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ISSUES AND CHALLENGES INWATER PRODUCTIVITY FOR SUSTAINABLE AGRICULTURAL GROWTH IN INDIA

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ABSTRACT

Providing food for the rising population has emerged as a challenge globally. The problem is further aggravated due to rising scarcity of natural resources like land and water. While increasing population is driving demand, climate change and other hydrological extremes are impacting the water availability in space and time. Under such conditions, water productivity plays an important role in modern agriculture which aims at increase in the crop yield per unit of water supplied for irrigation. The sustainable agriculture growth is a complex issue that depends on the productivity enhancement measures. Keeping this in mind, the present study aims at discussing the issues and challenges of sustainable agriculture and the water productivity. Further, it discusses the ways to improve the irrigation water productivity in terms of increasing the marketable yield of the crops, reducing the losses/outflows and by way of effective use of rainfall and irrigation, etc. Further, the improvement in water use efficiency is highlighted so as to increase the water productivity in India. Overall, the improvement of water productivity is envisaged through integrated, effective and efficient water management practices and policies.

INTRODUCTION

The world population, which was 3 billion in 1960 has increased to 7.5 billion in 2016 and is likely to increase to 8.5 billion by 2030. Food is the basic requirement for the sustenance of life along with water and energy. The fast growing population will require the considerable amount of food. Also, the water requirements for non-agricultural sectors like domestic and industrial are increasing. This has resulted in water-stress conditions in various parts of the world. Further, about 40% of the world area is under arid and semi-arid climatic conditions (Gamo, 1999) which requires more water for various purposes. Therefore, decisive handling of water resources like rainwater, optimal use of irrigation and improved water productivity are the important issues for the sustainable growth and development.

Historically, water was available in plenty and was considered as a free resource. However, with the rapid increase in world's population and the water demand for various purposes, the per capita freshwater water availability is declining at an alarming rate. For example, the total water use at the beginning of the last century was about 600 km^3/year. This rate witnessed a sharp increase and the global water use by the year 2000 was about 5300 km^3/year. Thus, there was a tenfold rise in the water use in the last century which is still increasing at a much faster rate.

At the global level, about 70% of the earth surface is covered with water, which amounts to about 1386 million cubic kilometers (m km^3). However, 97% of this water is in oceans and is salty. Fresh water availability is only about 35 m km^3 which is just about 3 % of the total water on the earth.Out of the total fresh water, 68.7% is frozen in ice caps, 30.1% is stored underground and only 0.3% water is available on the earth surface while 0.9% is in other forms. Further, out of the surface water, 87% is stored in lakes, 11% in swamp and 2% in rivers. As all the freshwater is not extractable, only 1% of the total water can be used by the human beings(Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources).

India has 16% of the world's population but only 4% of the average annual runoff in the rivers of the planet. For estimation purposes, the river system is divided into 24 basins, which has an average total runoff of about 1953 km^{3}per year. Out of this, total utilizable water resource in a year is about 1086 km^3 (690 km^3 is considered utilizable from surface resources and about 396 km^3 from ground water resources).The current population in India is about 1270 million. This means that the annual per capita water availability is about 1538 m^3 which is less than the 1700 m^{3}International critical limit and is termed as 'water stressed' condition. Further, water resources are not evenly distributedacross various continents. Some countries have surplus water while many other countries are facing scarcity of water. Likewise, there is skewed growth of population in different continents, resulting in a wide mismatch between the

