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# Foreword

Given the exponential increase in population and income growth, the water use in agricultural sector is expected to exaggerate. In many parts of the world, the increasing demand of water from different sectors has led to growing competition for this precious resource. Without efficient water use technologies, proper water management and integrated water use policies, the water-related problems are expected to intensify over the next few decades. Further, climate change is expected to alter the distribution of precipitation events which may consequently increase the irrigation water needs. Evolving and adopting agricultural technologies that would increase the production and productivity of land and water resources constitute an integral part of sustaining agriculture in the era of climate change.

Keeping in view the fact that the Indian agriculture consumes about 80% of the total water withdrawals in the country, a slight improvement in water productivity of agriculture would lead to considerable water savings. Therefore, it is increasingly recommended that efforts should focus on improving water productivity in agriculture. Despite the technological progress made in the past, the water productivity of Indian agriculture is increasing at a slower pace. It is essential to streamline the methods of water productivity assessments and better management practices to improve agricultural water productivity.

This bulletin brings out information related to basic concepts of water productivity and its assessment procedures, and provides a decent database on water productivity of major field and fodder crops, livestock and fisheries under distinct growing conditions. The document will assist in assessing the agricultural water productivity and provides pathways for its improvement through technological and policy interventions.

I congratulate the team of researchers involved in this project who have done a commendable work in gathering information, analyzing the facts and compilation of the same to bring out the document on "Crop, Livestock and Fish Water Productivity in Eastern India" in the form of a bulletin. I am confident that this bulletin will be useful to policy makers, researchers, irrigation planners, students and the farmers.

SKChaudhari

(S.K. Chaudhari)

# Contents

# 1. Introduction

Globally, agriculture is the largest user of water. In India, water is critical to agricultural and economic growth, and is the major determinant of sustainable development of agriculture. Irrigated agriculture has been an important contributor to the expansion of national and world food supplies since the 1960s, and is expected to play a major role in feeding the growing world population. However, irrigation accounts for about 70% of global and 90% of developing-country's water withdrawals (Cai and Rosegrant, 2003). Particularly, in India, the withdrawal for agriculture is about 80% of total water withdrawal (Fig. 1), however, there is a significant variation in the level of groundwater exploitation at regional scale.

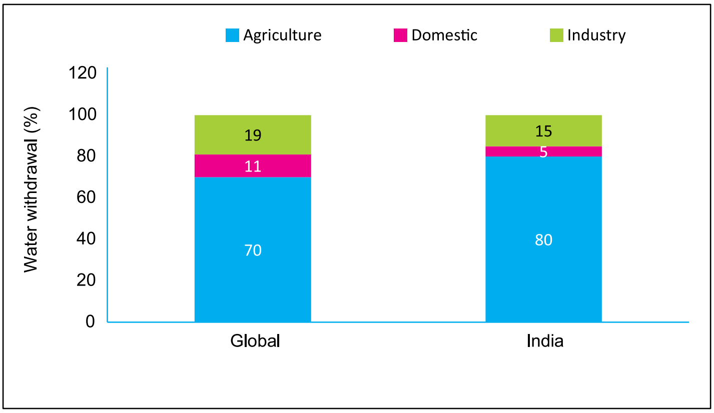


Fig. 1. Global and Indian water withdrawals for different sectors

The country may face a major challenge in future as the water resources are stressed and depleting while various sectoral demands are growing rapidly. Increasing population, urbanization and the irreversible impacts of climate change also put an additional demand on water resources and that the total annual demand for water will increase from 552 BCM in 1997 to 1050 BCM by 2025. The per capita water availability has reduced from 5177 cubic meters per year in 1951 to 1544 cubic meters per year in 2011. The present level of per capita water availability is far below the cutoff point of water stress (1700 cubic meters). India has become a water stressed country of the planet. Central Water Commission (CWC) predicts that by 2050, the total water demand will overshoot supply in the country and the share of irrigation will come down to 68 per cent (Fig. 2).

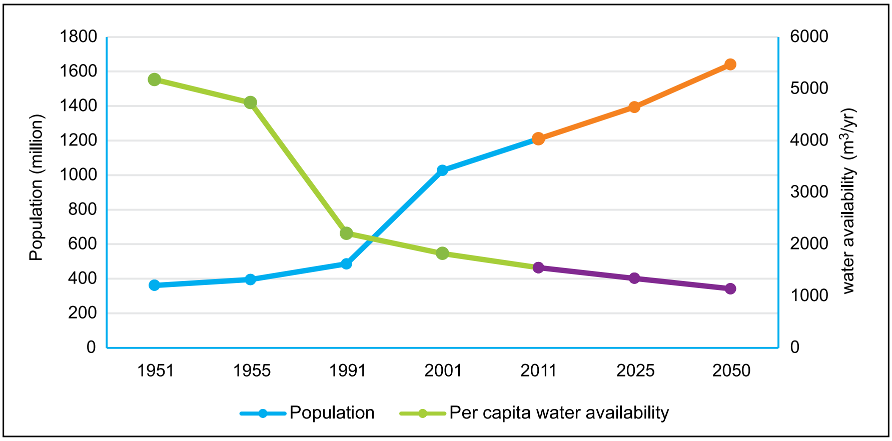


Fig. 2. Temporal trends in population growth and per capita water availability

Keeping in view the vulnerability of the Indian agriculture to droughts, the scarce water resource of the country need to be utilized efficiently. The water availability is further challenged due to negative impact of climate change. However, Govt. of India is concerned with the issue and has prioritized agricultural water use through schemes like "*Har Khet ko Pani* – Water for every field" and "per drop more crop". A separate Ministry of Water Resources, River Development and Ganga Rejuvenation has also been established by Govt. of India for managing the water resources at national scale. Implementation of these schemes calls for advances in water management and, therefore, reorienting the focus towards improving water productivity in agriculture would be an ideal response to emerging crises. Given the large amounts of water use in agriculture, it is believed that a small improvement in agricultural water productivity could have larger implications on water saving and water budgets at various spatial scales. The focus of such improvements would be to achieve higher agricultural production with the same amount of water, or the same amount of agricultural production with less water.

New approaches are required to properly define and account for each item of water use and productivity with water conservation and saving being the primary drivers to achieve higher performance (Foster and Perry, 2010). Many national and international organizations in water sector are recommending to include 'improving water productivity' as major goal of irrigation projects. FAO (2012) considers demand management as an important option to cope with water scarcity, with increasing agricultural water productivity as the single most important avenue for managing water demand in agriculture. A recent report brought out by NABARD and ICRIER suggests that the objective of agriculture development should not be of raising productivity per unit land but increasing productivity per unit water, especially irrigation water (Sharma *et al.*, 2018).

This bulletin aims at improving the understanding of irrigation professionals and agriculturists on the basic concepts and tools for assessing the water productivity of agricultural production. The methodology for water productivity accounting is elaborated with detailed data requirement and computational procedures. The bulletin also documents water productivities of major agri-horti crops, livestock and fisheries in Eastern India.

