increasing pollution, too.

GENERAL OVERVIEW

What is **Water Conservation in general** ? Water conservation is the physical control, protection, management, and use of water resources in such a way as to maintain crop, grazing, and forest lands, vegetative cover, wildlife, and wildlife habitat for maximum sustained benefits for people, agriculture, industry, commerce, and other segments of the national economy.

Water conservation in agriculture may be defined as the application of measures designed

(1) to improve the availability of water for agricultural purposes ("Supply Management"),
(2) to reduce the present size of water demand ("Demand Management"), and
(3) to keep water resources from being polluted or wasted.

The solutions found must be sustainable and possible negative effects e.g. on nature have to be avoided.

Water conservation must be an integral part of „**Integrated Water Resources Management**“, a long-term integrated strategy which seeks to make best use of the available water resources (Fig.1). Major features are:

- **Surface water management**: By diverting (more) water from rivers, e.g. by construction of hydraulic structures in rivers considerable quantities of water can be saved and used for agriculture, especially during the rainy season and under flood conditions. More reservoirs of high water holding efficiency are needed in future to cope with future water demands.
- **Groundwater management:** Groundwater tables are falling in most parts of the world and sustainable groundwater management deserves **artificial groundwater recharge**.

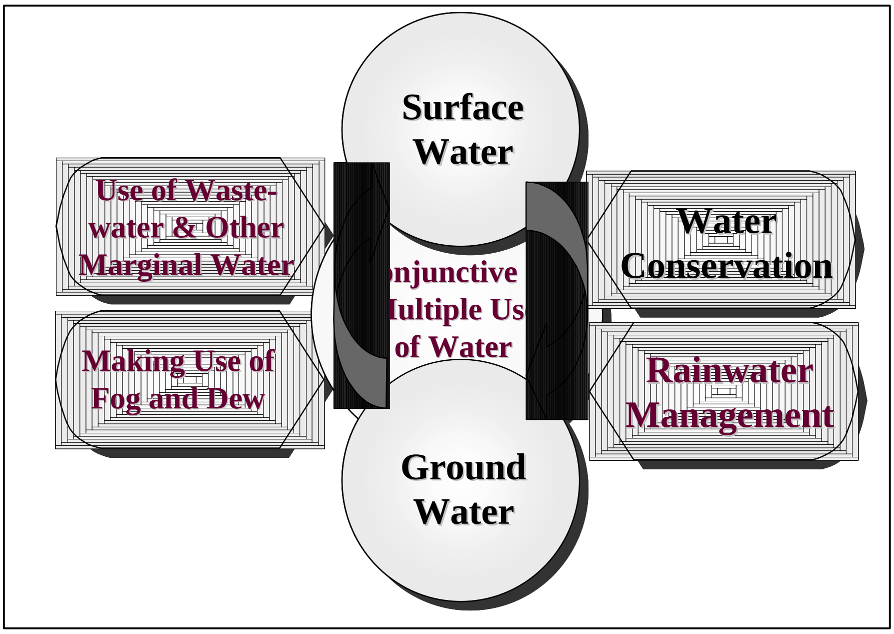

Fig 1: Water Conservation has to be an integral part of every "Integrated Water Resources Management" system

- Surface- and groundwater have to be used in a **conjunctive way**.
- The **multiple use of water** ("using every drop of water four times before draining it") is essential to cope with future water demand.
- **Rainwater management**: Rainwater management can be either "in-situ moisture conservation" or "**Water Harvesting**". Water Harvesting is defined as "the collection and concentration of rainfall (and overland flow) and its use for the irrigation of crops, pastures and trees for domestic and livestock consumption". The water storage can be done in the soil matrix or in a reservoir (Prinz and Wolfer 1998).
- Rain and surface runoff management serves also the purposes of **soil conservation, –** a prerequisite for water conservation-, and **flood control**.

- ❖ The use of waste water, drainage water and other **marginal water sources** becomes more and more imperative to cover the demand. It is one of those measures which need very close supervision to avoid damage to soils and plants – at least on a long term.
- ❖ Wherever the natural conditions allow it, the use of **fog and dew** should be promoted to cover agricultural water demand.