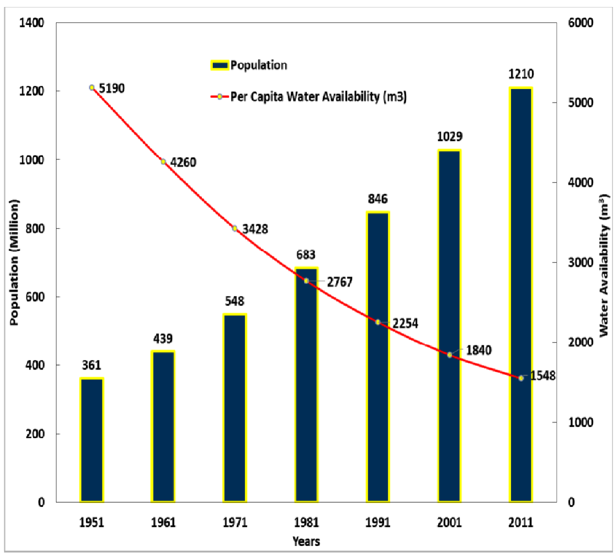

Fig. 1: Per capita water availability in India

per capita water availability. Among various continents, Asia has 36% of the available fresh water reserves, with over 60% of the world population where water is a scarce commodity. India receivesabout 1190 mm average annual rainfall but with a variation from 100 to 12000 mm. The number of rainy days are around 80. It is disturbing to note that only 18% of the rainwater is used effectively while 48% goes to the ocean through river flow. As the potential for increasing the utilizable water volume is hardly 5-10%, India is bound to face severe scarcity of water in the near future. Figure 1 shows the population and water availability variation over the past few decades and highlights how the scarcity of water is growing fast in India.

Since the water availability is decreasing and water requirements are increasing, it is likely to create a serious problem towards the food and water security in the country. Keeping this in mind, it is required to understand that water is an economic good and one should use it judiciously.

Without a major technological innovation, there is little hope of meeting the ever-increasing water demands. There is no doubt that new technological changes can help improve services for millions and reduce the stress on water systems around the world. For example, the agricultural sector witnessed a green revolution in many parts of the world during the last 4-5 decades. What is needed now is a super green revolution, a revolution that is more productive as well as more '*Green*' in terms of conserving natural resources and the environment. To emphasize appropriate utilization of water resources, this revolution is termed as the '*Blue*' revolution. Special emphasis is needed for drought-prone areas. An important and promising area of innovation is biotechnology, which is undergoing a revolution. It is fueled by the groundbreaking work in molecular genetics and the breathtaking advances in informatics and computing. New high yielding plants are being developed that are more environment-friendly and more drought- tolerant. These plants also have increased salt tolerance. Seeds of new variety coupled with agronomic techniques which are suitable to farmers with smallholding are necessary to yield "*more crop per drop*" of water.

SUSTAINABLE DEVELOPMENT AND ITS SCOPE

The concept of sustainable development has been developed to focus on the goal of "socially inclusive and environmentally sustainable economic growth". According to the principles of the UN Charter, the Millennium Declaration identified the principles and treaties on sustainable development encompassing the economic and social development with environmental protection as show in Fig. 2.

