

Crop Water Requirements and Water Productivity: Concepts and Practices

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Introduction

The most plausible means of mitigating the scarcity of water in different regions of the world is through increasing the productivity of existing water resources and produce more food with less water. Increase in water productivity provides a means both to ease water scarcity and to leave more water for other human and ecosystem uses. Irrigated agriculture underwent exponential growth over the past century- from 50 M ha globally in 1900 to 267 M ha in 2000. Similarly, the water use by crops- dominated by irrigation- saw a parallel rate of growth from about 40 cubic km to 3,700 cubic km during the same period. Most of the Asian countries use between 80-90 per cent of their developed water resources towards meeting the water requirements of the cultivated crops. These demands are likely to further enhance to satisfy the increasing food demands of very large and increasing populations. Projections of water demands of India for the year 2025 and 2050 as made by the National Commission on Integrated Water Resources Development (NCIWRD) and as worked out by IWMI are given in Table 1. Even with lower estimates projected by IWMI, there shall be substantial future increase in irrigation water requirements. The conditions are not much different in other countries in the Indus-Gangetic and Yellow River Basin of China.

Table 1. Projections of water demands in India under different sectors

Water Demand (km ³)	2000	Projections – 2025		Projections – 2050	
		NCIWRD demand	High IWMI* estimates	NCIWRD High demand	IWMI estimates
Irrigation	606	713	675(11.4%)	891	715(18.0%)
Domestic	15	63	40	111	91
Industrial	39	100	94	151	193
Total	660	876	809	1153	999
Difference with IWMI estimates			(-) 67		(-) 154

(*Source: Upali, Amarasinghe, IWMI; pers. comm.)

Crop Water Requirements

Crop water use, consumptive use and evapo-transpiration (ET) are the terms that are used interchangeably to describe the water consumed by a crop. Water requirement depend mainly on the nature and stage of growth of the crop and environmental conditions. Different crops have different water-use requirements under the same weather conditions. Hence the crop coefficients appropriate to the specific crops are used along with the values of reference evapo-transpiration for computing the consumptive use at different growth stages of the crop by water-balance approach. Crops will transpire water at the maximum rate when soil water is at field capacity. When soil moisture decreases, crops have to exert energy to extract water from soil. Usually, the transpiration rate does not decrease significantly until the soil moisture falls below 50% of field capacity. The evapo-transpiration (Etc in mm) of a crop under irrigation is obtained by the following equation:

$ET_c = K_c \times E_{to}$; where E_{to} is the reference evapo-transpiration and K_c is the crop coefficient.

Crop coefficient is dynamic in nature and varies according to crop characteristics, dates of (trans) planting, stage of growth and climatic conditions. Differences in crop coefficients also occur due to differences in crop height, crop roughness, albedos and soil and canopy cover. For practical reasons, different crop coefficients are assumed for following four stages of crop growth:

- i. *Initial stage*: Germination period and early growth of crop when the soil cover by the crop is less than 10%.
- ii. *Crop development stage*: The end of initial stage till the soil cover by the crop is about 70-80%.
- iii. *Mid-season stage*: From the end of the crop development stage to the start of maturing, for most crops this shall be beyond flowering stage.
- iv. *Late-season stage*: From the end of mid-season stage to the full maturity or harvesting.

Detailed procedure for computing the crop coefficients are given in FAO Irrigation and Drainage Paper- 24 on Crop Water Requirements. These values may be very general, and more specific values for important crops developed through weighing type lysimeters at CSSRI, Karnal are given in Table-1.

Table-1. Values of crop coefficients for different crops at Karnal, India

Crop	Crop growth stages				
	I	II	III	IV	Average
Wheat	0.50	1.36	1.24	0.42	0.87
Rice	1.15	1.23	1.14	1.02	1.14
Maize	0.55	1.00	1.23	0.67	0.86
Sorghum	0.53	0.82	1.24	0.85	0.86
Berseem	0.63	1.09	1.29	0.40	0.85
Sunflower	0.63	0.82	1.12	1.23	0.95

water is calculated through suitable measurements. The general water balance may be represented by the following equation:

$$\text{Irrigation} + \text{precipitation} = \text{Evapo-transpiration} + \text{surface run-off} + \text{sub-surface drainage} + \text{change in water contents}$$

Water balance components for important crops of the IG basin (Tyagi, 2006) are given in Table 2. The value of evapo-transpiration is estimated from the computed values. These values are generally for longer (seasonal/ annual basis) and should not be considered for short-term planning during the season.

