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Saving Water for Ecological Integrity: Agricultural Perspective of *Per Drop More Crop*

Suresh Kumar*

Division of Biochemistry, ICAR-Indian Agricultural Research Institute, India

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***Corresponding author:** Dr. Suresh Kumar, Principal Scientist, Division of Biochemistry, ICAR-Indian Agricultural Research Institute, New Delhi-110012, India

Abstract

Water is so essential for living organisms that it is said "save water, save life". Pollution of water, scarcity of water (drought), excess of water (flood) and excessive snow-fall are the different forms in which water becomes unusable/creates problems for the survival of many organisms. Therefore, saving water in its usable form is essential for the existence of life on the earth. One of the ways to save water is its judicial use, which is essential for increasing water productivity. Availability of water in sufficient amount, for those who require it, is necessary for ecological integrity as well as ecological efficiency. While ecological efficiency is related with resource utilization and the extent to which resources are converted into biomass, ecological integrity is crucial for biodiversity conservation. About two-third of the available fresh water is utilized for agricultural activities, and any imprudent/imbalanced use of water in agriculture would make it unavailable for other crops or other activities. Rice consumes plenty of water for its cultivation when grown by transplanting, which might pose challenges for its cultivation in future, particularly due to the changing climatic conditions. However, dry/direct-sown rice (DSR) is emerging as a resource-conserving, economical, and climate-smart alternative to transplanted rice (TPR). Therefore, the need of the day is to replace TPR with DSR for better water productivity, minimizing the emission of anthropogenic greenhouse gases, and proceeding towards the negative emission agriculture. To produce sufficient food/feed/fodder in safe and sustainable manners for the burgeoning global populations, it is necessary to wisely use the natural resources taking the help of modern tools and techniques, along with the conventional methods, considering the biosafety and ethical issues for better ecological efficiency and integrity.

Keywords: Direct-sown rice; Ecological efficiency; Ecological integrity; Emission of greenhouse gas; Saving water; Transplanted rice; Water-productivity

Introduction

Water is vital for all living organisms, as a living cell contains ~70% water. Just a loss of 4% of water from human body leads to dehydration, and merely a loss of 15% water from the body can be fatal. Water molecule possesses both negative and positive charges; each attracts the molecule having opposite charge. Such attraction allows water to interact with polar molecules around it. Water, being a polar molecule, interacts with other polar molecules, including other water molecules. The positively charged hydrogen atoms of one water molecule bond with the negatively charged oxygen of the adjacent water molecule. Thus, a water molecule can interact with maximum of four water molecules in the surrounding in its solid state. Such cohesive (hydrogen) bonding between the water molecules makes them to stick together, known as cohesion. This cohesion property of water is responsible for its higher boiling point, helps plants to take up water through roots, and animals to regulate their body temperature. Thus, dependence of living organisms on water for the survival is vital.

Human body continuously lose water through breathing, sweating, and digestive process; hence, it becomes crucial to rehydrate/replace water in the body by drinking fluids/eating foods that contain water. Similarly, plants lose water through transpiration from stomata; hence, it is essential for plants to regulate water homeostasis according to the surrounding environment. Only about 0.3% of the natural water on the earth is usable by human beings and many other living organisms. Scarcity of water is becoming more frequent in many regions of the world, with more than one billion people facing paucity of drinking water, particularly due to the changing global climate. Such a situation is one of the important reasons compelling us to care about and be conscious towards water resources.

Water, being one of the essential constituent of cell, is required for the survival of organisms on this planet. Pollution of water, uncontrolled use of pesticides, wastage of water, improper agricultural practices, diminishing water resources, global climate changes, drought, flood, and excessive snow-fall are threatening existence of life on this earth. Natural water resources are extremely important for civilization, agriculture as well as for industrialization. Water being essential for various personal/social usages for the human beings, its major portion is used for agricultural activities to cultivate/grow food, feed and fodder crops.

