WATER CONSERVATION IN IRRIGATED AGRICULTURE - PROVEN MEANS AND METHODS

Prof. Dr. Dieter PRINZ & Dr. Amir H. MALIK

c/o *Institute of Water Resources Management, Hydraulic and Rural Engineering, Dept. of Rural Engineering, University of Karlsruhe, D-76128 Karlsruhe, Germany. e-mail:* prinz@iwk.uka.de

Abstract

In irrigated areas as well as in dryland agriculture it becomes more and more imperative to look for water conservation measures, defining water conservation as "any beneficial reduction in water losses, waste or use". There are a number of proven water conservation means and methods used in agriculture. One group of them is concerned with ***avoidance of losses*** *i.e. losses in conveyance and distribution, in application of irrigation water, of evaporation losses from water and soil surfaces and of percolation losses from soil and water bodies. In larger irrigation schemes the conveyance losses alone sum up 30-50% of the total water demand. Evaporation losses from soil surfaces can be minimised by mulching and shading. The minimising of transpiration losses is of lower importance, with the reduction of wind speed and the shading of crops being the most important techniques to reduce transpiration.*

An ***increase in efficiency*** *in irrigation water application can be accomplished by a more rational use of water e.g. in "supplemental irrigation" or "deficit irrigation". Further-on, farmers can apply more efficient irrigation methods like trickle irrigation, subsurface irrigation or pitcher irrigation. Improved application techniques like surge irrigation have also shown a great potential to increase water productivity in irrigation. Other techniques improve the water retention within a field, allowing better infiltration and water storage in the soil matrix. The water storage capacity of soil can be improved by incorporation of organic matter and deepening the root zone.*

"More yield with less water" can be achieved to a very large extent by applying ***appropriate methods and techniques in irrigation management.*** *To arrive in reality at an efficient water use, the appropriate* ***means*** *like a supporting* ***water policy, suitable commodity prices*** *and* ***positive attitudes*** *as well as a* ***sound knowledge*** *of the farmers concerned are of major importance.*

Keywords

Water conservation, water efficiency, irrigation methods, irrigation management

1 INTRODUCTION

The drier parts of the tropics and subtropics, but also countries in temperate climates, experience severe water supply problems. **Agriculture** utilizes globally about 70 % of all the water managed by man, and about 80 % of the water used in the developing world (Brown 2001, Prinz 2000). At the same time, the competition between the various sectors – agriculture, communities, tertiary sector and industry 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, Postel 1985, Postel 1999). But it is not only a problem of water quantity, but of quality due to increasing pollution, too. Further on, it is a question of nature conservation, as sufficient quantities have to be left for "nature" to avoid the drying out of rivers, wetlands and lakes causing heavy strain on biodiversity and aggravating the problem of loss of species worldwide.

2 OVERVIEW

The water needed for crops amounts to 1000 – 3000 m^3 per ton of cereal harvested. With other words, it takes up to three tons of water to grow 1 kg of rice. Lowering these amounts can either be achieved by **reducing losses** or by **increasing efficiencies.**

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. **Recoverable losses include:** seepage, surface runoff, operational losses and losses due to deep percolation.

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.

Worldwide, irrigation is on average 37% efficient; the average in the United States is around 50% (Pimental, et. al., 1997; Postel, 1985).