Besides these supply side measures we have a wide variety of water **demand management measures**, which can be grouped into:

- ❖ Measures to **reduce losses**, and
- ❖ Measures **to increase the efficiency** of water applied.

As these demand side measures are regarded as the core measures of water conservation, water conservation is often defined as "measures designed to promote **efficient use** of water and to **eliminate waste of water**".

The term "**efficient use of water**" is a very critical one: The efficiency might be defined as " unit of water used by crops to produce one unit of dry matter" or "…to produce one unit of harvested produce".

When water is in short supply, farmers are very much interested in increasing the efficiency by limiting unproductive water losses (evaporation from soil, surface runoff, seepage). Even if the farmers can increase the efficiency per unit water available in their fields, this does not necessarily improve general, regional water efficiency.

Reduced seepage e.g. means a lower recharge of groundwater, less surface runoff means reduced surface water flows and fewer opportunities for using water further downstream, including less water supply for river valleys and wetlands. Therefore, we have to distinguish between **recoverable water losses** and **unrecoverable water losses**; the latter ones are those quantities of water lost to the atmosphere, to saline aquifers or to the sea.

When looking at water conservation measures (Figure 2), we might distinguish between **three groups of measures.**

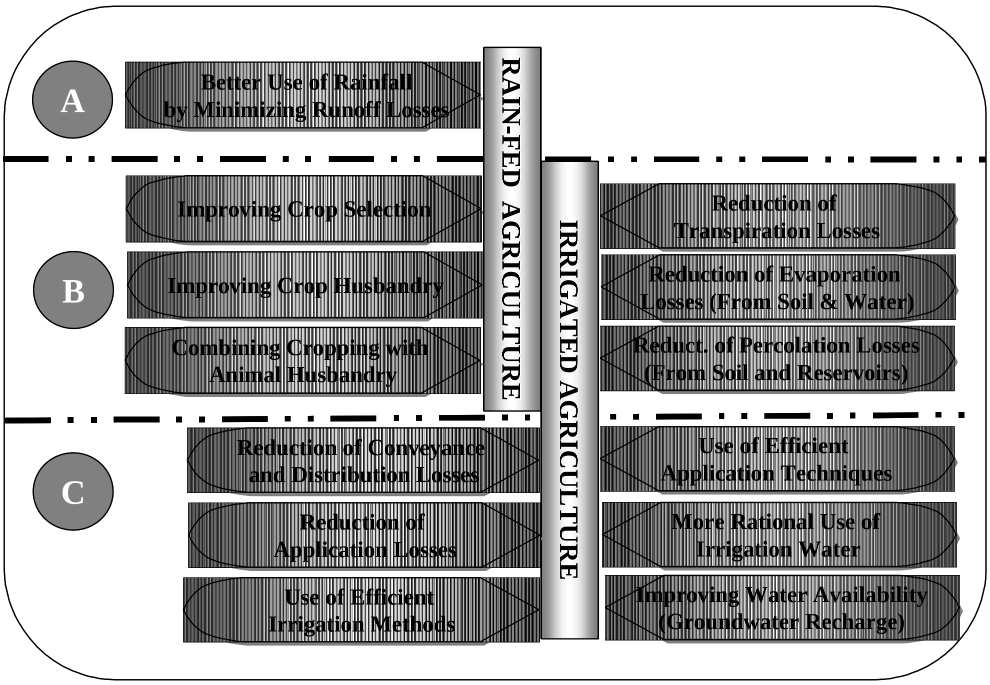

Fig. 2: Groups of measures to be applied in water conservation either in rain-fed cropping (A), in irrigated agriculture (C) or in both sectors (B)

A: measures are only applicable under **rain-fed agricultural** conditions
B: measures which are relevant to save water as well as in **rain-fed** agriculture as well as in **irrigated agriculture** and
C: measures which are relevant in **irrigated agriculture** only.