## 2. Indicators of Water Use

Indicators aid in decision making processes at the managerial level to decide upon the water resource management and allocation strategies. Comparisons of the different production systems within a single unit system are possible with the indices that are derived from the system parameters. The term 'water productivity (WP)' provides a more consistent conceptual approach and better understanding on the performance of a system in terms of efficiency and effectiveness of water use. A range of indicators is used when parameterizing the effectiveness of water use in agriculture (Table 1). The term 'irrigation efficiency (IE)' is used to characterize the performance of an irrigation method for a given event. The present trend

**Table 1. Indicators used to assess the water use and performance of systems**

| Indicator | Purpose | Sustainability perspective | Unit of measurement |
|---|---|---|---|
| Water withdrawal | Information on sector-wise water withdrawals from country's total water resources | Social, political | $m^3$ |
| Water consumption | Information on sector-wise actual water consumption. If compared with water withdrawals, can also provide quantitative information on losses. | Environmental | $m^3$ |
| Application efficiency | Field level evaluation of an irrigation system to assess the effectiveness of the system. It can be calculated per irrigation event and not on a seasonal time scale. | Performance | Per cent |
| Transpiration coefficient | Amount of water transpired by the crop in producing a unit weight of biological yield | Performance | $m^3/kg$ |
| Water productivity | Providing information on amount of physical produce per unit of water consumed | Performance | $kg/m^3$ |
| Economic water productivity | Potential of water use achieved in economic terms. | Economic | Rs./ $m^3$ |

is to abandon the term efficiency for irrigation water conveyance and distribution and to adopt service performance indicators (Bos *et al*., 2005; Merriam *et al*., 2007).

In last two decades the term 'water use efficiency (WUE)' has been commonly used to assess the overall performance of irrigation systems and effectiveness of crop production process. The WUE is the ratio of the harvested biomass to the water consumed to achieve that yield. It characterizes, in a specific process, how effective is the use of water. It was put forth that the commonly described relationship between volume of water ($m^3$) and agricultural product (ton) is an index, and not efficiency (Skewes, 1997). Still this concept of water use efficiency provides only a partial view because it does not indicate the total benefits produced, nor does it specify that water lost by irrigation is often reused by other users (Seckler *et al*., 2003).

## 3. Concept of Water Productivity

Productivity is a ratio between a unit of output and a unit of input. Here, the term "water productivity" is used exclusively to denote the amount or value of product over volume or value of water depleted or diverted. WP has been given different definitions by different researchers, often according to the scale of the plant, plot of land or watershed they were investigating or the purpose of their study. Molden (1997) defined WP as the physical mass of production or the economic value of production measured against gross inflow, net inflow, depleted water, process depleted water, or available water. WP is usually estimated as the amount of agricultural output produced per unit of water consumed. Mathematically, it is expressed as:

$$\text{Water productivity (kg/m}^3\text{ or Rs./m}^3\text{)} = \frac{\text{Output derived from water use (kg or Rs.)}}{\text{Water input (m}^3\text{)}}$$

In broader sense, it is defined as the ratio of the net benefits from crop, forestry, fishery, livestock, and mixed agricultural systems to the amount of water required to produce those benefits. Two specific types, most widely used in literature, are physical water productivity defined as the ratio of the mass of agricultural output to the amount of water used; and economic water productivity defined as the value derived per unit of water used. The denominator of the water productivity equation is expressed as volume of water either supplied or de-

**Table 2. Parameters considered in determining water use**

| Parameter | Symbol |
|---|---|
| Irrigation water | *Ir* |
| Crop evapotranspiration | *ETc* |
| Irrigation + rainfall | *Ir* + *R* |
| Irrigation + effective rainfall | *Ir* + *ER* |
| Irrigation + effective rainfall + soil water contribution | *Ir* + *ER* + *SM* |

pleted. Water is depleted when it is consumed by evapotranspiration, is incorporated into a product, flows to a location where it cannot be readily reused (to saline groundwater, for example), or becomes heavily polluted (Seckler 1996; Molden *et al.*, 2003). An extensive review of the published literature showed that, in determining the WP, various researchers have considered the water use in many different ways (Table 2).

WP analysis can be applied to crops, livestock, tree plantations, fisheries, and mixed systems at selected scales. The objectives of WP analysis range from assessing agricultural production (kilograms of grain per unit of water depleted by a crop on a field) to assessing incremental welfare per unit of water used in the agricultural sector.

## 3.1. Water productivity, water use efficiency and irrigation efficiency

The terminologies, WP, WUE and IE seem to cause some confusion among researchers. The fact is, all these terms do exist and have different definitions and applications. In some of the previous literatures researchers considered WP and WUE as synonymous. However, there is substantial difference between IE, WUE and the WP (Table 3). Irrigation efficiency aims at assessing the performance of the irrigation system. Molden (1997) mentioned that productivity takes different forms with different units but efficiency has only one form (dimensionless). Heydari (2014) indicated that WP is distinct from WUE. The term WP refers to crop production in relation to total water consumed while the WUE is a dimensionless ratio of total amount of water used to the total amount of water applied. Since, WP

**Table 3. Difference between irrigation efficiency, water use efficiency and water productivity**

| Irrigation efficiency (IE) | Water use efficiency (WUE) | Water productivity (WP) |
|---|---|---|
| Ratio of water consumed by crops to water diverted from the source. | Dimensionless ratio of total amount of water used to the total amount of water applied | Crop production/ benefits in relation to total water consumed |
| Applies to irrigation system | Applies to crop | Its related to benefits from a system |
| Used to evaluate the performance of water system | Performance of crop | Performance of production system as whole |
| Objective – water saving | Just an assessment of amount of water taken up by the plant | Getting best returns from applied water |
| Non-dimensional | Non-dimensional | Has dimension of $[M^1L^{-3}T^0]$ |
| Considers losses – seepage, soil evaporation | Does not consider losses | Loss accounting depends on context – Supply or depletion in water productivity |

terms are not dimensionless, i.e., can not be categorized in efficiency terms, they are just some ratios with different units in the numerator and denominator.

In literature published during the 1960s, the term WP was referred to as WUE. Some of the confusions in the definition of WP come from the fact that some researchers use it interchangeably with WUE. The recent literature shows that what previously was wrongly defined as WUE has been renamed as WP in the early 1980's. The context of application of these terms is completely different. While, IE is more important to the irrigation engineers to assess the performance of the irrigation systems, the term WUE is more useful to crop physiologist in order to assess the efficiency with which crop used the applied water and is applicable at individual plant scale. WP is a broader term that encompasses all the benefits from the system as a whole into one representative index.

