Water Use Efficiency for sustainable agriculture

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Abstract: India's agriculture is facing acute water scarcity and a major reason for this is very low water use efficiency – only about 25 to 35 percent in conventional irrigation. The overall irrigation project efficiency in developed countries is 50 – 60% as compared to only 38% in India. The effectiveness of plants in limiting water loss while allowing CO_2 uptake is given by the transpiration ratio.

Key words: Aerobic rice, Evapotranspiration, Millets, Transpiration ratio, Water use efficiency

Introduction

Water use efficiency (WUE) is a concept introduced 100 years ago by Briggs and Shantz (1913) showing a relationship between plant productivity and water use. They term, WUE, can be expressed as a measure of the amount of biomass produced per unit of water used by a plant. In irrigation, water use efficiency represents the ratio between effective water use and actual water withdrawal. Crop water use efficiency is the yield of the crop per unit of water lost through evapotranspiration of the crop whereas field water use efficiency is the ratio of yield of the crop to total amount of water used in the field. The crops that have high water use efficiency (WUE) are sorghum and pearl millet. The ratio of water used for plant metabolism to water lost through transpiration by plants is known as water use efficiency. Any method of irrigation that minimizes evaporation (but not transpiration) is likely to increase the efficiency of water utilization by the crop. Highest water use efficiency is observed in this order CAM> C3>C4 plants. CAM plants: Crassulacean acid metabolism photosynthesis is a carbon fixing pathway adapted in plants that grow in an arid climate. Maize has the highest WUE in irrigated conditions, and sorghum has the best WUE under rain-fed conditions among the cereals (Cooper et al., 1987). Rice uses two to three times more water than other food crops such as wheat or maize and uses 30% of the freshwater used for crops worldwide. Doyle and Fischer (1979) correlated dry matter accumulation and water use relationships in wheat crops. Sugarcane and rice are the least water-efficient crops that require 1800-2200 mm/season water.

Globally, agriculture is the largest single user of fresh water, consuming for over 90 per cent of fresh water. Irrigated rice utilizes 45 per cent of the total fresh water accounting for almost 2 to 3 times of that consumed by other cereals. With the world's population set to increase by 2050, the additional food required to feed future generations will put further enormous pressure on fresh water resource. Raising the Water-use efficiency of both irrrigated and rain-fed or water stressed arid or semi-arid areas crop production is an urgent imperative (Condon et al., 1990, 1993). In 1984, Sinclair et al. studied water use efficiency in various crops. Siddique et al. (1990) also compared water use efficiency of old and modern wheat cultivars in a Mediterranean-type environment. Different countries would be depleting its groundwater resource by 2020 at the current rate of exploitation. And if preventive steps are not taken, in less than three decades, Great Britain might face acute water shortage in view of present projections. The reasons are climate change (hotter and drier summers) and population growth. A change of attitude is essential towards water conservation to help tackle the problem. To avoid severe water shortages, demand would have to be reduced by taking measures like cutting down on leakage, having sustainable drainage systems and cutting down personal use, and the supply would have to be expanded. A twin-track approach is the right way to go, reducing demand of water and at the same time increasing supply to deal with the challenges of growth on one hand and climate change on the other.

Van den Boogaard et al. (1996, 1997) made a comparative study of growth, yield and water use efficiency of ten *Triticum aestivum* cultivars at different water availability in relation to allocation of biomass. One of the primary objectives of sustainable agriculture is to ensure that farmers can increase agricultural production while using water more efficiently and reducing environmental degradation. Several measures can be adopted to improve water use efficiency such as conducting water irrigation scheduling, reducing water pollution, using of harvested rainwater, checking for water losses in distribution systems, improving water management, reuse and recycling. In addition, good agricultural practices as managing soil fertility and reducing land degradation are important for increasing water efficiency.

Measures to improve water-use efficiency

1. Improve water use efficiency: There is still ample scope for water use efficiency improvements (getting more yields per cubic metre of water) and reducing the risk of causing diffuse pollution through over-irrigation by improving the farm irrigation system. One way of doing so is implementing a drip irrigation system which enhances irrigation efficiency relative to conventional techniques (such as gravity systems, which include flood irrigation of entire fields, and furrow irrigation using shallow channels or ditches to carry water to the crop). Farmers using a pumping systems to irrigate their fields should ensure that the pump and pipe size are fitting with their needs, thus avoiding water and energy overuse and consequent leakages. An important component of the evaluation of infield irrigation performance is the assessment of the irrigation uniformity. Ideally, the average volume applied should meet the crop requirements, avoiding over or under-irrigation.

   Conveyance losses can be reduced by substituting open irrigation channels or canals over a period of time with large diameter prefabricated piped irrigation network or closed conduits supplying water to one or more farms. A major aim of irrigation management is to apply water with a high degree of uniformity through the field. Besides this, to improve the performance of infield application systems it is recommended to ensure that land is properly levelled (in the case of flood or furrow irrigation), to check the condition of the irrigation system, pumps, mains and hydrants periodically and to repair worn items such as seals (for overhead and drip systems).