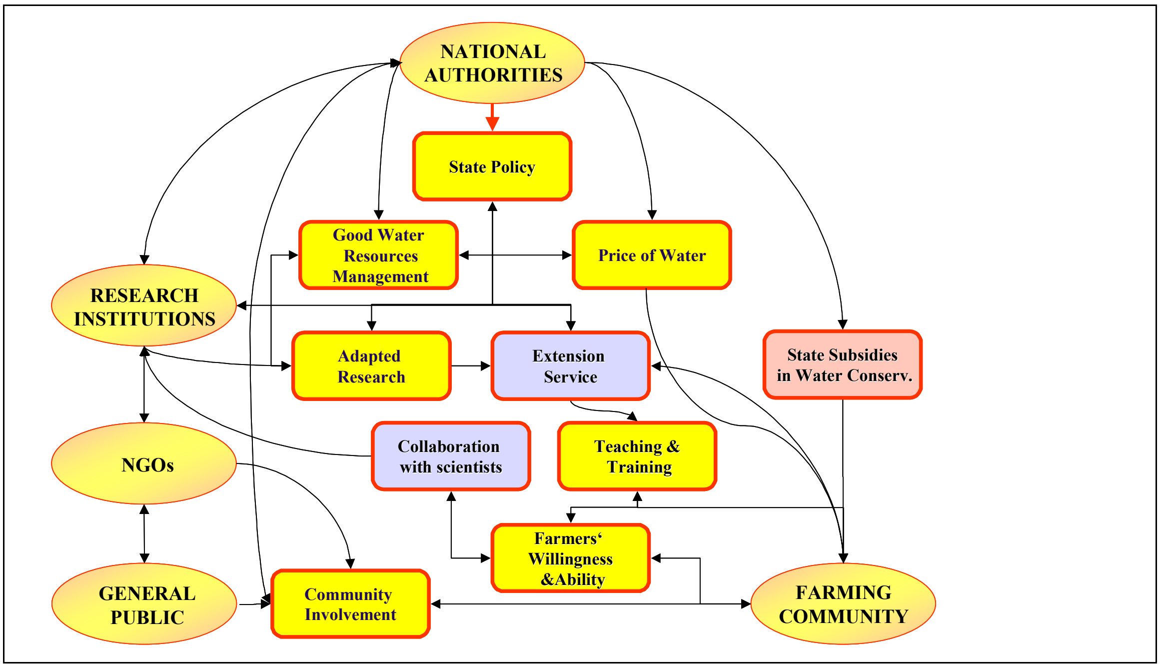

Fig. 1: Main actors and means in agricultural water conservation

As shown in Fig. 1, the **main actors** in agricultural water conservation are (1) the state and the national / regional authorities, (2) the farming community, (3) the general public and the (4) non-governmental organizations (NGOs), aside of (5) the various public and private research institutions including universities.

Their **means** to put water conservation directly and indirectly into practice are:

- A state policy which favours water conservation and which puts much more stress on **demand management** than on supply management of water.

- A wise state policy fixes the **price of water** in such a way that water is still affordable for the poorest part of the population, but avoids wastage of water in all sectors, including agriculture. In most cases a split price or a staggered price system is best suited.

- A good **water resources management** at all levels – from national over regional to local levels – gives incentives for an efficient water use, avoids pollution of surface and groundwater and is directed towards conjunctive and multiple use of water.

- The **research institutions** keep contact with the extension service and the farming community to carry out adapted research for water conservation at all levels. The research institutions are supplied with sufficient financial means by the state or private industry.

- The **extension service** keeps close contact with the farming community, offers teaching and training at all levels of water use and utilizes the results of adapted research, supplied by the various research institutions.

- **Farmers' willingness** and ability are pre-conditions for any success in water conservation. This includes collaboration with the extension service and with scientists doing adapted research.

- The state grants **subsidies** for efficient water use and water conservation to the farming community. State subsidies e.g. can be granted for a change in irrigation method applied, e.g. the change from surface irrigation to trickle irrigation.