## 3.2. Associated benefits with water productivity

Improving WP offers wide range of benefits, with quantifiable and non-quantifiable elements. Agricultural output, which can be evaluated for physical, nutritional or monetary benefit, within the bounds of the scale and time period being considered. Other benefits associated with crop production, for example, can be fodder for livestock and organic matter for soil quality improvement. Some cover crops also provide protection from soil erosion. Current approaches to assess the agricultural water-use benefits generally ignore secondary goods and services offered by the improvement in WP.

Apart from direct benefits like water saving and increased yield, it offers several long-term outcomes of livelihood improvement and better ecosystem services (Fig. 3). Some of these benefits can be quantified through technical and social data. Other benefits are inherent, but their quantification is difficult, rather systematic procedure to quantify these benefits is not available. The potential benefits of improving water productivity are summarised as:

- Non-grain benefits of water use in crop production such as the use of crop residues as fodder and/or mulch.
- Benefits from bi-products of livestock and fish production and their role as food supplements for livestock and fish production systems or as inputs to enhance soil fertility.
- Benefits from ecosystem goods and services (biodiversity, ecosystem integrity, habitat maintenance) and socio-cultural benefits, such as aesthetics and cultural importance, derived from hydrologic flows in agricultural water use systems.

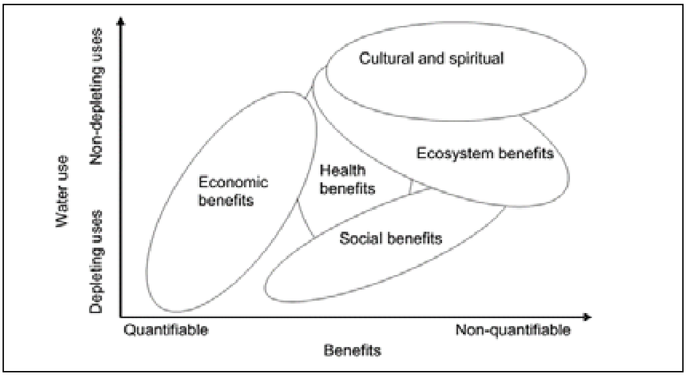


Fig. 3. Water use and associated benefits (*Source:* Gichuki *et al.*, 2015)

Water savings resulting from improvement in WP can enable poor and marginalized people to gain access to water and use it more effectively. Increased WP may benefit poor people through multiplier effects on food security, employment, and income. The current focus of WP has evolved to include the benefits and costs of water used for agriculture in terrestrial and aquatic ecosystems. WP analysis can be seen as part of an ecosystem approach for managing water. Rain, natural flows, withdrawals, and evaporation support terrestrial and aquatic ecosystems, which produce numerous services for people.

## 3.3. Trade-offs between land and water productivity

The absolute yield per unit of land increases with the increasing amount of water applied leading to increased land and water productivity. This trend continues up to a certain depth of water application, where land and water productivity both become maximum (Max WP) (Fig. 4). Thereafter, further increase in depth of water application may result in increased land productivity but reduced WP. This is mainly because the yield increase is not in the direct proportion of the quantity of water applied. At the point of inflection (Max WP), the benefits derived per unit of water are the highest which is important from WP point of view. After the point 'Max Yield', both

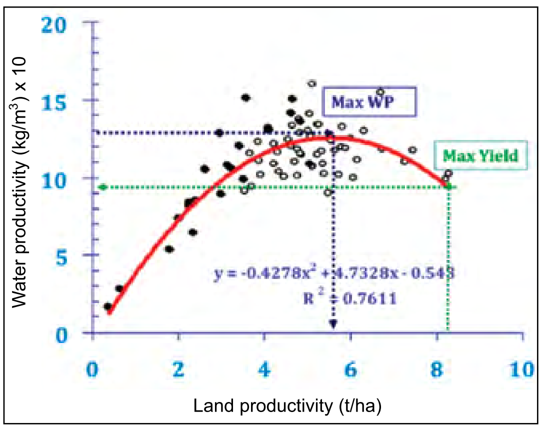


Fig. 4. Relationship between land and water productivity (*Source:* Zhang and Oweis, 1999)

the land and water productivity will decline as increased amounts of water applied may lead to water logging and reduced crop yields.

## 4. Methodology for Water Productivity Assessment

Assessment of WP can be performed at spatial scales varying from a field level to a national or global scale depending on the type and quality of data available. To assess the performance of the crop production, one would be more interested in working out the WP at field scale while to make informed policy decisions, a national scale of WP assessment would be more appropriate. The temporal scale of WP assessment is typically a crop's growing season. The framework representing various determinants of denominators in the WP equations for three types of water productivities is presented in Fig. 5.

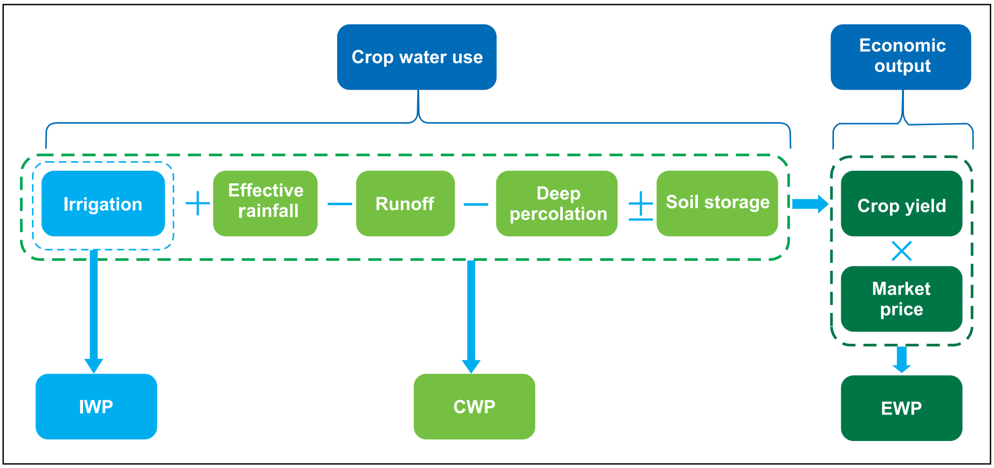


Fig. 5. A framework for crop water productivity assessment

### 4.1. Water productivity of crops

Crop water productivity (CWP) is a quantitative term used to define the relationship between quantity of crop produced and the actual amount of water involved in crop production. CWP assessments require data pertaining to crop yield and seasonal crop water use [crop evapotranspiration ($ET_c$)] of the crop. The crop yields may be in kg/ha or t/ha and the seasonal water use may be expressed in volumetric units ($m^3$ or l) or in depth units (mm). Depending on the units used for the crop yield and water use, the CWP may be expressed as kg/$m^3$ or t/ha-mm. The term ha-mm represents a 1 mm depth of irrigation water over a hectare area, which amounts to 10,000 *l* or 10 $m^3$.

$$CWP\left(\frac{kg}{m^3}\right) = \frac{Y_c\ \left(\frac{kg}{ha}\right)}{V_{ETc}\ \left(\frac{m^3}{ha}\right)}$$

$$V_{ETc} = ETc * 10$$

Where, $Yc$ is the crop yield (kg/ha) and $V_{ETC}$ is the total volume of seasonal crop evapotranspiration ($m^3$/ha), $ETc$ is the seasonal ET of crop (mm). The crop yield data is comparatively easy to record and is available with the farmers or the state agencies involved in agricultural development. In case of crops having multiple harvests, it is important to consider the total marketable yield of the crop. Apart from crop yields, estimation of CWP also requires consumptive use (CU) of the crop to be precisely quantified. Various climatic and water balance approaches are available to estimate the crop's seasonal consumptive crop water use ($ET_c$) (Allen *et al.*, 1998).