   Drip irrigation is the most efficient water and nutrient delivery system for growing crops. Water and nutrients are delivered across the field through "a filter" into a special drip pipes, with emitters located at different spacing .Water and nutrients are uniformly delivered directly, through a special slow release emitters, to plant's root zone in the right amounts and right time into the soil . Farmers can produce higher yields with huge saving on water (no evaporation or no runoff, or no leaching thus avoiding contamination of ground water) and fertilisers, energy, and even crop protection product, reducing the evaporation that happens with open channels or spray watering systems. More efficient solar powered drip irrigation kits are available in the market.

2. Rainwater harvesting: The quantity of rainwater to be harvested by the farmers will depend on the location of the farm and the climatic conditions as well as size, slope and material of the collecting container. Now it is mandatory for building establishments or farmland to install rainwater harvesting systems .
3. Understand soil structure and manage moisture conditions: Understanding how soil properties affect water storage before designing an adequate irrigation system can help optimising water use by plants. Soil moisture depends on climate, topography and other soil characteristics. Some plant species are highly adaptable and can tolerate a range of moisture conditions. Others have very specific moisture requirements.
4. Schedule irrigation : Reduce direct evaporation during irrigation by avoiding midday sprinkling. Reduce runoff and percolation losses due to irrigation scheduling. Irrigation scheduling takes into account the evapotranspiration rate and soil moisture deficits and climate conditions to calculate the exact amount crop water requirement per day. An efficient use of water results when providing the crop with the exact amount of water.
5. Alternative sources of water: An alternative source of water that farmers can use is rainwater collected from containers, roofs of farm buildings. This source of water can be used for a variety of activities, including washing down yards and various equipments. Establishment of giant desalination plants, and even slightly brackish water (though not good for drinking for human consumption) can be used for irrigation.
6. Use alternative washing and cleaning processes: To diminish the water use in washing materials it is recommended, wherever applicable, to use alternative washing such as dry cleaning techniques. Scrapers, squeegees and brushes can be used to remove solid waste before cleaning them with water. This can help reduce the amount of water use, as well as the volume of dirty water that needs treating, storing and disposing of. It can also reduce the risk of creating diffuse pollution. In addition, farmers can use pressure washers to improve efficiency of cleaning and reduce water use. In the case of crop wash, it is recommended to recycle and reuse wash water. Instead of letting water go to waste, it can be recycled and used where high quality water

is not needed, or even cleaned and recycled for high quality use. Integrating waste water being recycled and majority of it being diverted for agricultural use.

7. Avoid water pollution: Agricultural processes such as tillage, ploughing of the land, use of pesticides, fertilisers, over-irrigation, spreading of slurries and manure can cause the contamination of water if not properly managed. Some ways of avoiding water pollution is by implementing conservation measures such as riparian buffers, integrated pest management and manure management. It is recommended to assess the risk of pesticides use on water resources.
8. Establish a water management plan: A good way of managing water use and water pollution is to establish a comprehensive Water Management Plan (WMP) for the farm that identify water use and sources of pollution, water footprints of the crops, water efficiency plans within the farm. Waste water generated by big consumers should be cleaned, refined, and reused for horticulture, thus avoiding use of fresh water. Singapore has become self-sufficient in water by recycling all sewage water.
9. Reduce transpiration and evaporation: Transpiration can be reduced by weeds, keeping inter-row strips dry and apply weed control measures wherever required. Evaporation can be reduced by using compost, mulch and cover crops from bare soil by keeping the inter-row strips dry. Boast and Robertson (1982) used ‘micro-lysimeter’ method for determining evaporation from bare soil. Yunusa et al. (1993) also studied dynamics of water use in spring wheat growing in dry Mediterranean environment using four evaporation models by microlysimetry technique.. Drought-tolerant crops suitable for dry farming can be grown in arid and semi-arid regions.
10. Minimise land degradation : Reducing land degradation is important for increasing water use efficiency and also minimise soil erosion. No-tillage, for example, not only protects soil architecture through minimal soil disturbance, but also can increase water use efficiency by permitting an efficient water and nutrient cycling as a result of root development and stable biological porosity. These soil organisms undertake biological ripping that improves soil structure, preventing compaction and facilitating root penetration.

Transpiration ratio

The reciprocal of transpiration ratio is termed as water use efficiency. Transpiration ratio is defined as the amount of water transpired by the plant divided by the amount of CO_2 assimilated through photosynthesis. It is a parameter to assess the effectiveness of plants in balancing loss of water coupled with adequate intake of CO_2 for photosynthesis. Pilbeam et al. (1995) studied transpiration efficiency of maize and beans in semi-arid Kenya region. This was followed by the studies of Zhang et al. (1998) where they calculated water-use efficiency and transpiration efficiency of wheat under rain-fed conditions and supplemental irrigation in a Mediterranean-type environment.