Table 2. Water balance components for different crops

Crop	Irrigation, mm	Rainfall, mm	ETc, mm	Percolation, mm	Soil moisture depletion, mm
Rice	733.6	706.3	587.0	852.9	---
Wheat	251.5	106.4	337.6	20.3	---
Maize	100.2	659.5	334.5	270.4	---
Sorghum	221.2	488.4	495.2	224.8	---
Berseem	375.0	176.3	480.0	71.3	---
Sunflower	445.0	28.5	655.4	--	181.9

Deficit of water at any particular stage significantly reduces the potential yields of the crops and is more critical at the sensitive stages (Figure-3)

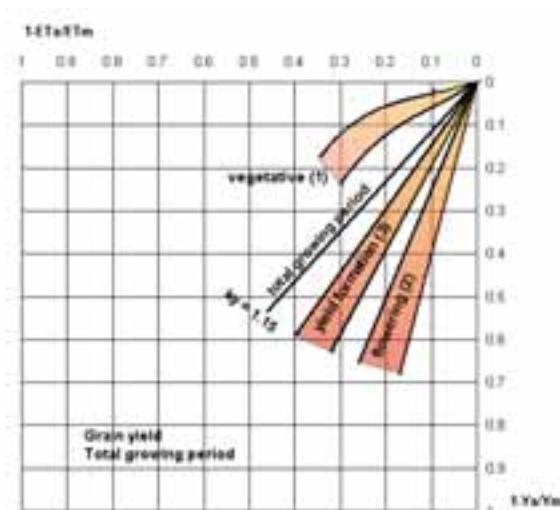


Figure 3. The relationships between relative yield decrease ($1 - Y_a/Y_m$) and relative evapo-transpiration deficit for the total growing period of spring wheat. (Source: FAO Manual 24)

Irrigation Scheduling for Crops

Once we know the crop water requirements, the most important step is to supply the right quantity of water at right time through an appropriate application method to satisfy the crop water requirements. This is called irrigation scheduling and serves the objectives of high yield of good quality, attaining high water use efficiency without any damage to soil productivity and applying water at a reasonable cost. Different criterion suitable for different objective functions are available for scheduling irrigation to the crops and the important ones include the following:

- i. **Crop Growth Stages:** Physiological stages of the crops are important criterion for irrigation scheduling to ensure good crop growth and yield. Commonly observed growth stages and the stages critical for irrigation for the important crops of the basin are given in Table 3. In case of a good rainfall around a given stage, the suggested irrigation should be avoided.

Table 3. Important physiological and critical growth stages of crops for irrigation

Crop	Physiological stage	Critical stage
Wheat	Crown root initiation (CRI), late tillering, late jointing, flowering, milk and dough	CRI and flowering
Paddy	Early tillering, panicle initiation, flowering, milking and dough	Early tillering and flowering
Maize	Early vegetative growth, tasselling, silking and dough	Tasselling and silking
Sugarcane	Sprouting, tiller initiation, tillering and grand growth	Sprouting
Cotton	Branching, pre-flowering and boll formation	Pre-flowering and boll formation
Potato	Sprouting, stolonisation, stolon development; 20, 40, 60 and 80% of tuber weight	Sprouting and tuberisation
Groundnut	Emergence, flowering, pod formation and pod development	Flowering and pod development
Mustard	Vegetative growth, flowering	Flowering

- ii. **Meteorological Indicators:** When soil moisture is not limiting, evapo-transpiration of a crop is controlled by the evaporative demand of the atmosphere. A simple ratio of Irrigation water (mm)/ Pan-evaporation (mm) since the previous irrigation has also been suggested as a means of scheduling irrigation. Based on this approach, optimum irrigation schedules for various crops have been developed.
- iii. **Plant Indices:** Some of the important plant characteristics have been found to have close relationship with water supply situations for the crops and have used for scheduling irrigation to crops. Some of the important indices include: canopy temperature, relative turgidity, stomatal pressure etc. but require very precise and continuous instrumentation.

When the farmers have adequate supplies of water as per demand (conjunctive use/ groundwater source), the aim is to achieve maximum yield per unit of land without wasting water. In case of limited amount of water, the aim is to maximize production per unit of water by rationalizing its distribution over the available land and also applying it at more sensitive stages of crop growth. Agricultural Universities and research institutes located in these basins have developed optimum irrigation schedules for important crops of the region and the same should be used for general guidance.