Instead of ETc, if we consider the quantity of water applied, the result will be termed as Irrigation Water Productivity (IWP). Computation of IWP requires precise records on amount of water applied throughout the growing season while in case of CWP, it is important to estimate the seasonal CU of the crop under consideration. Accurate quantification of the crop water use or amount of irrigation water applied is crucial phase of WP accounting. At field level, data on irrigation water use can be obtained by using discharge measuring instruments like notches, flumes and flow meters etc.

In case of fodder crops, the quantity of green biomass produced can be considered as the crop yield. If the fodder crop has multiple cuts during its growing season, the biomass collected in each cutting is summed up for the entire growing season. In case of perennial fodder crops, annual biomass yield and the annual water use is considered in the computation of WP (Singh *et al.*, 2014) and fodder production is expressed in terms of kg biomass/$m^3$ of water supplied (irrigation and/or rainfall).

## 4.2. Water productivity of livestock

Livestock water productivity is also based on principles of water accounting and is defined as the ratio of livestock beneficial outputs and services to the amount of water depleted and degraded in producing these products and services (Peden *et al.*, 2007). WP of milk is estimated for the productive periods only. Water requirement of animals included the water used in production of feeds and fodder, the drinking water requirements and water use in sanitization (cleaning and washing of animals and barns). The water required for producing feeds and fodder can be estimated as per Allen *et al.* (1998). Drinking water requirement of each animal needs to be recorded on daily basis for the entire study duration. In case of egg production, the WP is expressed in terms of number of eggs per unit of water supplied to the batch of chickens.

### 4.3. Water productivity of fish production

WP of fish production was measured against gross or net inflow. Gross inflow refers to the total amount of water flowing into the domain from precipitation and surface and subsurface sources. Net inflow is the gross inflow plus any changes in storage. If water is added to storage, net inflow is less than gross inflow. Water added to storage can be used for fish production and WP of fish grown in dams, ponds, etc., can be estimated using following equation:

$$\text{PWs}= \frac{\text{P}_{\text{fish}}}{|I_{gross} - I_{net}|}$$

Where, PWs = Water storage productivity, $P_{fish}$ = fish productivity, I = Inflow in to the pond *(Source:* Nguyen-Khoa *et al.*, 2008)

### 4.4. Economic water productivity

Economic water productivity (EWP) takes into account values of output, opportunity costs of inputs, and externalities. This requires physical output to be transformed into economic terms. Higher EWP is achieved when scarce water resource is allocated and used such that net value or net returns is maximized. To compare the performance of different crops in using water efficiently, WP needs to be expressed as income per unit of water depleted (Rs./$m^3$). This indicator is a function of market prices and thus can differ between years and between regions. Given that market prices of the products vary on day-to-day basis, it is important to keep the track of market prices and the quantity of product sold by the farmers during each picking or each marketing event. Since, the denominator in the WP equation can be either irrigation water or crop evapotranspiration, the EWP can be presented in two distinct forms. It can be estimated on the basis of volume of irrigation water use, termed as Irrigation Economic Water Productivity (IEWP) or it can be estimated on the basis of seasonal water use of crop, termed as Crop Economic Water Productivity (CEWP).

$$IEWP = \frac{(q_{mp} \times P_{mp}) + (q_{bp} \times P_{bp})}{V_{iw}}$$

$$CEWP = \frac{(q_{mp} \times P_{mp}) + (q_{bp} \times P_{bp})}{V_{ETc}}$$

Where, $q_{mp}$ and $q_{bp}$ are the quantities of the main product and by-product (kg/ha), and $p_{mp}$ & $p_{bp}$ are the prices of main product and bi-product (Rs./kg), respectively. $V_{iW}$ and $V_{ETC}$ are the volume of irrigation water and crop evapotranspiration ($m^3$), respectively. Details on estimation of $V_{iW}$ and $V_{ETc}$ are presented in previous sections.

## 5. Values of Water Productivity

This section provides the WP assessment of field and fodder crops, livestock and fish production. The data presented on WP of field and fodder crops, livestock and fisheries are based on the experiments conducted at ICAR Research Complex for Eastern Region, Patna. However, the WP of important vegetables was assessed at its regional station, Ranchi. The data mentioned here are based on seasonal crop water use.

### 5.1. Field crops

Very few studies have been conducted on WP of field crops in farmers' field. According to one estimate, irrigation water productivity of rice in Eastern India has been accounted for 0.49 kg/$m^3$ (Sharma *et al.*, 2018). States like UP, Bihar, Odisha and Assam have very low irrigation water productivity as evidenced from the data mentioned in Fig. 6. However, it could be improved through various technological interventions like improved irrigation methods, conservation tillage, improved crop variety and other crop management practices.

Application of micro-irrigation is relatively new in rice and wheat cultivation in India. Field experiments with different irrigation and crop establishment methods were conducted to assess the WP of rice and wheat. Three methods of irrigation, i.e., Low Energy Water Application (LEWA), micro-sprinkler and check basin were combined with three establishment methods *viz.* System of Rice Intensification (SRI)/ System of Wheat Intensification (SWI), line transplanting/sowing and farmers' practices of transplanting/sowing. As compared to farmers practice and check basin irrigation, the combination of SRI/SWI and

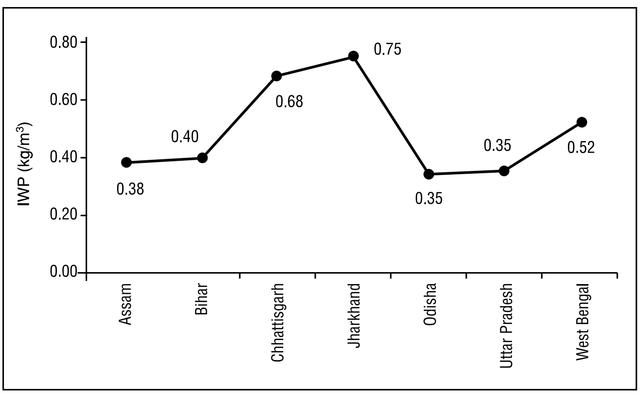


Fig. 6. Irrigation water productivity (IWP) of rice in farmers' field (*Source:* Sharma *et al.*, 2018)

micro-irrigation (LEWA or micro-sprinkler) significantly increased the WP of rice and wheat (Table 4). WP values of important field crops as obtained by dividing the crop yields with total water use are presented in Table 5.