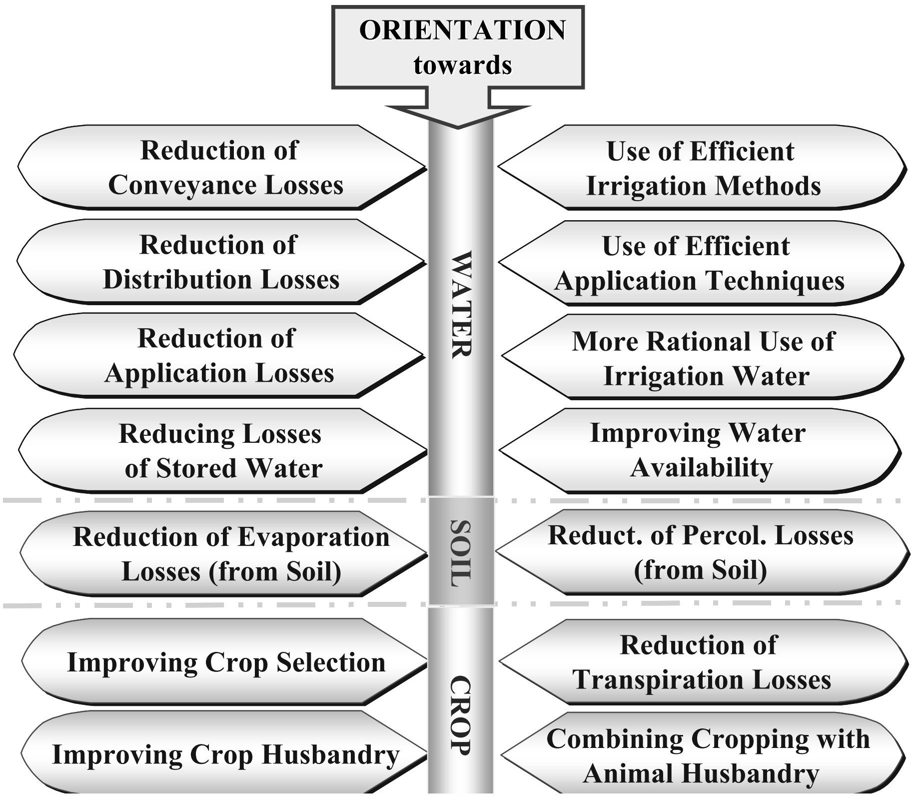

Fig. 2: Water conservation methods used in agriculture, directed either towards loss reduction or increase in efficiency of water use

- The **general public** is interested in topics of efficient water use and, supported by **NGOs** and research institutions, is involved in activities to promote water conservation.

There are a number of important water conservation **methods** used in agriculture; they are oriented either towards ‘water’, ‘soil’ or ‘crops’. One group of them is concerned with **avoidance of water losses, e.g.** (1) in conveyance and distribution, (2) in application of irrigation water, (3) of stored water, (4) of evaporation from soil, (5) of deep percolation from soil and (6) reduction of transpiration. **Other methods and techniques to conserve irrigation water** deal with (1) use of efficient irrigation methods, (2) use of efficient water application techniques, (3) more rational use of irrigation water, (4) improving water availability to crops, (5) improving crop selection, (6) improving crop husbandry and (7) combining cropping with animal husbandry (Fig. 2).

Fig. 3 gives some overview over the main losses in large scale irrigation schemes (average figures, taken from different case studies) and shows some of the most promising techniques to reduce those losses and to reach the higher water irrigation efficiency.