WATER PRODUCTIVITY

The great challenge for the coming decades will be the task of increasing food production with less water particularly in basins with limited water resources such as Indus basin and Yellow River Basin. Increasing the productivity in agriculture will play a vital role in easing competition for scarce resources, prevention of environmental degradation and provision of food security. Water productivity is dependent on several factors, including crop genetic material, water management practices and the economic and policy incentives to produce. In a broad sense, productivity of water refers to the benefits derived from use of water and is most often given in terms of mass of produce, or its monetary value, per unit of water. IWMI researchers have been of the view that this definition is scale dependent. For a farmer, it means getting more crop per drop of irrigation water. But at a regional, basin or a country level water productivity means getting more value per unit of water resources used. Increasing water productivity is then the business of several actors working in harmony at plant, field, irrigation-system and river basin levels. The issues of scale heavily influence concepts of water productivity and IWMI's framework for water accounting provides a means to generalize about water use across scales and to understand the denominator of the water productivity better (Molden and Sakthivadivel, 1999). Water accounting can be applied in at all scales of interest, and requires the definition of a domain bounded in three dimensional space and time. The task in water accounting is to estimate flows across the boundaries of domain during the specified time period. Water may enter through rainfall, sub-surface flows and as surface irrigation and may be depleted through evaporation and transpiration or outflow as surface runoff and sub-surface flow. In estimating water productivity, we are interested in water inflows and water depletion. The water accounting procedure classifies these inflow and outflow components into various water accounting categories (Fig.4) and are explained below:

- i. Process depletion: by crops, cities, industries
- ii. Non-process but beneficial depletion: evaporation by trees, wetlands, fisheries
- iii. Evaporative depletion of low or negative benefit: evaporation from fallow lands, waterlogged areas etc.
- iv. Flows directed by irrigation into sinks: to sea, inland water bodies that do not add value but are considered as water depleted by irrigation
- v. Uncommitted flows: utilizable within the irrigation system or elsewhere

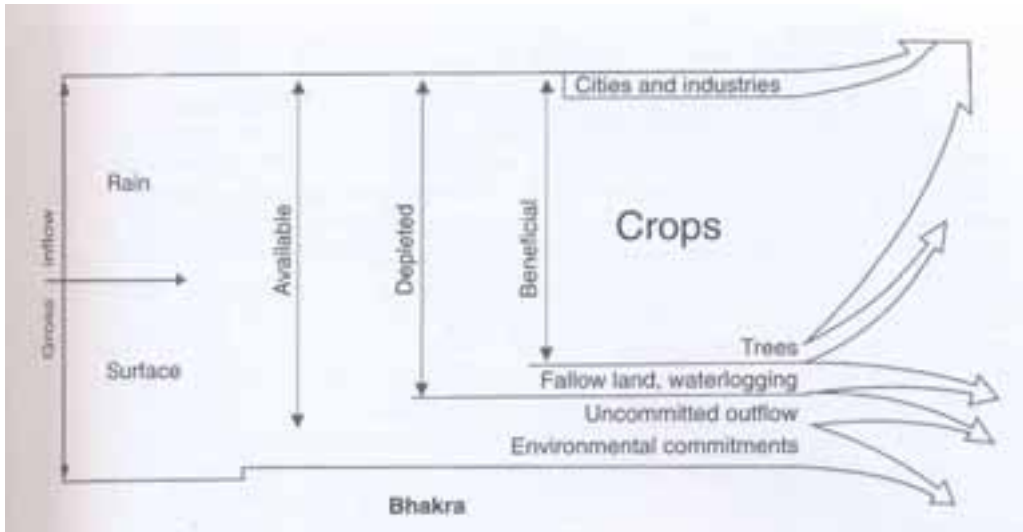


Figure 4. Water accounting representation of the Bhakra irrigated area (Molden et. al., 2001)

- vi. Committed flows to meet environmental needs and traditional rights of downstream users.

A useful conceptual advance has been the partitioning of basin water into ‘blue water’, which contributes to river runoff, and ‘green water’ which evaporates or is transpired (Falkenmark 2000). By concentrating only on blue water, one may omit the benefits derived from the rain and chances of increasing productivity of overall supplies. However, the fundamental question is how much production or value is derived per unit of crop transpiration. If we could increase the mass per unit of ET all over the basin, production would rise without an increase in water depleted by agriculture. A simple case is the source of irrigation and surveys made by IWMI in Punjab have shown that groundwater irrigation has much higher productivity as compared to canal or conjunctive use (Table- 4).

Table 4. Impact of source of irrigation on water productivity of rice and wheat in Punjab, India.

Name of district	Source of irrigation	Crop yield, t/ha	
		Paddy	Wheat
Jalandhar	Well	6.26	4.68
Kapurthala	Well	5.98	4.73
Hoshiarpur	Conjunctive	4.46	3.82
Hoshiarpur	Canals	2.77	3.52

Source: Kumar et al., 2006 (Unpublished).