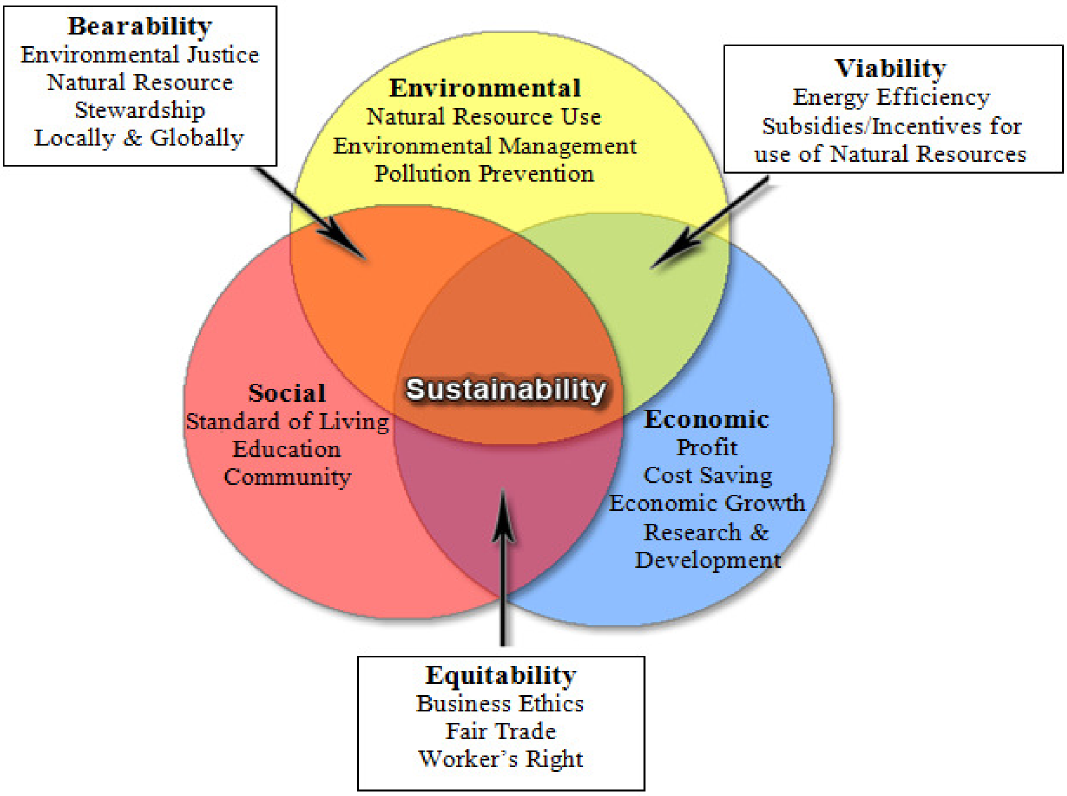

Fig. 2: Scope of Sustainable Development

Source: http://www.un.org/sustainabledevelopment/

Fig. 3: Sustainable Development Goals

The term sustainable development as stated by the UN incorporates the issues of land development along with human development in terms of education, public health, and the general standard of living.The Sustainable Development Goals (SDGs), officially known as transforming our world: the 2030 Agenda for Sustainable Development is a set of seventeen aspirational "Global Goals" on sustainable development issues as shown in Fig. 3. These included ending poverty and hunger, improving health and education, making cities more sustainable, combating climate change, and protecting oceans and forests.

Water is needed for various human activities, and therefore, most of the civilizations have developed on the banks of rivers. However, as the density of people increases, the flood plains are encroached for various anthropogenic activities. Sustainable development means that development which meets the needs of the present without compromising the ability of future generations to meet their own needs (*World Commission on Environment and Development, Our Common Future, 1987).*

Sustainability of watershed / region is affected by various issues like social, economic, and environmental issues.UNESCO's International Hydrologic Program-IHP adopted a framework in 1999 which includes hydrology, environment, life, and policy (HELP) issues. Considering that the water management is dynamic process, and assuming that the water sustainability of a basin is a function of its hydrology (H), environment (E), life (L), and policy (P), a dynamic, pressure-state-response model (OECD, 2003) was applied to those four indicators (H, E, L, P) in a matrix scheme. As a result, a watershed sustainability index-WSI was obtained(Chaves, et.al , 2007). Numerically, the WSI is given by:

$$WSI = (H+E+L+P) / 4$$

HELP is a cross-cutting and trans-disciplinary initiative and contributing to beneficial water management and policy, with the objective of meeting human needs and increasing societal benefit through appropriate use of water and sustainable development.

SUSTAINABLE AGRICULTURAL GROWTH – ISSUES AND CHALLENGES

Agriculture can be defined as "the science or practice of farming, including cultivation of the soil for the growing of crops and the rearing of animals to provide food, wool, and other products."

This issue has changed dramatically, especially since the end of World War II. Food and fiber productivity soared due to new technologies, mechanization, increased chemical use, specialization and government policies that favored maximizing production. Although these changes have had many positive effects but one has to pay some costs for that.Prominent among these are topsoil depletion, groundwater contamination, the decline of family farms, continued neglect of the living and working conditions for farm laborers, increasing costs of production, and the disintegration of economic and social conditions in rural communities. Sustainable agriculture integrates three main goals--environmental health, economic profitability, and social and economic equity. A variety of philosophies, policies and practices have contributed to these goals. People in many different capacities, from farmers to consumers, have shared this vision and contributed to it. Despite the diversity of people and perspectives, the following themes commonly weave through definitions of sustainable agriculture.