Transpiration ratio of C3, C4, and CAM plants are as follows:

- C3 plants have a transpiration ratio of 400 (hence, water use efficiency is 0.0025 or 1/400; approximately 400 water molecules are lost for one carbon dioxide molecule assimilated through photosynthesis).
- C4 plants have a transpiration ratio of 150 (comparatively less water gets transpired per molecule of CO_2 assimilated. This is because C4 phototosynthesis results in a lower CO_2 concentration in the intercellular air space, thus creating a larger driving force for the uptake of CO_2 and allowing these plants to operate with smaller stomatal apertures and thus lower transpiration rates.
- CAM plants have even lower transpiration ratio, approximately 50. Because their stomata open at night, so transpiration is much lower at night.

Causes of high transpiration ratio

(i) The concentration gradient responsible for water loss is approximately 50 times more as compared to that of the intake of CO_2.This might be because of the low concentration of CO_2 in air (0.036%) and relatively high concentration of water vapour within the leaf.
(ii) The diffusion rate of CO_2 is about 1.6 times slower through the air than that of water. This is because the CO_2 molecule being bigger than the water molecule, has a lower diffusion coefficient.
(iii) In order to be assimilated in the chloroplast, CO_2 must diffuse across the plasma membrane and the chloroplast membrane through cytoplasm, which contribute to the resistance of the CO_2 diffusion passage.

Millets can be wonder crop, providing food, nutrition, and livelihood security besting the adverse impact of climate change. Aerobic rice is another better remedy for future climate change under drought conditions.

Millets –the super crop

In view of shortages of water, millets (Sorghum, Pearl Millet and Finger Millet as well as minor millets like foxtail millet, little millet, kodo millet, proso millet, and barnyard millets) are increasingly being included in the food basket of rural and urban households. The millets can be grown even in dry land, using only 20 cm of rainfall, thus solving the issue of drought. Only 200 litres of water is required to grow one Kg of millet, as opposed to almost 9,000 litres of water for growing one Kg of rice or wheat. They cost less than rice or wheat and keep us healthier. They need less water to grow and can tolerate high temperatures, crucial for farmers in the era of climate change. Millets, the yesteryear staple diet of a majority of people in the semi-arid regions of Asia, especially India, could be the climate-resilient crops. Millets can counter many of the adverse effects of climate change better than most other food crops. They can grow in almost any type of soil-sand or varying levels of acidity. They hardly need any fertilisers and irrigation. Millets are generally resilient to pests. Millets have no gluten and low glycemic index, thus ideal for those with celiac diseases and diabetes. As millets have more tillers or branches than corn and sorghum, they provide better fodder too. All they require is support of policy makers.

Aerobic rice – the way to go in future

Rice is the staple food of about 3 billion people. Globally rice is grown over and area of about 149 million hectares with an annual production of 600 million tonnes and the demand is expected to rise as population increases. This will put enormous pressure on our fresh water resources that are dwindling. IRRI, Philippensis has developed the "Aerobic Rice Technology" to address the water crisis in the tropical agriculture. Rice is grown in the well-drained, non-puddled, and non-irrigated or nonsaturated soils , like wheat, maize and sorghum etc. that grow on dry soils (Bonachela et al.,1995). Aerobic rice is direct-seeded into the fields, eliminating the cost of raising nursery, transplantation and its related impact on labour. Direct seeding also reduces "seed rate" dramatically. Water requirements can be lowered by reducing water losses due to seepage, percolation and evaporation. In a pioneering effort in 2007, India officially released for cultivation its first drought tolerant Aerobic Rice Variety MAS 946-1, followed by MAS 26, developed at the University of Agricultural Sciences, Bangalore . Yield was at par with the traditional irrigated-puddled rice paddies with an average of 5.5- 6 tonnes/ hactare. Aerobic rice systems can reduce water use in rice production by as much as 50 percent . Additionally, it emits 80-85 per cent less methane gas into the atmosphere, thus keeping the environment safe.

Conclusions

Improvement of agricultural water use efficiency is of major concern with drought problems being one of the most important factors limiting grain production worldwide. Effective management of water for crop production in water-scarce areas requires efficient approaches. Increasing crop water use efficiency and drought tolerance by genetic improvement and physiological regulation may be a means to achieve efficient and effective use of water. Plant nutrients play a very important role in enhancing water use efficiency under limited water supply. Gregory et al. (1981) and Morgan (1986) while studying nutrient relations in winter wheat crop, observed the effects of nitrogen nutrition on the water relations and gas exchange characteristics. Waraich et al. (2011) suggested that the agricultural water use efficiency can be improved by nutrient management in crop plants.

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