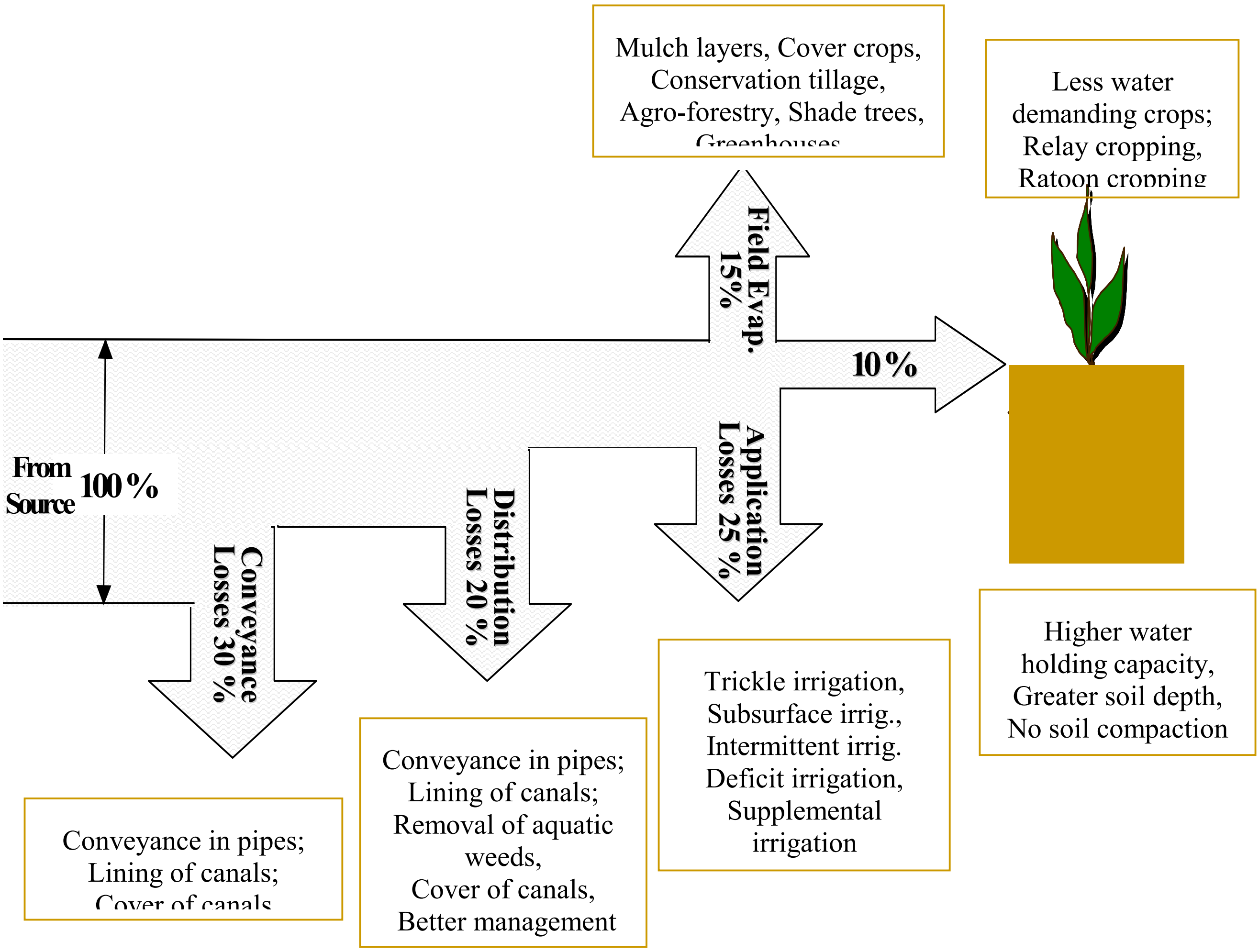

Fig. 3 : Average losses in large irrigation schemes and techniques to arrive at a higher irrigation water efficiency

3 HOW TO AVOID IRRIGATION WATER LOSSES

3.1 Conveyance and distribution losses

The conveyance and distribution losses in unlined irrigation systems are often enormous: on average, 33-50% of water diverted for irrigation is lost 'en route'. In large irrigation systems, losses from canals may even exceed 50% of total water conveyed, especially when the canals are covered by phreatophytes. By lining and covering 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 in most cases recoverable losses; the water might be lifted up from the groundwater layer downstream.

. The questions which arise in regard to seepage losses are the following:

- What quantities of water are lost?
- Are these losses easy to recover?
- What feasible lining methods could be used?
- How high are the costs of lining and of maintenance?
- What are the benefits of the saved water?
- Could the unlined canal be used in the rainy season to recharge an aquifer?

3.2 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.

Operational losses depend on

- the chosen distribution system,
- the available regulating and mechanical facilities and
- the skill and discipline of the operator.

Practices being promoted to decrease application losses include: application of improved irrigation methods and techniques, land-leveling, straw mulching, improved scheduling methods, and tailwater re-use systems.

3.3 Stored water losses

Surface storage capacities are developed to overcome dry period water scarcities, but high evaporation and percolation losses reduce the value of ponds and other surface reservoirs. Tall trees decrease wind speed and reduce evaporation of small reservoirs. A favourable ratio between surface stored volume and the surface area of the surface water body contributes to a minimization of losses. There is a trend to store more water underground in near-surface aquifers, but a suitable hydro-geological setting is a precondition.