MEASURES IN RAIN-FED AGRICULTURE ONLY (A)

Globally, rain-fed agriculture is practised on 83% of cultivated land and supplies more than 60% of the world's food (FAO 2001). In–situ water conservation, often combined with water harvesting measures, can contribute significantly making better use of the rain in dry areas to supply the crops during the rainy season with sufficient water. One element of in-situ moisture conservation is the curbing of **runoff losses**, which can amount to **30-50% of rainfall** on sloping grounds.

Runoff losses can be minimized e.g. by

- Tying ridges: A **tied ridge system** can double crop yields in semi-arid areas, while simultaneously preventing soil erosion. The water storing capacity in a tied ridge system amounts to 40-70 mm.
- Cultivating crops in **furrows**
- Construction of **earth basins** and **sunken beds** to cultivate crops in them. A very remarkable example is the Zay technique (Chritchley et al. 1992). Pits of 30 cm diameter are dug, 90 cm apart and 15-20 cm deep. An experiment in Niger showed a doubling of yield from 600 kg/ha on a (manured) field without Zay to 1200 kg/ha on fields with Zay pits (Fatondji at al. 2001).
- **Lines of stones** and trash, bunds and ridges
- **Contour farming** and **strip cropping** are also well established measures in soil and water conservation.
- The application of **Fanya Juu** techniques, catching the rain in uphill or downhill trenches and inducing the establishment of terraces over a longer period.
- Construction of **ditches and basins** to retain water in the field
- Construction of the various kinds of **terraces**; level terraces with lips and reverse sloped terraces are being the most efficient ones.

MEASURES BEING APPLIED AS WELL FOR RAINFED AGRICULTURE AS FOR IRRIGATED AGRICULTURE (B)

Improving crop selection

It is well established, that different crops need rather different quantities of water to produce a yield. Rice, e.g. is a very water intensive crop, using twice as much water per hectare as wheat (FAO 2001). When farmers decide to switch from **rice** cultivation to any so called **upland crop**, this will save substantial amounts of water. But the cultivation of less water demanding crops than rice is not the only measure suggested in this respect:

- using **crops of high water use efficiency**
- using well adapted, high yielding varieties; short – strawed wheat gives double or triple yield per unit water in comparison to the traditional varieties.

Improving crop husbandry

In areas with a short rainy season, the **right timing** of the crop is a decisive feature, as well as the type of cropping, e.g. relay or sequential cropping.

A high water use efficiency can only be achieved if all the other growth factors are kept **near the optimum**. Important elements in this respect are:

- nursery techniques with optimal water supply, but little percolation
- optimal seeding density and seeding methods, e.g. "**dry seeding**"
- the optimal association of crops
- **crop protection**, to avoid any suffering of the crops from pests and diseases
- supply of **nutrients**, i.e. the manuring and applying mineral fertiliser
- timely **weeding** of the crop to avoid water losses by unwanted plants.

Figure 3 shows an example of water production function for maize under Kenyan conditions, illustrating the dependency of the yield level under given rainfall conditions from the level of management.

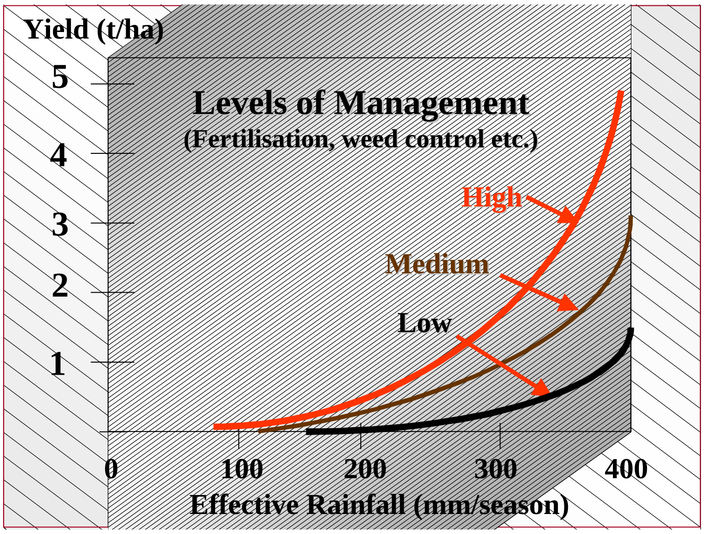

Fig.3: Water-production function for maize in Machakos District, Kenya.
Source: Beets 1990

Combining cropping with animal husbandry

According to Cape (1995) it needs 700 l of water to produce one litre of **milk**. This water, of course, is needed to produce fodder plants and one kg of alfalfa hay needs roughly 600 l of water. The combination of cropping and raising animals, e.g. cows, can be very water efficient as can be the cultivation of fishes in rice fields (**aquaculture**).