**Table 4. Water productivity and economic water productivity of rice and wheat under different irrigation and establishment methods**

| Irrigation methods | Wheat | | | Rice | | |
|---|---|---|---|---|---|---|
| | SWI | Line sowing | Farmers' practice | SRI | Line transplanting | Farmers' practice |
| Water productivity (kg/m$^3$) | | | | | | |
| LEWA | 3.10 | 2.50 | 1.77 | 0.86 | 0.68 | 0.55 |
| Micro-sprinkler | 3.56 | 2.79 | 1.94 | 0.87 | 0.72 | 0.47 |
| Check basin | 1.59 | 1.76 | 1.07 | 0.55 | 0.63 | 0.34 |
| Economic water productivity (Rs/m$^3$) | | | | | | |
| LEWA | 59.68 | 48.13 | 34.07 | 15.61 | 12.34 | 9.98 |
| Micro-sprinkler | 68.53 | 53.71 | 37.35 | 15.79 | 13.07 | 8.53 |
| Check basin | 30.61 | 33.88 | 20.60 | 9.98 | 11.43 | 6.17 |

(*Source :* Kumar *et al.,*2015)

**Table 5. Water productivity and economic water productivity of important field crops**

| Crop | Water productivity (kg/m$^3$) | Economic water productivity (Rs/m$^3$) | Crop | Water productivity (kg/m$^3$) | Economic water productivity (Rs/m$^3$) |
|---|---|---|---|---|---|
| Puddled Transplanted Rice | 0.65 | 11.80 | Foxtail millet (CT) | 0.33 | 8.30 |
| Machine Transplanted Rice | 0.56 | 10.20 | Pearl millet (CT) | 0.70 | 14.00 |
| SRI | 0.52 | 9.40 | Finger millet (CT) | 0.31 | 9.80 |
| Direct Seeded Rice (CT) | 0.67 | 12.20 | Lentil (ZT) | 2.24 | 107.50 |
| Direct Seeded Rice (ZT) | 0.66 | 12.00 | Chickpea (ZT) | 2.64 | 128.70 |
| Wheat (CT) | 1.87 | 36.00 | Pigeonpea (ZT) | 3.34 | 193.70 |
| Wheat (ZT) | 2.01 | 38.70 | Soybean (CT) | 0.38 | 14.10 |
| Mung bean (ZT) | 1.19 | 83.90 | Toria (ZT) | 1.57 | 65.80 |
| Winter Maize (ZT) | 2.73 | 48.10 | Mustard (ZT) | 1.31 | 58.00 |
| Sorghum (CT) | 0.76 | 19.40 | Safflower (ZT) | 2.80 | 146.00 |

CT- Conventional Tillage; ZT- Zero Tillage

## 5.2 Vegetables

WP values of vegetable crops, as obtained from different field experiments are compiled in this section. Under drip irrigation, the WP of chili was significantly affected by planting geometry. Higher plant densities (closer spacing) (30x40 cm) used the water more efficiently as compared to wider plant spacing. A similar experiment in tomato showed the highest WP of 10.75 and 12.75 kg/$m^3$ under wider (50x75 cm) and closer plant spacing (40x50 cm), respectively (Table 6). WP of broccoli under dense and sparse plant population was 14.5 and 10.9 kg/$m^3$, respectively. Cultivation of broccoli at 40x30 cm spacing is optimal for improving yield and WP. Subsurface drip improved the WP of cucumber and bitter gourd crops. Compared to surface drip, the subsurface placement of laterals at 10-15 cm depth improved the WP of cucumber and bitter gourd by 19 and 34%, respectively.

**Table 6. Water productivity and economic water productivity of important vegetables**

| Crop | Management practice | Water productivity (kg/$m^3$) | Economic water productivity (Rs./$m^3$) |
|---|---|---|---|
| Chili | Drip irrigation with mulch (30 x 40 cm) | 2.73 | 109.20 |
| | Drip irrigation with mulch (75 x 50 cm) | 2.20 | 88.00 |
| Tomato | Drip irrigation with mulch (40 x 50 cm) | 12.70 | 444.50 |
| | Drip irrigation with mulch (50x75 cm) | 10.75 | 376.30 |
| Cucumber | Drip irrigation (surface) | 4.50 | 112.50 |
| | Drip irrigation (subsurface at 10-15 cm depth) | 5.34 | 133.50 |
| Bitter gourd | Drip irrigation (surface) | 3.21 | 64.20 |
| | Drip irrigation (subsurface at 10-15 cm depth) | 4.29 | 85.80 |
| Broccoli | Dense plantation (40x30 cm) | 14.50 | 362.50 |
| | Normal plantation (40x60 cm) | 10.90 | 272.50 |

(*Source:* Jha *et al.*, 2015)

Experiments conducted to evaluate the response of *Rabi* (*viz.* cabbage, cauliflower and broccoli), *Zaid* (*viz.* okra, cowpea and french bean) and *Kharif* crops (tomato, vegetable soybean and capsicum) to assess the WP under three irrigation methods comprising of drip irrigation (DI), drip irrigation with bicolor polythene mulch (DIM) and furrow irrigation (FI). The results pertaining to WP implied that the drip system in conjunction with bi color (silver- black) polyethylene mulch was effective in increasing WP of vegetable crops (Table 7).

**Table 7. Water productivity of important vegetables under different irrigation practices**

| Crop | Water productivity (kg/m$^3$) | | | Economic water productivity (Rs/m$^3$) | | |
|---|---|---|---|---|---|---|
| | Furrow | Drip | Drip + Mulch | Furrow | Drip | Drip + Mulch |
| Cabbage | 9.60 | 12.30 | 13.94 | 144.00 | 184.50 | 209.10 |
| Cauliflower | 6.80 | 9.25 | 12.10 | 136.00 | 185.00 | 242.00 |
| Okra | 0.07 | 1.63 | 3.66 | 1.80 | 40.80 | 91.50 |
| Cowpea | 0.17 | 2.90 | 3.80 | 3.40 | 58.00 | 76.00 |
| French bean | 0.83 | 1.13 | 1.93 | 20.80 | 28.30 | 48.30 |
| Vegetable soybean | 0.98 | 2.10 | 3.10 | 29.40 | 63.00 | 93.00 |
| Capsicum | 0.35 | 0.76 | 1.45 | 10.50 | 22.80 | 43.50 |
| Potato | 1.17 | 7.94 | DNR | 23.40 | 158.80 | DNR |
| Pea | 0.42 | 0.97 | DNR | 12.60 | 29.10 | DNR |

DNR- Data Not Recorded

(*Source :* Jha *et al.*, 2017)

## 5.3. Fodder crops

WP of major green fodder crops is presented in Table 8. Among all the studied fodder crops, cowpea had the highest WP of 19.94 kg/m$^3$ while the rye had the lowest WP.