3.4 Evaporation losses (from soil)

Shading the surface can substantially reduce the evaporation losses. The more of less unproductive evaporation from soil surfaces should be reduced wherever possible (Hudson 1987). Proven measures are e.g.:

- The application of **mulch** layers of organic origin, gravel mulch or 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 than conventional tillage, but reduces the capillary rise of 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.
- Greenhouses and tunnels reduce not only transpiration, but also significantly the evaporation from the ground.

3.5 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 used for 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 four means: (1) by reducing wind speed, e.g. by planting shelter belts, (2) by planting crops in greenhouses or in plastic tunnels, (3) by cultivation of crops under shade trees or in shade houses and (4) by breeding or genetic engineering: The breeders have already succeeded in developing a number of new grain varieties with lower transpiration rates per kg of dry matter produced.

4 METHODS AND TECHNIQUES OF IRRIGATION WATER CONSERVATION

4.1 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 to 60% efficiency, sprinkler irrigation can be 70-80 % efficient and drip irrigation might reach over 90% efficiency (Wolf and Stein 1998, Fig. 4). 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. In some cases, traditional techniques like pitcher irrigation are best suited for local farmers' needs.

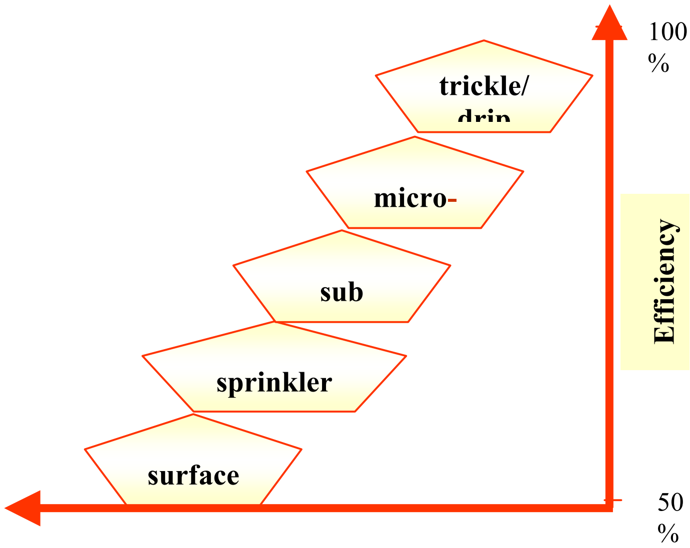

Fig. 4: The five basic methods of applying water to the soil

These methods are arranged according to their average efficiency.

4.2 Use of efficient water application techniques

Within each of the mentioned irrigation methods there are techniques of higher water efficiency. One of them, applied in surface irrigation, is '**surge irrigation**'. It has shown to markedly improve the efficiency of water application. It is the practice of intermittently stopping and starting water flows across a field (Fig. 5)

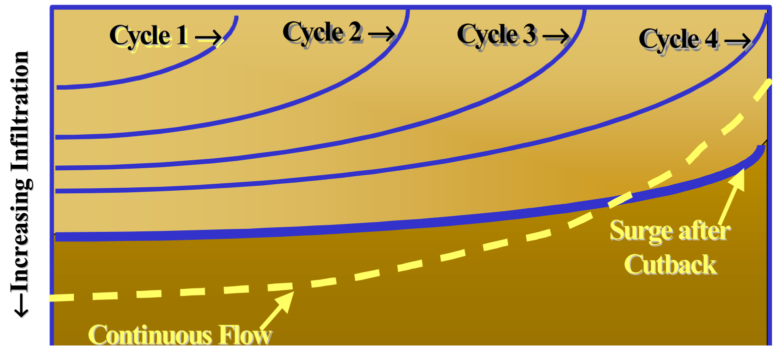

Fig. 5: Surge irrigation: Water percolation in surge and continuous flow

Center pivots are one of the most efficient irrigation technologies available. With "Low Energy Precision Application (LEPA)", where the water is applied near the ground surface below canopy, their efficiency can beeven more increased.