Reduction of transpiration losses

Transpiration of plants counts for the largest share of the water used by a crop stand. The high evaporative demand of the atmosphere determines largely the amount of water lost by transpiration. If the air suction is higher than the water supply of the plant, the closing of the leave pores (stomata) is a counter measure, but a measure which lowers productivity. The grower can interfere by two means: (1) by **reducing wind speed**, e.g. by planting shelter belts and (2) by planting crops in greenhouses (Figure 4) or in plastic tunnels. Measure 2 is the cultivation of crops under **shade** trees or in shade houses. The **breeders** have already succeeded in breeding a number of new grain varieties with lower transpiration rates per kg of dry matter produced.

Reduction of evaporation losses

According to Hudson (1987), shading the water surface can substantially reduce the evaporation losses. The more of less unproductive evaporation from soil and water surfaces should be reduced wherever possible. Under irrigation, the evaporation losses depend strongly on the irrigation method and technique applied. Sprinkler irrigation e.g. wets all surface whereas under drip irrigation the wetted surface remains rather small. Proven **measures** are e.g.:

- The application of **mulch** layers of organic origin or as plastic mulch
- The use of certain cover crops, which need less water for transpiration than they save from evaporation
- The use of **conservation tillage** which disturbs to a lesser degree the ground, but disturbs the capillary rise of the water to the surface.

- Various systems of **agro-forestry** produce shade and reduce temperatures for the annual crops grown below. **Shade trees** often belong to the Leguminosae family.
- Contour hedges and shelter belts **reduce wind** speed.
- As already mentioned, greenhouses and tunnels reduce not only transpiration but also significantly the evaporation from the ground.

Fig.4: Tomato cultivation using the bag culture technique with drip irrigation in a greenhouse in S. Tunisia. Evaporation is minimised and transpiration losses are reduced. Drip-irrigation is employed in less that 1% of the world's irrigated area but the potential for efficiency increases is enormous.

Open water surfaces can be only marginally protected from high wind speeds or high temperatures. Fatty alcohols can be sprayed on water surfaces as **evaporation retardant** (UNEP 1998). About 50 mg /m^2 per day of the chemical are required and can result in the saving of **30%** of the daily loss of water due to evaporation. Floating material has being used, too, but there are still too many drawbacks related to those measures, and therefore the implementation was very slow until now.

Reduction of percolation losses

Percolation losses occur as well under rain-fed agriculture as under irrigation, from soils to groundwater layers as well as from ponds and reservoirs to deeper layers.

Applying the right quantity of water and wetting only the root zone would be optimal, but this is technically often not feasible. To improve soil management in regard to water efficiency, the following **measures** are recommended:

- Improving rain water intake by keeping an **open soil** surface, by **mulching** with organic material and by keeping a high organic content in the soil and a good soil structure.
- Improving soil **water holding capacity** by keeping a high level of soil fertility (high percentage of organic material, good structure etc.)
- Avoiding **compacted layers**, e.g. a plough pan, allowing water to reach deeper soil layers and to increase the wetted soil volume
- **Optimising the root environment**: A soil environment is optimal for plant growth, contributing to a high water application efficiency, if it is deep enough, if the soil is well structured and well supplied with nutrients, if it contains a high water storage capacity, has no hard pans or stone layers, has no salt and toxic element accumulation and has no drainage problems.