Sustainability rests on the principle that we must meet the needs of the present without compromising the ability of future generations to meet their own needs. Therefore, stewardship of both natural and human resources is of prime importance. Stewardship of land and natural resources like water involves maintaining or enhancing this vital resource base for the long term.

"The basic challenge for sustainable agriculture is to make better use of available biophysical and human resources. This can be done by minimizing the use of external inputs and by utilising and regenerating local or internal resources more effectively. The challenges to pursues five goals for sustainable agriculture growth is as mentioned below:

1. How to integrate the natural processes such as nutrient cycling, nitrogen fixation, soil regeneration and pest-predator relationships into agricultural production processes, so ensuring profitable and efficient food production whilst increasing natural capital.
2. The pathway for minimization of the use of those external and non-renewable inputs that damage the environment or harm the health of farmers and consumers, and a targeted use of the remaining inputs used with a view to minimizing costs.
3. How to do improvement in the welfare and quality of life of farm animals.
4. To get full participation of farmers and other rural people in all processes of problem analysis, and technology development, adaptation and extension (including a greater use of farmers' knowledge and practices in combination with new technologies emerging from research), leading to an increase in local self-reliance and social capital
5. How to enhance both the quality and quantity of wildlife, water, landscape and other public goods of the countryside

Factors affecting sustainable agricultural growth

Agricultural productivity refers to the output produced by a given land of input(s) in the agricultural sector of a given economy (Fulginiti and Parrin, 1998). Formally, it can be defined as the ratio of the value of total outputs to the value of total inputs used in farm production (Oluwatayo et al, 2008). Increasing inputs in order to expand output involves raising both the quality and quantity of inputs which would involved mechanization of agriculture, use of high yielding varieties, use of fertilizer, irrigation, and use of agrochemicals such as herbicides and pesticides. Sustainability can be understood as ecosystem approach to agriculture. Figure4 depicts a number of different factors which can cause agricultural productivity to increase. Most of these factors not only increase agricultural productivity but also maintain sustainability. Green color in pie chart represents the factors which increases agricultural productivity with sustainable agricultural growth.

Sustainable agriculture and water productivity is very closely linked to each other. Agriculture sector, the largest consumer of water (82.8%), is facing competition from other sectors due to the ever increasing demands of the burgeoning population and accelerated pace of urbanization and industrialization in the country. It is expected that reduction in the average size of land holding, declining per capita water availability, deterioration of water quality etc. will seriously affect the sustainable use of water resources and will make it difficult to accomplish the target of producing in future. To achieve the targeted food production, sustainable agriculture and increase in the water productivity is required. This can be done by practices as mentioned below.

Crop species type

Large quantity of water is loosed by crop when they open their stomata for CO_2 uptake in an unsaturated air. Water