But the use of a **pivot irrigation** system guarantees by no means a high water efficiency: Al Rumikhani (2002, pers. communication) reports on a survey done in Saudi Arabia in an area with more than 2,500 centre pivots of different sizes, covering roughly 1,500 ha of irrigated land. When applying the **Penman-Monteith equation** it was detected that the pivots applied roughly **double the needed amount** of water. In this case, the technology was available, but the water management was deficient to arrive at a higher water efficiency.

Drip/trickle irrigation is among the most efficient irrigation methods. It is characterized by the following:

- low flow rate,
- long duration irrigation,
- frequent irrigation,
- water applied near or into the plant's root zone,
- a low-pressure delivery systems,

Significant water savings can be achieved, but the high investment costs and maintenance demand prevent a large scale implementation.

Therefore, a drip irrigation technique was developed, which is not as efficient as the conventional ones, but which is cheap enough to be installed by small farmers e.g. in vegetable cropping: The **bucket drip irrigation** (Fig. 6) is, already applied on thousands of farms in East Africa (Prinz and Malik 2001).

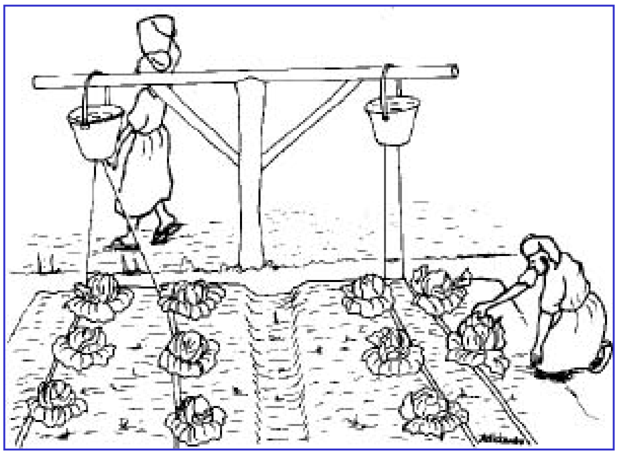

Fig: 6: Bucket drip irrigation system

4.3 More rational use of irrigation water

Often the irrigation method or technique is of lower importance than the management of water use. Two examples of a more rational use of water are discussed here: **Supplemental Irrigation** and **Deficit Irrigation.**

Supplemental irrigation (SI): is the application of small quantities of irrigation water to essentially rain-fed crops in times when the demand can not be covered by rainfall (Oweis 1997). SI is usually practiced in the wetter parts of the dry areas with 300 to 600 mm annual rainfall in order to improve and stabilise yields (Oweis et al. 2001). Supplemental irrigation might be taken from groundwater or from excess water stored during the rainy season.

Deficit irrigation: Another technique which allows a very high water use efficiency under fully irrigated conditions is deficit irrigation. 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 and the full amount of water applied 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 other 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. Precondition for deficit irrigation management is the knowledge of the sensitive periods by the farmers or the irrigation managers.

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4.4 Improving water availability

The potentials of artificial groundwater recharge are by far not yet exploited. Many techniques have been developed to recharge aquifers to sustain the water table and to allow further pumping of 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.

4.5 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 demanding 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: Within each crop species there is a number of **high water use efficiencent varieties,** often well adapted, high yielding varieties. There are e.g. short – strawed wheat varieties which give double or triple yield per unit water in comparison to the traditional varieties.

4.6 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 other **factors** are kept **near the optimum,** such as

- ❖ **nursery techniques** with optimal water supply, but little percolation
- ❖ 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.

It is a proven fact, that, with proper management, it is possible to achieve irrigation efficiencies as high as 85% or even 90% (Hillel, 1987)

Fig. 7: Technological innovations, such as laser levelling, have improved water efficiency,

Photo source: http://lawr.ucdavis.edu/hsgg/concs.htm

Technological innovations, such as laser levelling (fig. 7), have improved water efficiency (Smith 1998).