MEASURES APPLIED IN IRRIGATED AGRICULTURE (C)

Worldwide, about 60 percent of global food is produced under rain-fed conditions without any irrigation. But irrigation water, if in ample supply, reduces considerable the risk of production and allows yields double as high as the yields which can be obtained from rain-fed agriculture (FAO 2001). Roughly 40% of the food is produced on irrigated land, on **17%** of the total cultivated land. The water needed for crops amounts to **1000 – 3000 m^3 per ton** of cereal harvested. With other words, it takes one to three tones of water to grow 1 kg of rice.

As mentioned before, the **losses** of water have to be covered as well as number of measures to **increase the efficiency** of water use in irrigation.

Reduction of conveying and distribution losses

33-50% of water diverted for irrigation is lost 'en route': The **conveyance and distribution losses** are enormous. By lining the canal system or by conveying the water in pipes, these losses can be significantly reduced. It should be kept in mind, that at least the seepage losses are **not** unrecoverable losses, but might be lifted up from the groundwater layer downstream.

Reduction of application losses

Application losses are either surface runoff losses or percolation losses, often summarised as "**operational losses**". The water applied, should be sufficient to wet the volume of root penetration, but should not go beyond. Numerous technical means are available to apply exactly the amount of water needed, but financial and labour problems, in large irrigation schemes also **management problems**, hinder this.

Use of efficient irrigation methods

The large differences in water efficiency between the various irrigation methods are quite well known: Traditional surface irrigation generally achieves only around 40% efficiency, sprinkler irrigation can be 70-80 % efficient and drip irrigation might reach over 90% efficiency (Wolf and Stein 1998). Modern irrigation technology could in theory save about half of the water presently consumed in irrigation, but technical, economic and socio-cultural factors hinder the transformation of theory into practice. Wolf and Stein (1998) cite a study made in Israel by Hagan (1994), who found surface rrigation to be 70% water efficient but drip irrigation only 42-56%.

This deviation from generally believed figures is due to differences in the available underlying conditions. For the farms using surface irrigation, water was in very short supply and therefore it had to be used as efficiently as possible. Drip irrigation on the other hand has been used under conditions of sufficient water to grow crops of high market value. Low cost of water and high market prices did not give any incentive to the farmers to use water efficiently.

Of course there are many examples showing the high efficiency, e.g. of drip irrigation: in Maharashtra State in India the use of drip irrigation of pomegranates resulted in saving of about **44%** as compared to conventional check basin irrigation, with a further water savings of about 14% when compared to unmulched plots (Saksena 2000).

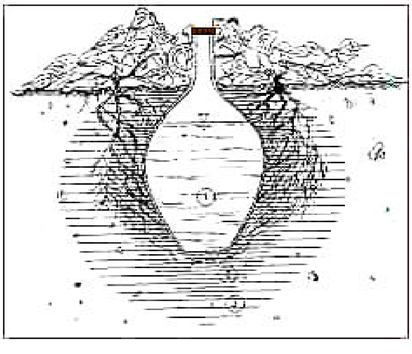

Fig. 5: **Pitchers** are a low cost, traditional irrigation technology, based on local manpower and know how and with a high water efficiency for garden crops (Prinz and Malik 2001)

Use of efficient application techniques

Within the various irrigation methods (surface, sprinkler, subsurface, drip and micro-sprinkler) there are application techniques which are more efficient than others. In furrow irrigation, e.g. surge irrigation can save considerable quantities of water. Surge irrigation is the practice of intermittently stopping and starting water flows across a field. LEPA stands for Low Energy Precision Application and is a very water efficient form of application of water under pivot irrigation systems. The water is applied near the ground surface below canopy.

In drip irrigation some techniques were developed which are not as efficient as the more costly ones, but which allow even small farmers a very high efficiency e.g. in vegetable cropping: the **drip bucket irrigation** is such a low cost and relatively efficient technique, applied already on thousands of farms in East Africa (Prinz and Malik 2001).