Ecological Efficiency

Ecological efficiency is determined by a combination of many related efficiencies that define resource utilization and the extent to which resources are converted into biomass. Generally, ecological efficiency of an ecosystem is an approximation. For example, assessing the ingestion requires the gross amount of food consumed in an ecosystem and its caloric content. Such estimations are mostly approximation, particularly in case of the ecosystems that are less accessible to ecologists and/or the tools of measurement. In agricultural ecosystem, maximum energy transfer from producer (e.g., plant/food) to the consumer (livestock) results in better economic benefits. The Lindeman's 10% law of transfer of energy from one trophic level to the next actually deals with the ecological efficiency [1]. This states that during the transfer of organic food energy from one trophic level to the next higher level, only ~10% of the transferred energy is stored as flesh. The remaining energy is broken down in respiration, lost during transfer, or lost due to incomplete digestion of the food consumed by the consumer at higher trophic level. Similarly, when a carnivore consumes herbivore, only ~10% of energy is fixed in the flesh of the higher trophic level. However, only ~1% of the light energy can be taken up by plants from the sun. For example, when the sun releases 10,000 J of light energy, the plants take only 100 J of the sunlight energy. Thereafter, a goat/deer takes only 10 J (10%) energy from the plants eaten, and a wolf eating the deer receives only 1 J (10%) of the energy from deer. A tiger eating the wolf would receive only 0.1 J (10%) of energy from the wolf. Thus, the 10% law deals with energy transfer efficiency in ecosystem through various trophic levels. A logical conclusion drawn from this is that energy efficiency can be maximized by sourcing food being at closer to the initial energy source/producer. Water being one of the essential ingredients of photosynthetic process, it plays important role in energy transfer process in an ecosystem. More importantly, plants (those organisms which can perform photosynthetic process) are the only living organisms which can put/introduce energy into the ecosystem by absorbing it from the sun. As per the law of thermodynamics, energy can neither by generated nor it can be destroyed, but is can be transferred from one form to another with a certain amount of energy lost in the transfer process. However, the total amount of energy in the system (available energy in one form = energy converted in another form + energy lost during the transfer) remains the same. This is equally true for the Lindeman's 10% law of transfer of energy. Whatever different forms of energy we observe around us, be it electrical energy, hydro-energy, mechanical/chemical energy in living organisms, chemical energy in fuels, etc., are all put into the system by plants taking/absorbing from the sun. Thus, plants are not only responsible for providing fresh air (oxygen), but they also pour energy in the ecological systems. Needless to mention hat water is always present as an essential component whether it is the process of oxygen generation or conversion of energy.

Water Productivity

Water productivity of a plant is the measure of economic/biophysical gain from the use of a unit of water consumed by the plant. Thus, water productivity can be improved by saving/optimizing the use of rainwater for crop production, maximizing the utilization of existing irrigation water resources in a sustainable manner, and designing new efficient strategies for irrigation. A significant improvement in water productivity can be brought by selecting/breeding crop plant for better water use efficiency, the amount of carbon assimilated as biomass/grain produced per unit of water used by the plant, using appropriate planting methods, minimum tillage to minimize water losses, nutrient management, etc. Various features of the crop like early plant vigour, short stature, and shorter crop duration also help increasing the water use efficiency. Increase in water productivity of improved crop varieties has been observed mainly because of the increased water use efficiency of varieties and better irrigation management practices. The goal of *Per Drop More Crop* could be realized only if appropriate strategies for water savings and its more efficient uses in agriculture are adopted.

Excessive loss of water (due to transpiration from plants, evaporation and percolation from rice field) results in very low productivity of water, when rice is cultivated by transplanting under irrigated lowland production system. Assessment of the components of evapotranspiration (ET) in rice (1.6kg/m) was reported to be comparable to that of many other cereal crops. However, when other components of water losses were taken into account, the field level water productivity of rice was found to markedly less. Water productivity with respect to ET was reported to vary from 1.39-1.61, while the water productivity with respect to ET + seepage + percolation varied from 0.48-0.68. When water productivity was calculated considering ET, seepage, percolation, and water required for land preparation, it was observed to be the least ranging from 0.29-0.39 [2]. This clearly indicates that water productivity of rice when grown by transplanting is very low, which justify the need for replacing TPR with more water productive way of growing rice.