**Table 8. Water productivity and economic water productivity of important fodder crops**

| Season | Fodder crop | Water productivity (kg/m$^3$) | Economic water productivity (Rs/m$^3$) |
|---|---|---|---|
| Rainy | Cowpea | 19.94 | 29.90 |
| | Maize | 12.20 | 18.30 |
| | Multi-cut sorghum | 19.15 | 11.50 |
| | Soybean | 16.30 | 24.50 |
| Winter | Berseem | 10.51 | 12.60 |
| | Oat | 11.78 | 11.80 |
| | Annual Rye | 9.96 | 12.00 |

## 5.4. Livestock

In traditional animal husbandry practices, the WP of milk in Bankura district of West Bengal where rice-fallow cropping system is prevalent, has been estimated as 0.03 kg/m$^3$ for local cows and 0.13 kg/m$^3$ for crossbred cows (Clement *et al.*, 2010). However, the same was improved manifolds in intensive system of livestock rearing, which is evidenced from the data given in Table 9.

**Table 9. Water productivity and economic water productivity of milk, meat, chicken and egg production**

| Livestock/ poultry | Product | Water productivity (kg/m$^3$ or No./m$^3$) | Economic water productivity (Rs/m$^3$) |
|---|---|---|---|
| Crossbred cattle | Milk | 1.31 | 49.80 |
| Sahiwal cattle | Milk | 1.10 | 44.00 |
| Buffalo | Milk | 0.93 | 40.90 |
| Goat | Meat | 0.09 | 45.00 |
| Broiler chicken | Chicken | 0.47 | 61.10 |
| Backyard chicken | Egg* | 4.17 | 25.00 |
| Duck (Khaki Campbell) | Egg* | 5.24 | 26.20 |

*Expressed in number of eggs per m$^3$ of water used

## 5.5. Fish production

The WP of fish was calculated using eight identical fish ponds of 800 $m^2$ area having and average depth of 1.5 m. Six integrations *viz.* cattle–fish, buffalo– fish, goat–fish, duck–fish, poultry – fish and pig–fish and without any feed and manure (control) were considered in this assessment. In all the study ponds, livestock manure was applied daily at the rate of 100 kg of nitrogen per ha fish pond per year. Six species of fish *viz.* rohu (*Labeo rohita*), catla (*Catla catla*), mrigal (*Cirrhinus mrigala*), grass carp (*Ctenopharyngodon idella*), batta (*L. batta*) and puthi (*Puntius gonionotus)* were stocked in the pond. The stocking density was 10000 numbers of fingerlings per ha of water area. For different integrations, the WP of fish production was in the range of 0.38 to 0.54 kg/$m^3$ (Table 10). On an average, the WP was 3.8-folds higher in integrations compared to control.

**Table 10. Fish and water productivity and economic water productivity of different integrated fish farming systems**

| Type of integrations | Fish productivity (kg/ha) | Water productivity (kg/$m^3$) | Economic water productivity (Rs/$m^3$) |
|---|---|---|---|
| Buffalo -fish | 3508 | 0.47 | 94.0 |
| Cattle-fish | 4030 | 0.54 | 108.0 |
| Duck-fish | 3200 | 0.43 | 86.0 |
| Goat-fish | 3089 | 0.41 | 82.0 |
| Pig-fish | 3378 | 0.45 | 90.0 |
| Poultry - fish | 2825 | 0.38 | 76.0 |
| Control | 879 | 0.12 | 24.0 |

# 6. Pathways for Improving Water Productivity

WP enhancements are possible by improving crop yields or reducing water use in the production process. These improvements can be effected at plant level or at field level. At plant level, most significant improvements come from breeding technology, while at field level there are number of factors that influence the WP. Pathways for excelling in WP include improving

**Table 11. Primary pathways to increase the productivity of water at different scales**

| Pathways | Plant level | Field level | Basin level |
|---|---|---|---|
| Increase marketable yield per unit of water transpired | ✓ | ✓ | ✓ |
| Reducing outflows (drainage, seepage and percolation) and non-productive depletions (evaporation from soil and water, weeds) | ✓ | | ✓ |
| Increasing non-irrigation inflows (Rainfall, stored water, marginal quality water, waterlogged/ drainage water) | | ✓ | ✓ |
| Increasing the effective use of water from the storage | | ✓ | ✓ |
| Using not yet committed flows | | | ✓ |
| Reallocating and co-managing water (multiple use) among uses | | ✓ | ✓ |

(*Source:* Molden *et al.*, 1998)

the productivity of rain and irrigation water for crops, livestock and fisheries, applying an integrated approach to increase the value per unit of water, and adopting an integrated basin perspective to understand WP trade-offs (Table 11).

Following sections outline the approaches to improve water productivity of crop, livestock and fisheries sectors:

## 6.1. Improving water productivity in crop production

Agricultural water productivity is influenced by many biotic and abiotic factors. Climatic conditions, soil type and structure, plant type, and the irrigation techniques applied are among the main factors that influence the WP of crops. At a given location having specific agro-climatic setup, the WP can be improved by making the right decisions regarding crop choices, irrigation practices, soil health management and better crop protection measures. There are many well-known practices to improve WP. These include more reliable and precise distribution and application of irrigation water, supplemental and deficit irrigation, improved soil fertility, and soil conservation practices. Researchers have shown that 50-60% improvement in WP is possible through land and water management.

### 6.1.1. Genetic improvements in crops

At plant level genetic improvements in crops for higher yields, resistance against pests and diseases, tolerance to drought and cultivation during off-season offer good potential in improving WP. Only moderate impacts on crop water productivity can be expected from genetic improvements to plants over the next 15-20 years. It has been assessed that the potential contribution of genetic improvements in increasing WP was about 10-20% in cereals and up to 50% in vegetables.

### 6.1.2. Irrigation method

Choice of irrigation method is the most critical aspect in improving the crop water productivity. Water saving and increased crop yields are the twin factors that are responsible for improved WP under efficient irrigation systems like drip and sprinkler. Because of their low water application efficiencies (30-40%), the irrigation water productivities under conventional methods, like furrow and check basin, are very low. New agronomic practices like zero tillage, mulching, raised bed planting, ridge-furrow method of sowing, alternate wetting and drying (AWD), subsurface irrigation, and precision farming, however, offer a vast scope for economizing water use in agriculture.

Low energy precision application (LEPA) in combination with appropriate water-saving farming techniques, can achieve efficiencies as high as 95%. Drip irrigation is the most efficient way of watering the plants and allows precise application of water-soluble fertilizers and other agricultural chemicals directly in the crop root zone. The research conducted all over the world in different crops under various ago-climatic conditions have shown that by the adoption of drip systems, crop yields increased by 30-80%, water savings of 40-80%, fertilizer savings up to 15-30% with associated savings in pesticide, and labour over conventional irrigation systems.