In another study to estimate the irrigation water needs of India, it was found that in 1995, average irrigated grain yields were 2.7 t/ha and about 600 cubic kilometers of water were diverted for irrigation. Considering the growth in population, changes in diet pattern and

environmental requirements, diversion requirements in 2025 were calculated for different settings (Fig. 5). If there is no increase in grain yield, India will have to double diversions

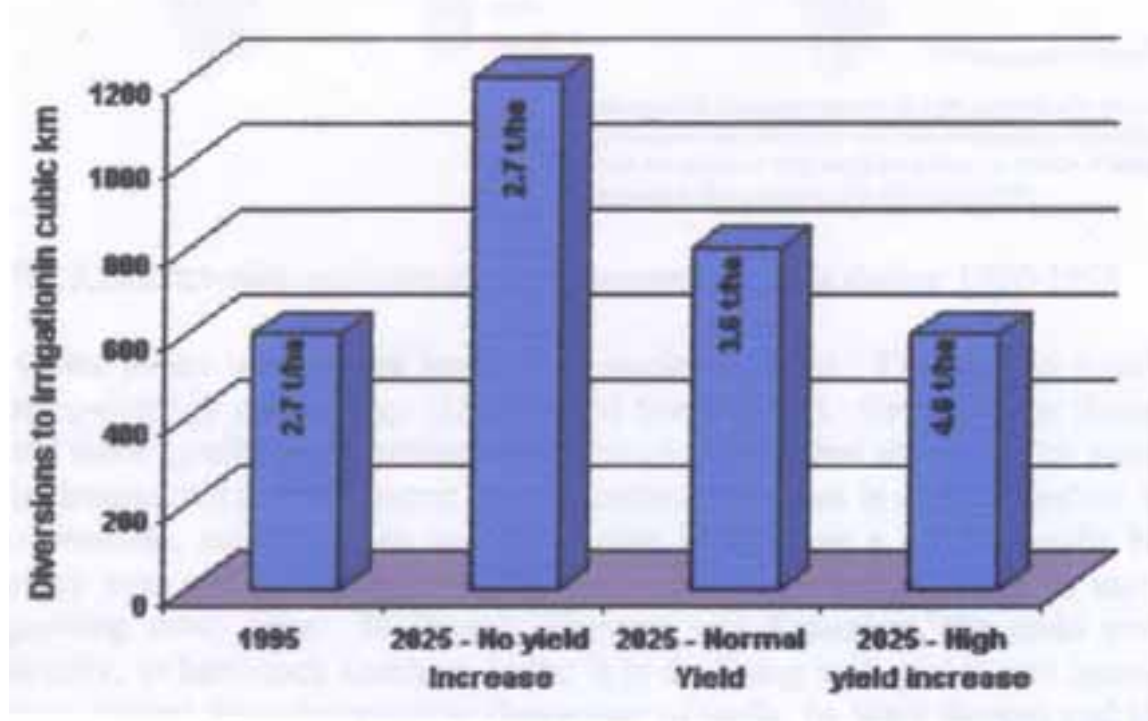


Fig.5. Relationship between agricultural productivity and water diversion to irrigation in India

to irrigation with the risk of environmental damage. On the other hand, if grain yields increased by 70 per cent, no more increase in water diverted to irrigation will be required (Anonymous, 2000). Molden et al. (2003) suggested the following strategies to increase water productivity at different levels of consideration:

1. Increasing the productivity per unit of water consumed
 - *Improved water management*- better irrigation scheduling to avoid stress to plants, increasing reliability of water supplies to synergise other production inputs.
 - *Improving non-water inputs*- better agronomic management, resource conservation technologies.
2. Reducing non-beneficial depletion
 - *Cutting non-beneficial evaporation*- fallow lands, free water surfaces, weeds, and low-value vegetation.
 - *Reducing water flows to sinks*- irrecoverable deep percolation and surface runoff.

- *Minimising salinization of return flows*: applying just the right amount of water to saline soils or soils with saline aquifers and shunting polluted water directly to appropriate sinks.

3. Reallocating water among uses

- *Reallocating water from lower-value to higher value uses*- it can dramatically increase the economic productivity of water.

Enterprise	Productivity of water, Rs./ m ³
Crops alone	16.54
Crops and livestock	20.74
Crops and fisheries	53.00

Source: Palanisami and Ramesh, 2006 (Unpublished)

4. Tapping uncommitted outflows

- *Improving management of existing facilities*- obtain more beneficial use from existing supplies. Policy, design, management and institutional interventions.
- *Reusing return flows*- to increase irrigated area.
- *Adding storage facilities*- to meet the peak requirements during scarcity periods through reservoirs, groundwater recharge, small tanks and ponds at farmers' fields.

There are a variety of inter-connected paths that can improve the productivity of water and include the following:

- Crop breeding for improved water productivity and abiotic stress tolerance.
- Improved agronomic and field practices including resource conservation technologies.
- Low cost supplemental irrigation technologies for rainfed water scarce areas
- Improved irrigation management practices and precision/ micro irrigation
- Integrating recycling and reuse into basin and irrigation management.
- Integrated natural resource management within basins.

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