More rational use of irrigation water

Supplemental irrigation (SI) is the application of small quantities of irrigation water to a rain-fed crop in times when the demand can not be covered by rainfall (Oweis 1997). SI is usually practiced usually in the wetter part of the dry areas with 300 to 600 mm annual rainfall (Oweis et al. 2001). Supplemental irrigation might be taken from groundwater or from excess water stored during the rainy season. Another technique which allows a very high water use efficiency under fully irrigated conditions is **deficit irrigation**. The deficit irrigation is the distribution of limited amounts of irrigation water to satisfy essential water needs of plants. The water supply is reduced in less critical periods of water demand by the crop and supply of full amount of water during stress-sensitive periods. A similar technique is the “intermittent submerged irrigation technique" for rice (ISI). This technique has been promoted in China but it is now applied in many rice growing areas world wide. Up to 20% of the irrigation water can be saved, if the paddy crop is not grown under submerged conditions through out the main growing season, but only intermittently. The phases where submerged conditions are recommended are those “sensitive” stages mentioned earlier.

Improving water availability

As mentioned earlier, aquifer depletion is a common problem in many dry areas of the world. Many techniques have been developed to artificially recharge aquifers to sustain the water table and to allow further control of pumping water to cover the water needs of humans and crops. One interesting example of combined basin irrigation with groundwater recharge is reported from Uttar Pradesh Province in India (IWMI, 2002). In the monsoon season, surface water is diverted through an unlined canal system to provide farmers with irrigation water for rice crops. Around 60% of the irrigation water applied is used by the plants, most of the remaining 40% filters through the soil to recharge the groundwater. Combined with seepage from unlined canals those “losses” provide farmers with groundwater to irrigate dry season crops. The research showed, that the water table in the study area, which had been progressively declining, has been raised from an average of 12 m below ground level to an average of 6,5 m.

CONCLUDING REMARKS

Important **socio economic factors** of water conservation are:

- Population stabilization reduces also pressure on water resources.
- Community involvement is essential for effective water conservation.
- Access to water can be viewed as a human right, therefore a fair distribution should be aimed for.
- Water conservation should benefit from a multidisciplinary team.
- Preference should be given to the application of nonstructural solutions, for example pricing of water.
- To develop water conservation institutions, public education and awareness are essential.

- ❖ Selection of appropriate low cost technology is a prerequisite for widespread implementation.
- ❖ Planners should consider both traditional and modern technologies.

Criteria to select water conservation measures are according to Emerson (1998):

***** program costs,
***** ease of implementation,
***** staff resources and capability,
***** rate payer impacts,
***** water rights and permits,
***** regulatory approvals,
***** timeliness of savings, and
***** cost-effectiveness,
***** budgetary considerations,
***** environmental impacts,
***** environmental and social justice,
***** legal issues or constraints,
***** public acceptance,
***** consistency with other programs.

Lessons learnt from various projects are e.g., that the adoption of a new irrigation system depends on farmer's capacity to finance and operate it, as well as on the type of crop being produced.

A modernised surface irrigation might be a better water saving technique than drip or sprinkler irrigation in certain locations; the latter ones are often not affordable. A modernised 'old' system is also more easily adopted by farmers since it is closer to traditional practices.

FUTURE OUTLOOK

FAO expects that the area of land being irrigated in a large number of developing countries will continue to increase until 2030 and if farmers apply improved water management techniques to increase efficiency, **an increase of 34 % in irrigated land can be achieved using only 12 % more water** (FAO 2001)**.** To accomplish this, farmers will have to be more efficient in their use of water, learning to produce more crop per drop. If this is achieved, no major water crisis should affect irrigated food production at the global level and future demand for irrigation water beyond 2030 is expected to continue to slow as world population growth also slows.

- ❖ Water conservation policy to be effective, must include both water quantity and quality in the water conservation programme (Emerson 1998).
- ❖ Efficiency, economy and equity in water use can be ensured through cooperative management of watersheds and command areas.
- ❖ Conjunctive use of water, including water harvesting and water conservation should be promoted combining also traditional and new methods.
- ❖ Strong efforts are needed to transfer the huge amounts of flood and excess rain/runoff water from the rainy season to the dry season. Storage media are aquifers or reservoirs, to a lesser extent the soil matrix. Water conservation measures can provide valuable tools to make best use of this water.
- ❖ Sustainable groundwater exploitation (e.g. through qanat systems) should be supported and deep drilling, aquifer over-exploitation and aquifer polluting should be prosecuted.
- ❖ National and international organizations should promote the dissemination of successful case-studies between countries to avoid or minimize duplication, to avoid repetition of mistakes, and to enhance collaboration between users.