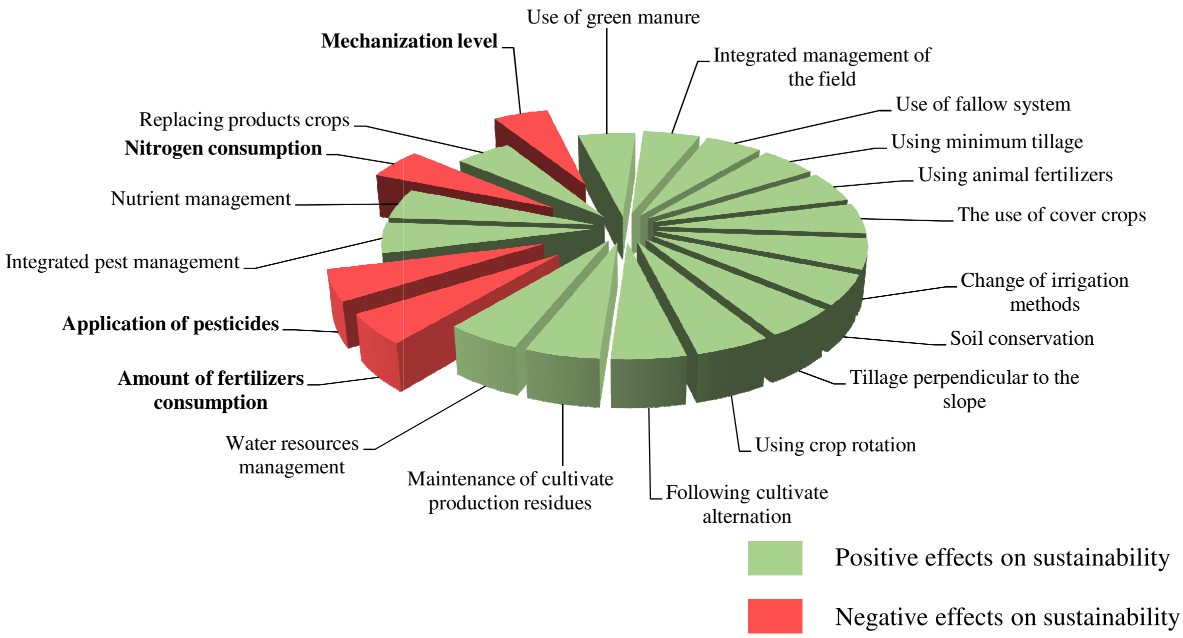

Fig. 4: Factors affecting sustainable Agriculture

productivity is largely a function of the CO_2 and vapor concentration gradients between the inside and outside of the leaf (Jones, 1992). These two opposing fluxes are regulated by stomata. Therefore, the stomatal behavior will determine the water productivity of a particular species. It is well known that C_4 plants have higher water productivity than C_3 plants. Within C_3 plants, many reports have shown that genotypes can be selected for higher water productivity according to their carbon isotope discrimination, a function of the CO_2 concentration gradient between the inside and outside of the leaf (Craufurd et al., 1991; Ehdaie et al., 1991).

Application of Irrigation

In agriculture, many ways of conserving water have been investigated. Techniques such as partial irrigation, deficit irrigation or drip irrigation have shown that water productivity can be increased (Ali et al., 1997, 2007; Jalota et al., 2006; Zhang et al., 2004; Oweis et al., 2000, 1998; Talukder et al., 1987, 1999; Oweis, 1997). Recent research has shown that in some irrigated situations, grain yield can be improved while reducing the amount of water applied to the crop (Yang et al., 2000, 2001, 2002), mainly via improved harvest index which has been shown as a key component to improve water productivity (Ehdaie and Waines, 1993).

Soil factor

Evaporative loss of water from the soil surface plays a significant role on plant growth during germination and seedling establishment, and also during other growth periods. Soil texture and organic matter content determine the water storage and release properties. Rapid drying of soil does not provide opportunity for osmotic regulation and adjustment, and thus affects yield and water productivity.

Agronomic factor

Agronomic factors which can affect water productivity are timeliness of sowing, evenness of establishment, use of herbicides, and the role of previous crop. Water productivity depends not only on how the crop is managed during its life, but also on how it is fitted into the management of a farm, both in space and time (Ali et al., 2005). Practices that particularly contribute to agronomic factors are early sowing, selection of varieties with early growth (under cool condition), adequate fertilization, adequate plant population and close spacing (Gregory, 1991; Harris et al., 1991).

Economic factors

Economic factors also influence the optimum level of water productivity. Many a time large additional costs are involved in increasing water productivity, for example, the investment in sprinkler, drip or hose pipe irrigation systems. These systems include the fixed and operational costs of changing the irrigation system. The return is more crop per drop of irrigation.

Table 1: Water productivity gains using drip over conventional irrigation in India

(Source :Molden et al. (2007)

Crop	Increase in yield in %	Decline in water application in %	Gains in water productivity in %
Bananas	52	45	173
Cabbage	2	60	150
Cabbage (evapotranspiration)	54	40	157
Cotton	27	53	169
Cotton	25	60	212
Cotton (evapotranspiration)	35	15	55
Cotton	10	15	27
Grapes	23	48	134
Okra (evapotranspiration)	72	40	142
Potatoes	46	0	46
Sugarcane	6	60	163
Sugarcane	20	30	70
Sugarcane	29	47	143
Sugarcane	33	65	280
Sugarcane	23	44	121
Sweet potatoes	39	60	243
Tomatoes	5	27	44
Tomatoes	50	39	145

Note: Water productivity is measured as crop yield per unit of irrigation water supplied or as the ratio of yield to evapotranspiration where evapotranspiration is indicated in parentheses.