4.7 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. feeding cows with crop residues, can be very water efficient as can be the cultivation of fishes in rice fields (aquaculture). Paddy cropping can be combined with fish raising if certain preconditions are given. This allows a multiple use of water and hence water saving per unit produce.

5 CONCLUDING REMARKS

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 (Prinz & Malik 2002).

- Water conservation policy to be effective, must include both water quantity and quality in a water conservation programme.

- 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.

- 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 duplication, to avoid repetition of mistakes, and to enhance collaboration between different 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 (Prinz & Malik 2002).

To achieve optimum water conservation and improved water use efficiency, a **water conservation enabling environment** is needed that includes (Prinz & Malik 2002):

1. education and training, improvement of systems and public incentives: these measures might allow increase in further 20 % water use efficiency

2. Irrigation management transfer to users, management of supply infrastructure and an optimised resource policy;

3. further research of the public and the private sector to utilise fully the available potential.

REFERENCES

Agarwal, A.: 2001, Increasing water harvesting and water conservation is the only way to ensure food security. Down to Earth, Vol 10, No. 3, June 30, 2001.

Brown, L. R.: 2001, How water scarcity will shape the new century, *Water Science and Technology* 43(4), 17-22.

Cape, J.: 1995, Irrigation Research: Past, present and future. Irrigation Australia Vol.10, 30-32.

FAO: 2001, Crops and drops: Making the best use of land and water. Food and Agriculture Organisation (FAO), Rome.

Hillel, D.: 1987, The efficient use of water in irrigation, principles and practices for improving irrigation in arid and semiarid regions, World BankTechnical Paper 64.

Hudson, N. W.: 1987, Soil and water conservation in semi-arid areas. Food and Agriculture Organisation (FAO), Soil Bulletin 57 pp.109-122.

IWMI.: 2002, A success story in reversing groundwater decline. IWMI Research Update, June 2002.IWMI, Colombo, Sri Lanka.

Khurana, I. and Khaware, R.: 1999, Punjab, is staring at an impending groundwater crisis., Down To Earth, Oc. 15, 1999.http://www.punjabilok.com/misc/environment/parched_pun.htm

Oweis, T.: 1997, Supplemental irrigation: A highly efficient water-use practice. ICARDA, Aleppo, Syria, 16pp.

Oweis, T., Prinz, D. and Hachum, A.: 2001, Water harvesting, indigenous knowledge for the future of the drier environments, ICARDA, Aleppo, Syria, 36pp.

Pimental, D. et al.: 1997, Water resources: Agriculture, the environment, and society, Bio Science 47 (2), 97-106.

Postel, S.: 1985, Conserving water: The Un-tapped Alternative, Worldwatch Institute, Washington, D.C.

Postel, S.: 1999, Pillar of sand: Can the Irrigation Miracle Last?, WW Norton, New York.

Prinz, D.: 2000, Global and European water challenges in the 21st century. Keynote Speech, 3rd Inter-Regional Conference on Environment-Water, "Water Resources Management in the 21st Century", 1-3 June 2000, Budapest/Hungary. Proceedings, p. 247 – 254.

Prinz, D. and Malik, A. H.: 2001, Water cconservation in agriculture, FAO Training Course, Draft Version on CD ROM, FAO, Rom.

Prinz, D. and Malik, A.H.: 2002, More yield with less water – How efficient can be water conservation in agriculture?. Proceedings, 5th Internat. Conference on Water Resources Management in the Era of Transition, Athens, Greece, 4-8 September 2002.

Rijsberman, F. R.:2001, Balancing water uses, water for food and water for nature. Thematic Background Paper, International Conference on Freshwater – Bonn 2001. International Water Management Institute (IWMI), Colombo, Sri Lanka.

Saksena, R.S.: 2000, Ministry of Water Resources, Government of India, New Delhi. http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8e/drip.asp

Smith D.I.: 1998, Water in Australia, Resources and Management, Oxford University Press, Melbourne.

Wolff, P. and Stein T. M.: 1998, Water efficiency and conservation in agriculture - opportunities and limitations. Agriculture + Rural Development; vol 5; no 2; pp 17-20; 8 ref.