Future research fields will include biotechnology, bioengineering and plant breeding which should be employed to arrive at species and varieties with a significant lower water demand. Future research should be multidisciplinary.

To achieve optimum water conservation & improved water use efficiency, a water conservation enabling environment is needed that includes (Fig. 6):

(1) education and training, improvement of systems and public incentives: these measures might allow in increase in further 20 %
(2) irrigation management transfer to users, management of supply infrastructure and an optimised resource policy to arrive at 60 % of the potential;
(3) further research of the public and the private sector to utilise fully the whole available potential.

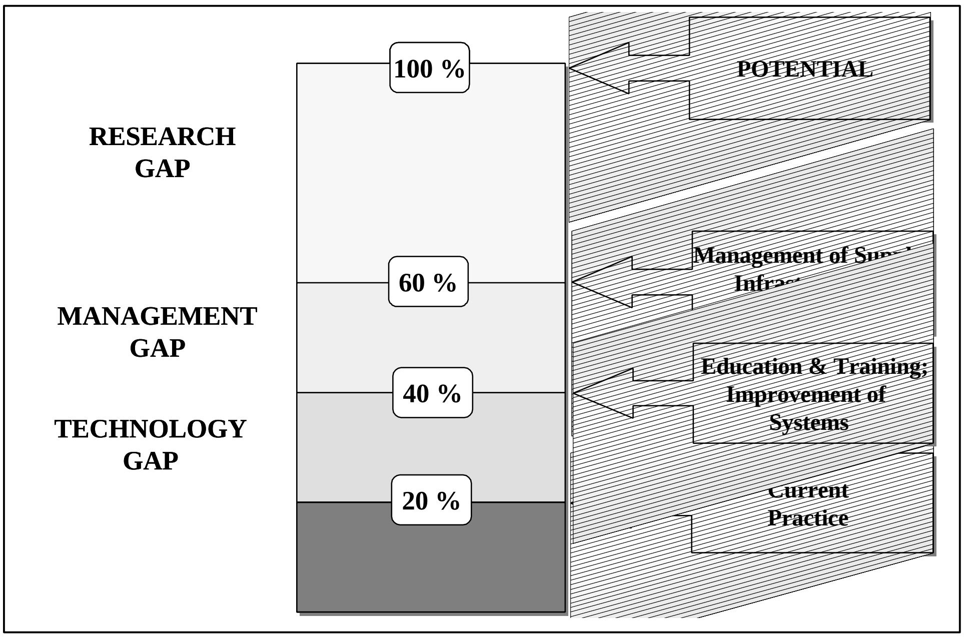

Fig. 6: Ways of making better use of production potential.
Source: Wolff & Stein 1998 (redrawn), based on Cape 1995 (Original data based on Australian conditions)

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ANNEX

Case study: Drip Irrigation Systems (DIS) in India (Saksena 2000)

Drip Irrigation Systems in India are being praticised since 1970, being used on a limited scale in Tamil Nadu, Karnataka, Kerala and Maharashtra States, mainly for high value, horticultural crops like coconut, coffee, grape and vegetable production without the benefit of any subsidies from the governments. At Rahuri, in Maharashtra State, the use of **drip irrigation of pomegranates, grown in gravely soils, resulted in a savings of about 44% (as compared to conventional check basin irrigation systems)** with a further water savings of about 14% when compared to un-mulched plots.
The capital costs involved are high compared to conventional irrigation systems, but the labor and operational costs are low in India. **The net result is that the benefit-cost ratio for DIS is very favourable compared to conventional systems since the payback period for investment very short.** The cost of using drip irrigation system is summarized in the table 1.