Source: Adapted from Postel and others 2001; Tiwari, Singh, and Mal 2003 for cabbage row 2; Rajak and others 2006 for cotton row 3; Shah and others 2003 for cotton row 4; Tiwari and others 1998 for okra; and Narayanmoorthy 2004 for sugarcane row 5.

Table 2: Water productivity from a unit of water for selected commodities

(Source :Molden et al. (2010a)

Product	Water productivity			
	Kilograms per m^3	Dollars per m^3	Protein gram per m^3	Calories per m^3
Cereal				
Wheat ($0.2 per kilogram)	0.2–1.2	0.04–0.30	50–150	660–4000
Rice ($0.31 per kilogram)	0.15–1.6	0.05–0.18	12–50	500–2000
Maize ($0.11 per kilogram)	0.30–2.00	0.03–0.22	30–200	1000–7000
Legumes				
Lentils ($0.3 per kilogram)	0.3–1.0	0.09–0.30	90–150	1060–3500
Fava beans ($0.3 per kilogram)	0.3–0.8	0.09–0.24	100–150	1260–3360
Groundnut ($0.8 per kilogram)	0.1–0.4	0.08–0.32	30–120	800–3200
Vegetables				
Potato ($0.1 per kilogram)	3–7	0.3–0.7	50–120	3000–7000
Tomato ($0.15 per kilogram)	5–20	0.75–3.0	50–200	1000–4000
Onion ($0.1 per kilogram)	3–10	0.3–1.0	20–67	1200–4000
Fruits				
Apples ($0.8 per kilogram)	1.0–5.0	0.8–4.0	Negligible	520–2600
Olives ($1.0 per kilogram)	1.0–3.0	1.0–3.0	10–30	1150–3450
Dates ($2.0 per kilogram)	0.4–0.8	0.8–1.6	8–16	1120–2240
Others				
Beef ($3.0 per kilogram)	0.03–0.1	0.09–0.3	10–30	60–210
Fish (aquaculturea)	0.05-1.0	0.07–1.35	17–340	85–1750

Source: Adapted from Muir (1993), Verdegem et al. (2006), Renault and Wallender (2000), Oweis and Hachum (2003) and Zwart and Bastiaanssen (2004).

[a] Includes extensive systems without additional nutritional inputs to superintensive systems

CONCEPT OF WATER USE EFFICIENCY AND WATER PRODUCTIVITY

Water use efficiency (WUE) and water productivity(WP) are the two terms used quite frequently and are confused most of the times. WUE is the % of water supplied to the plant that is effectively taken up by the plant, i.e., that was not lost to drainage, bare soil evaporation or interception. Mathematically,

$E_f = V_u/V_e$

where,

E_f = Efficiency, dimensionless

V_u= Volume utilised, m^3; and V_e = volume extracted from the supply source, m^3

The various types of water efficiency used in irrigation are storage efficiency, conveyance efficiency, and irrigation efficiency etc.