### 6.1.3. Irrigation management

Productivity gains are possible through better water distribution systems. Seepage and evaporation are the twin factors responsible for considerable water loss in the delivery systems. Lining of canals and water distributaries (using compacted clay or concrete) can reduce water seepage considerably. The uncontrolled deliveries to fields generate excess drainage that is hard to control. Use of efficient and effective water delivery systems gives water managers more flexibility to deliver water with reduced water use leading to improved WP from the command areas. There is substantial scope to improve water deliveries to irrigation using range of technical and management practices like lining of canal, use of pipes in water conveyance, adoption of drip and sprinkle irrigation systems.

Deficit irrigation (DI) maximizes WP by stabilizing yields at obtaining maximum WP rather than maximum yields at higher water use. In areas with limited irrigation water supplies, DI will gain importance over time as farmers strive to increase the productivity of their limited land and water resources. Crops and irrigation strategies should be carefully selected to maximize the value of crop production. DI will play an important role in farm-level water management strategies, with consequent increases in the output generated per unit of water used in agriculture.

### 6.1.4. Multiple use of water

WP can be improved by adopting the concept of multiple water use, which is beyond the conventional sectorial barriers of the productive sectors. There is scope for increasing income through crop diversification and integration of fish, livestock, poultry and other enterprises in the farming system. The multiple water use approach can generate more income benefits, and decrease vulnerability by allowing more diversified livelihood strategies and increasing the sustainability of ecosystems.

### 6.1.5. Field levelling and conservation tillage

Proper field levelling, in order to allow the water to travel in an optimum speed, is an approach that assists uniform distribution of water and reduces runoff, particularly in surface and micro irrigation. Further water savings can be achieved through residue management and conservation tillage, where the amount, orientation, and distribution of crop residue on the soil surface are managed. These practices improve the ability of the soil to hold moisture, reduces water run-off from the field, and reduces surface evaporation.

## 6.2. Increasing the livestock water productivity

Livestock production is a key strategy for livelihood diversification in the smallholder production systems. Keeping in view the fact that 20% of agricultural water consumption is by livestock, reducing the amount of water use in livestock sector could contribute considerably to reducing future water needs in the agricultural sector. Water required for animal feed and sanitation are the major water consuming activities, while the drinking water requirements of livestock are negligible. Water consumption by the animals depends on management practices, type of feed (concentrate/roughage), water consumed in production of animal feed, how crop products/bi-products are used as feed, and how well the animals convert feed and plants into the animal product. Further, valuing manure as a beneficial output of livestock systems would result in a much higher figure for LWP than when only meat and milk are taken into account. The measures for improving LWP can be grouped in three categories as depicted below (Peden *et al.*, 2009; Descheemaeker *et al.*, 2010; Herrero *et al.*, 2010):

- **Management of animal feed:** The careful selection of feed types, including crop residues and other waste products; improving the nutritional quality of the feed; optimizing the use of multi-purpose food–feed–timber crops; increasing feed water productivity by appropriate crop and cultivar selection and improved agronomic management; and implementing more sustainable grazing management practices.
- **Water management strategies:** Water harvesting, strategic placement and monitoring of watering points, and the integration of livestock production into irrigation schemes.
- **Animal husbandry practices:** Improved breeds, disease prevention and control, supported by raising awareness among livestock keepers that the same benefit can be obtained from smaller and fewer, but more productive, herds.

## 6.3. Increasing water productivity in fish production

Water use in the fisheries sectors include the amount of water required for feed plus the amount of evaporation from the pond. Total mass or value of the fish production is to be divided by this water use. Aquaculture can consume 500–800 litre in super intensive recirculation systems and as high as 40,000 litres of water per kilogram of produce in extensive systems. Cage aquaculture offers several benefits in terms of water saving and improved production consequently leading to enhanced water productivities. Cages allow natural water exchange and, like capture fisheries, do not induce significant water losses to the system. There is tremendous scope to improve WP of fisheries through integrating it with agricultural water management systems. In order to make this integration to happen at community to national levels, there is need of new set of laws and regulations. The WP of aquaculture can be increased through improving system design and management, using good quality water, productive brood stock, or using a combination of non-competing species that fill different niches in the aquatic ecosystem (Descheemaeker *et al.*, 2013).

# 7. Policy, Legislative and Regulatory Framework

The speculations on water scarcity made in the past are becoming real. Many parts of the country are facing acute water shortages not only for agriculture but also for domestic and industrial sectors. With increasing water demand from competing sectors, the investments on agricultural water management programs are expected to result in less water being used in agricultural sector. This is with the aim of providing more water to other sectors and increase the efficiency of water use in agriculture. Therefore, increasing agricultural 'water productivity' is the key approach to mitigate water shortage and to reduce environmental issues. It's high time that 'water productivity' should be given due consideration in developing informed irrigation policies at state and national level. The policy framework for improving WP should focus on technological advances, social acceptance and environmental impacts of proposed interventions. A popular intervention is the provision of support to farmers for transitioning to more capital-intensive irrigation technologies. In water scares areas, the focus should be on improving WP through '*water saving*' approaches while in water surplus areas, improving WP through '*improving land productivity*' may be a better approach. Formulation of policy guidelines can be in view of the following facts:

## 7.1. Water pricing

Pricing water and water related services can bring an inclusive change in the mind-set of the farmers and can encourage them to reduce water wastes and invest more in water-related infrastructure. In most states, electricity is provided free to pump water for irrigation purposes. This is resulting in over exploitation of the natural resources which may have long-term implication on WP of agriculture. Imposing charges on the amount of water withdrawn would make farmers to invest more on water efficient technologies, consequently increasing the agricultural water productivity.

### 7.2. Regulations on water use

Presently water pumping from aquifers and other surface bodies has no restriction and water is treated as free commodity. Farmers and other stakeholders are free to pump the water as per their need. Bringing in some regulation on water use can lower down the water usage to considerable extent and farmers may adopt technologies to utilize their share of water in an efficient manner.

### 7.3. Easy access to incentives on water efficient technologies

Cutting short the rigorous formalities involved in obtaining the incentives (grants, subsidies etc.) on improved technologies would be an important policy intervention. At present, many farmers distance themselves from adoption of technology mainly because of range of formalities involved in obtaining the subsidies. The central and state governments can implement the subsidy programs by employing FPOs, SHGs or *Kisan Mitra* to dispense the benefits of governments' schemes to farmers. This will definitely increase the adoption of improved technologies like drip, sprinkler, fertigation, solar systems, etc. which can have a positive impact on agricultural water productivity.

## References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop evapotranspiration. Guide-lines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, FAO, Rome.

Bos, M.G., Burton, M.A. and Molden, D.J. (2005). Irrigation and Drainage Performance Assessment. Practical Guidelines. CABI Publish, Wallingford.