With DIS in India, there was an improvement in **crop yields and savings in water use of between 18% and 40%.** Consequently, there was a **substantial improvement in the water use efficiency** that ranged up to three times that of conventional surface irrigation methods, even with the use of poor quality irrigation water. See table 2 for w**ater savings and increased yields achieved using drip irrigation in Indian case.**

Tab. 1: Drip irrigation cost, water savings v. increased yield achieved in India

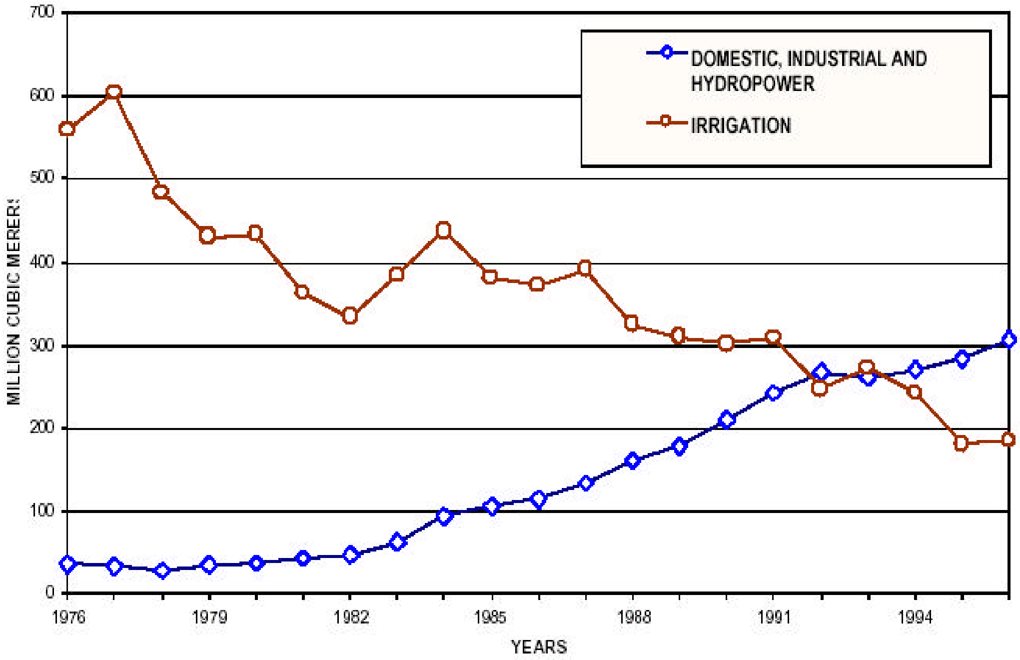
Crop	**Sugar-cane**	**Bananas**	**Citrus**	**Grapes**	**Pomegr-anates**	**Guavas**	**Apples**	**Mosam-bi**	**Ground-nuts**	**Tomat-oes**
% Saving of water	50	50	50	65-70	50-55	55-60	50-55	60	35	30
% increase in yield	35	50	50	30	30	25	20	50	20	50
Cost US $	715	1150	575							
Payback period (months)	18	2	12							

Source: (Saksena 2000)

Case study: Growing More Rice with Less Water (China)

One method to save water in irrigated rice cultivation is the intermittent (submerged) irrigation. This example shows real water saving and increase of production. Production levels remained stable over the time period in spite of this massive shift of water (see Tab. 2) out of agriculture. Growing more rice with less water improves also the productivity of water was made possible through policy, management, and technological changes (Fig.1) (Rijsberman, F. R., 2001).

Fig. 1, Growing more rice with less water improves also the productivity of water was made possible through policy, management, and technological changes (Rijsberman, F. R., 2001).



Tab. 2 Changes in land and land productivity in Zhanghe Irrigation District, China (1966-

Period	Annual irrigated area (10^3 h)	Rice crop production (tons 10^3)	Rice yield (T/ha)	Rice water productivity (kg/m^3 water supply)
1966-78	139	561	4.04	0.65
1979-88	135	905	6.72	1.17
1989-98	118	920	7.80	2.24

Source: Rijsberman, F. R., 2001

SOURCE: Prinz, D. & Malik, A.H (2002). More Yield with Less Water – How Efficient Can be Water Conservation in Agriculture ? Proceedings, 5th Internat. EWRA Conference on Water Resources Management in the Era of Transition, Athens, Greece, 4-8 September 2002 (in print)