On the other hand, WP aims to increase the yield production per unit of water used, both under rainfed and irrigated conditions. This can be achieved either by marketable yield of the crop for each unit of water transpired, by reducing outflows/ losses, or by enhancing the effective use of rainfall/ water stored in the soil and of marginal quality water. All these options lead to the on-form management aspects of crop growth through the best crop management practices which will permit the use of less water for irrigation, decrease evaporation losses, optimize fertilizer supply, allow better pest control and improve soil conditions. In other terms, the increase in WUE would lead to better WP and would help the farmer in improving the economic returns from the investments in irrigation water supply, and not the other way around. Heydari (2014) highlighted that the WUE is a dimensionless ratio of total amount of water used to the total amount of water applied, whereas, the WP is not a dimensionless term as it reflects the crop production per unit water. In broader sense, WP defines the net benefits from crop, forestry, fishery, livestock and mixed agricultural systems to the amount of water consumed to produce those benefits. One can distinguish the ‘physical water productivity’ (i.e., ‘more crop per drop’) and the ‘economic water productivity’ (i.e, ‘value’ derived per unit of water which may be in terms of economic, nutrition, social, environment etc.). For example, Molden et al. (2007) in Table 1 shows how the water use efficiency associated with the use of drip irrigation instead of surface water has led to the increase in water productivity of a number of crops in India. Further, Table 2 (Molden et al. (2010a) shows the productivity of selected commodities from a unit of water.

WAYS TO IMPROVE IRRIGATION WATER PRODUCTIVITY

The term “increasing or improving water productivity” implies how most effectively one can improve the outcome or yield of a crop with the lesser water. Figure 5 explains three pathways to attain highest irrigation water productivity.

Based on these pathways, there are number of techniques which can improve irrigation water productivity (Table 3).

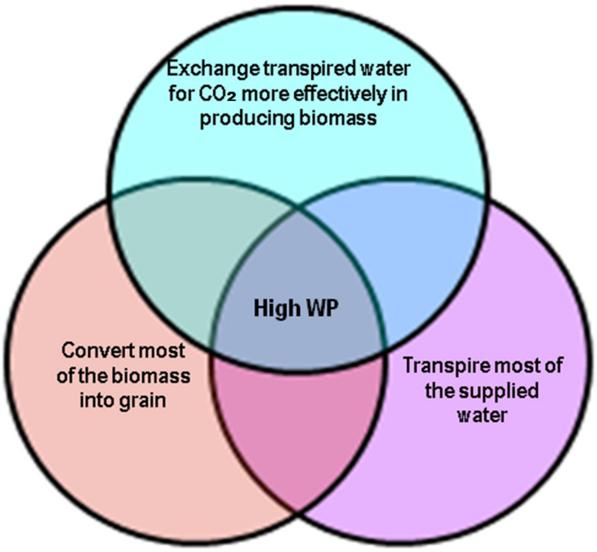

Fig. 5: Pathway for highest water productivity

Table 3: Techniques to improve irrigation water productivity

Techniques	Implication to improve water productivity
Deficit irrigation	Reduce the irrigation depth, refill only part of the root zone, reduce the irrigation frequency by increasing the interval between successive irrigations, refill a fraction of the soil water capacity of the root zone, wetting furrows alternately or placing them further apart.
Proper sequencing of water deficit	Alternate deficit bydrying-watering alternation. It had a significant compensatory effect that could reduce transpiration.
Surge irrigation management in vertisol	Application of irrigation water in a series of pulses, rather than the conventional continuous flow increases water productivity in vertisol.
Increasing soil fertility	In many dry-area soils having inherent low fertility, judicious use of fertilizer is important to increase yield at highest water productivity.
Improving assimilate partitioning to grain	By increasing harvest index and harvest ratio.
Manipulation of seedling age	Crop duration in the field (from transplanting to maturity) can be reduced by use of older seedling which reduce crop water requirement.
Wet-seeded or direct-seeded rice	The wet-seeded or direct-seeded technique is an alternative to the transplanting method which increase crop yield.
Priming or soaking of seed	Soaking seeds in water for a specific period before showing causes earlier maturity and increased seed yield.
Application of organic matter, farmyard manure and bio-fertilizer	Nitrogen management is one of the major factors to attain higher crop productivity which in turn increase water productivity in dryland farming where inorganic fertilizer is restricted due to limited water supply
Tillage and sub-soiling	Tillage roughens the soil surface and breaks any soil crust. This leads to increased water storage by increased infiltration.
Management factors	Suitable crop rotation, sowing dates, crop density, mulching, pests and disease control, water conservation measures
Water harvesting	Water harvesting may be defined as the process of concentrating precipitation through runoff and storing it for beneficial use
Minimizing transpiration	
Water-saving irrigation	Sprinkler and drip irrigation can save non-effective water loss.
Crop choice	By selecting a low water-demanding crop, water can be saved and the saved water can be used to irrigate additional land.
High value crop selection	A high economic return can be obtained with limited water resources, if proper crops are chosen. This, in turn, produces higher return per unit of water, a form of water productivity.
Modernization of irrigation system	Modernization and optimization of irrigation systems can contribute to increase water productivity
Integrating agriculture–aquaculture	Intensive aquaculture systems provide the possibility of using the nutrient-rich pond water for irrigation.