Ecological Integrity

The concept of ecological integrity was initially used as a guiding framework for restoration and monitoring of protected areas [3]. Ecological integrity is crucial for biodiversity conservation based on habitat-based approaches, species-specific management and monitoring. The US Forest Service uses ecological integrity to guide assessment, land-use planning, and monitoring of forest ecosystems. Since literature on ecological integrity is scanty, researchers use their own viewpoints to interpret and apply the strategies. Practical approaches of conservation biology and

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community ecology in context of resource conservation make the scientific foundations of ecological integrity. Ecological integrity emphasizes the importance of ecological processes that provide the structures and functions on which various species in an ecosystem depend [4]. Ecological integrity also depends on native biodiversity for function and renewal of ecosystem structure [5]. An ecological system is considered to have integrity when its composition, structure, function, and processes are within the natural range of variation and can recover from the perturbations caused by natural or human disruptions [6].

Agriculture: Feeding the Burgeoning Global Populations

The global human population is expected to reach 7-9 billion by 2050, which would pose challenges in sustainably feeding such a burgeoning global population. To feed the burgeoning population, we need to produce more food and livelihood opportunities from diminishing availability of arable land and water [7]. Providing food, feed, and fodder for the growing global populations (human and domestic animals) are only the preliminary challenge; other more important challenges would be to produce them in a safe and sustainable manner. The changing global climate affects productivity and quality of the produce due to the environmental variations, which create issues for the availability and quality of food/feed/fodder [8]. Agriculture consumes about two-third of fresh water, and the reducing availability of fresh water (even for human consumption, which receives first priority) would bring challenges in sustainable agriculture. Moreover, due to various human activities the availability of usable water is decreasing, also because it is getting polluted and used unconsciously.

Globally, the use of ground water has increased considerably (about five-fold) between 1940–2010, and shortage of water is being faced in many countries. The major factors that limit water availability include unpredictable/reduced rainfall, increased temperature/evaporation, and water runoff. Moreover, the global climate change is responsible for uneven distribution of rainfall over the year and throughout the geographical regions. Both the scarcity of water and excess of water cause severe damage to several species. Therefore, the need of the day is to take necessary care, implement measures to make water available throughout the year, and use the water resources wisely. Water resources are very important not only for adequate supply of drinking water but also for ample supply of foods, which can be produced with the use of water. Therefore, efficient use of water has become a need of the hour to maintain ecological balance/integrity. Hence, there is growing realisation of the need to save water and water resources.

The share of freshwater for agriculture is declining continuously because of the increasing human consumption, lowering ground water table, deteriorating water quality, inefficient irrigation systems, and the increasing use of water for non-agricultural purposes. Currently, agriculture accounts for the use of 70% of freshwater. The share of water used globally in agriculture is declining continuously from 98% (in 1900), through 80% in 2000 to ~72% in 2020. Certain crops (e.g., rice) require more water for irrigation/cultivation, compared to that required for other crops.

Feed and Fodder Required to Meet the Demands of Food

The improving per capita income would certainly increase the demands for livestock products like milk, egg, meat etc. Therefore, to meet the demand, farmers would require using improved breeds of domestic animals and high-quality feed/fodder to feed their animals. This would further increase the pressure on available lands to produce more feed and fodder for the animals [9]. Animal husbandry, another important component of agriculture, is equally important to produce food (e.g., egg, meat, milk, etc.) for human consumption. However, animal husbandry requires feed/fodder for the domestic animals, cultivation of which also requires water. Hence, it would be necessary to minimize wastage of irrigation water not only in cultivation of food crops, but also in growing feed/fodder crops so as to produce more crops per drop of water (more food/feed/fodder with less water).

Some of the grass species (such as *Cenchrus*, now a component of *Dichanthium-Cenchrus-Lasiurus* grasslands) are resilient to harsh environmental conditions such as strong wind, acute erosion, drought and nutrient-depleted soil, which can be used to grow fodder for domestic animals in the less-fertile/degraded lands [10] without much input of water. Similarly, Stylosanthes is a leguminous fodder crop which not only provides fodder for domestic animals but also restores soil fertility, improve soil physical properties, and provide permanent vegetation cover to minimize soil erosion. *Stylosanthes* species play vital roles in the development of grassland and wastelands. *S. seabrana* is a potential range-legume and a diploid progenitor of drought tolerant *S. scabra* [11]. Increasing the availability/quantity of feed/fodder is quality important along with improving the quality of feed/fodder. Genetically improved fodder with increase digestibility of low-quality roughage can improve the feed value. Increasing forage quality and producing novel pharmaceutical proteins can be a focus of forage improvement programs [12]. Future food and forage production will increasingly be affected by competition for the natural resources like land and water [9]. Fodders are the foundation upon which good dairy nutritional programs are built. Digestibility and intake of forage by livestock directly affect their rumen function and health as well as their meat/milk production. Thus, forages indirectly make a significant contribution to food security by providing feed/fodder for ruminants towards meat and milk production [13].