Cai, X. and Rosegrant, M.W. (2003). World water productivity: current situation and future options. *In* Kijne, J.W., Barker, R. and Molden, D. (eds.). *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. Wallingford, UK: CABI; Colombo, Sri Lanka: International Water Management Institute (IWMI), pp.163-178.

Clement, F., Haileslassie, A., Ishaq, S., Samad, M., Mit, R., Shindey, D.N., Dey, A., Khan, M.A., Blümmel, M., Acharya, N.S. and Radha, A.V. (2010). Livestock water productivity in the Ganga basin. Completion report of the Improving Water Productivity, Reducing Poverty and Enhancing Equity in Mixed Crop-livestock Systems in the Indo-Gangetic Basin. CPWF Project (PN 68), CGIAR Challenge Program on Water and Food (CPWF). International Water Management Institute, Colombo, Sri Lanka, pp. 103.

Descheemaeker, K., Amede, T. and Haileslassie, A. (2010). Improving water productivity in mixed crop– livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, **97**: 579–586. doi:10.1016/j.agwat.2009.11.012.

Descheemaeker, K., Bunting, S.W., Bindraban, P., Muthuri, C., Molden, D., Beveridge, M., Brakel, M., Herrero, M., Clement, F., Boelee, E. and Jarvis, D.I. (2013). Increasing water productivity in agriculture. In: Boelee, E. (ed.) *Managing Water and Agro-ecosystems for Food Security*. CAB International, pp. 104.

FAO (2012). Coping with water scarcity: An action framework for agriculture and food security. FAO Water Reports-38, Rome.

Foster, S.S.D. and Perry, C.J. (2010). Improving groundwater resource accounting in irrigated areas: a prerequisite for promoting sustainable use. *Hydrogeology Journal*, **18**: 291–294.

Gichuki, C.N., Mutuku, M.M. and Kinuthia, L.N. (2015). Influence of participation in table banking on the size of women-owned micro and small enterprises in Kenya. *Journal of Enterprising Communities: People Places in the Global Economy*, **9**(4): 315-326.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H.A., Bossio, D., Dixon, J., Peters, M., van de Steeg, J., Lynam, J., Rao, P.P., Macmillan, S.,Gerard, B., McDermott, J., Sere, C. and Rosegrant, M. (2010). Smart investments in sustainable food production: revisiting mixed crop-livestock systems. *Science*, **327** (5967): 822–825.

Heydari, N. (2014). Water productivity in agriculture: challenges in concepts, terms and values. *Irrigation and Drainage,* **63**: 22–28.

Jha, B.K., Mali, S.S., Naik, S.K. and Sengupta, T. (2017). Yield, water productivity and economics of vegetable production under drip and furrow irrigation in eastern plateau and hill region of India. *International Journal of Agricultural Science and Research,* **7**(3): 43-50.

Jha, B.K., Mali, S.S., Naik, S.K., Kumar, A., Singh, A.K. (2015). Optimal Planting Geometry and Growth Stage Based Fertigation in Vegetable Crops. ICAR-Research Complex for Eastern Region, Technical Bulletin No. R-56/Ranchi-25.

Kumar, A., Singh, S.K., Kaushal, K.K. and Purushottam, P. (2015). Effect of micro-irrigation on water productivity in system of rice (*Oryza sativa*) and wheat (*Triticum aestivum*) intensification. *Indian Journal of Agricultural Sciences,* **85**(10):1342-1348.

Merriam, J.L., Styles, S.W. and Freeman, B.J. (2007). Flexible irrigation systems: concept, design, and application. *Journal of Irrigation and Drainage Engineering,* **133** (1): 2–11.

Molden, D. (1997). Accounting for water use and productivity. SWIM Paper, 1-16. International Irrigation Management Institute, Colombo, Sri Lanka.

Molden, D., Murray-Rust, H., Sakthivadivel, R. and Makin, I. (2003). A water-productivity framework for understanding and action. In: Kijne, J.W., Barker, R. and Molden, D. (eds.), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*. CABI Publishing and International Water Management Institute, Wallingford, UK/Colombo, Sri Lanka.

Molden, D.J., Sakthivadivel, R., Perry, C.J., de Fraiture, C. and Kloezen, W.H. (1998). Indicators for comparing performance of irrigated agricultural systems. IWMI Research Report 20, International Water Management Institute. Colombo, Sri Lanka, pp. 26. Doi: 10.3910/2009.028.

Nguyen-Khoa, S., van Brakel, M. and Beveridge, M. (2008). Is water productivity relevant in fisheries and aquaculture? In: Humphreys, E. *et al.* (eds) *Fighting Poverty through Sustainable Water Use*. Proc. of the 2nd Forum on Water and Flood, Ethiopia, Vol. 1, 1pp. 22-27. https://digi talarchive.worldfishcenter.org/ handle/20.500.12348/1573?show=full

Peden, D., Taddesse, G. and Haileslassie, A. (2009). Livestock water productivity: implications for sub Saharan Africa. *The Rangeland Journal,* **31**: 187–193. doi:10.1071/RJ09002.

Peden, D., Tadesse, G. and Misra, A.K. (2007). Water and livestock for human development. In: Molden, D. (ed.) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. London and Colombo: Earthscan and International Water Management Institute.

Seckler, D. (1996). The new era of water resources management: from 'dry' to 'wet' water savings. Research Report 1, International Irrigation Management Institute (IIMI), Colombo, Sri Lanka.

Seckler, D., Molden, D. and Sakthivadivel, R. (2003). The concept of efficiency in water resources management and policy. In: Kijne, J.W., Barker, R., Molden, D. (eds.). *Water Productivity in Agriculture: Limits and Opportunities for Improvements*. Comprehensive Assessment of Water Management in Agriculture Series 1, CABI International, UK.

Sharma, B.R., Gulati, A., Mohan, G., Manchanda, S., Ray, I. and Amarsinghe, U. (2018). Water productivity mapping of major crops. NABARD and ICRIER publication. Available at https://www.nabard.org/auth/writereaddata/tender/1806181128Water%20Productivity%20Mapping%20of%20Major%20Indian%20Crops,%20Web%20Version%20(Low%20Resolution%20PDF).pdf accessed on 27-11-2019.

Singh, S., Mishra, A.K., Singh, J.B., Rai, S.K., Baig, M.J., Biradar, N., Kumar, A. and Verma, O.P.S. (2014). Water requirement estimates of feed and fodder production for Indian livestock vis a vis livestock water productivity. *Indian Journal of Animal Sciences*, **84** (10): 1090–1094.

Skewes, M.A. (1997). Technology vs management skill - the challenge of efficient irrigation. Striking the balance: Irrigation and the environment - the 44th ANCID Conference and Study Tour. Deniliquin, NSW, ANICD, Australia.

Zhang, H., and Oweis, T. (1999). Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. *Agricultural Water Management*, **38**: 195-211.