Precision irrigation is widely seen as an excellent method to save water and fertilizer and maximize irrigation water productivity. Globally, approximately 82 percent agricultural land, does not irrigated at all. They rely only on rainwater. The remaining 18% employ three main methods of irrigation: Surface (flood), Micro (drip) and Mechanized (sprinkler, center pivot, water gun). While flood irrigation is by far the most popular and least efficient there exists a general trend towards smarter micro and mechanized irrigation systems.

Surface irrigation is considered imprecise. When you water an entire field you irrigate a large area where there are no crops, thereby wasting water. Since the fertilizer is delivered via the water you also waste a lot of fertilizer. Surface irrigation also makes it very difficult to ensure all the crops receive a uniform amount of water. For example, plants at the beginning of a field usually receive more water while those at the end receive less.

Drip irrigation, in contrast, is the most precise as it waters plants directly at their roots, so no water is wasted watering areas that do not contain the crop. It also ensures every plant gets an exact and uniform amount of water and fertilizer.

Precision irrigation improves the crop yield. More water does not necessarily equal a better crop. You need to give the plant the exact amount of water it needs to ensure optimal growth. Over or under watering stunts growth. With fertilizer the situation could be even worse as too much fertilizer can induce plant toxicity.Precision irrigation conserves both water and fertilizer. It also improves crop yield.Take cotton for example. If you water cotton too much it will grow into a big plant but produce little cotton. With cotton you want to stress the plant and even dry it out. Only when it feels it is going to die, does the plant release all its cotton. Grapes for wine are another example. If you over water them they grow large but do not produce enough of the sugar which is important for wine making.So precision irrigation is not just to save water, it is also for the more precise application of water. If you water improperly you damage the quality of the crop.

CONCLUSION

Improving agricultural water productivity in India will persist to increase to cope up demand for increased grain production because of growing population. But the high water productivity value is of scant interest if it is not balanced with high potential or acceptable/moderate (about 70-80% of the highest) yields. This balance of high or moderate productivity values with high or moderate yields has critical implications for attaining efficient use of water resources for crop management in water scarce areas like Gujarat, Rajasthan, M.P., Orissa and Andhra Pradesh. From this study, it is concluded that there are many options for enhancing irrigation water productivity. However, the most appropriate option(s) will vary from State to state, place to place, and will also depend on social and economic conditions of the farmers. Numerous technical implicationsare available to increase WP for a particular situation or hydro-ecological condition.

Themain pathways for enhancing irrigation water productivitydepends on various aspects like engineering and agronomic management aspects, environmental aspects, social aspects.Engineering and agronomic management increasesthe output per unit of water. Environmental aspect enhances water productivity byreducing losses of water to unproductive sinks and water degradation. By dealing with social aspect through reallocating water to higher priority uses crop per drop can be increased. By practice of water-saving agriculture will not only increase water productivity, but also reduce the structural adjustment needed for agriculture. Drought tolerance by genetic improvement and physiological regulation is a biological watersaving measure. By promoting a combination of this with engineering solutions, and soil and agronomic manipulation may solve the problem of low irrigation water productivity of many places of India. Not only in India but this issue should be taken up with international coordination. Globally, water resources may be used more efficiently when food will be imported from the countries with high crop water productivity (CWP) to the countries with low CWP. With the increasing integration of the world economy, there is an emerging need to support water and food policy formulation and decision-making at the global level. New and innovative scientific information are needed to improve irrigation water potential along with economic.

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