Cultivation of Rice: A Staple Food Crop

Rice is staple food for more than half of the global populations providing food security and livelihood opportunity for millions of people world over. Rice is the source of calories to the extent

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of 30-75% for >3 billion Asians and it is grown commonly by transplanting of seedlings in puddled soil. Rice cultivation by transplanting is water-, labour-, and energy-intensive process. Moreover, rice cultivation is becoming less profitable because of increasing cost of labor and other agricultural inputs. Rice being a water loving crop, its cultivation require about 2000 liters of water to produce 1 kg of rice under irrigated lowland production system. There are certain advantages of rice cultivation through transplanting which include better nutrient (phosphorus, iron, zinc, etc.) availability due to anaerobic conditions, and suppressed weed infestation. However, rice cultivation by transplanting leads to higher losses of water through transpiration, evaporation and percolation. Repeated puddling of soil for rice cultivation adversely affects physical properties of soil, reduces permeability of subsurface layers, and leads to the formation of hard pans at shallow depths, all of which negatively affect the subsequent crops. Transplanted rice (TPR) requires higher labor and water inputs for uprooting seedlings from the nursery, puddling, and transplanting of seedlings in the main field. Thus, a number of problems are associated with the cultivation of rice. TPR requires lots of water starting from preparation of land (puddling) until maturity for continuous irrigation. However, the changing climatic conditions and increasing input costs threaten sustainable rice production in the future [14]. In addition, TPR is one of the major causes of global greenhouse gas emissions which is estimated to be responsible for >11% emission of anthropogenic gases like CH_4 [15]. Alternate wetting–drying [16], and dry/direct-sown rice (DSR) have been suggested to be one of the safer alternatives of TPR [17]. In view of the imminent water crisis, water-demanding nature of TPR, and increasing labor cost, the need of the day is to search for alternative strategies for rice cultivation so as to increase water productivity, sustain rice cultivation, and maintain ecological integrity. Thus, extensive cultivation of rice by transplanting might not prove to be a sustainable practice with respect to ecological efficiency and integrity. The excessive use of water for irrigation (compared to a similar staple food crop like wheat) in this era of scarcity of fresh water, and emission of anthropogenic greenhouse gases are attracting the attention of researchers to look for the alternative strategies to replace/minimize areas under TPR (irrigated lowland production system).

Global climate change and environmental stresses affects productivity and quality of the produce; thus, create issues for food safety and health [8]. Environmental stresses like extremes of temperature, water, salts etc. adversely affects biological activities in living organisms by disrupting water/cellular homeostasis. However, acclimatization and evolutionary (biochemical, physiological, genetic and epigenetic) changes enable the organisms to withstand recurrent stresses [18]. Therefore, the requirements are not only limited to increasing the yield but the quality of the product also utilizing modern tools, breeding and agronomic practices towards mitigating the effects of abiotic stresses. Reduced biomass production often results due to reduced photosynthetic carbon assimilation. The stress-induced stomatal closure, decreased transpiration rate, and impaired photosynthetic activities (particularly due to the effects on PS II and photosynthetic enzymes) lead to early crop maturity and poor productivity. Certain nutrient (e.g., phosphorus) deficiency stress not adversely affect plant growth due to the lack of that nutrient but it also affects availability of other nutrient(s) which ultimately affect the crop yield [19]. Photosynthetic process is inhibited under P deficiency mainly because of the limiting effect of Pi for ATP synthesis, rubisco activation, and RuBP regeneration in chloroplasts. Expression level of genes for photosystem II reaction center were reported to be down-regulated under P-starvation stress [20]. Therefore, appropriate care requires to be taken about the stress(es) that would be faced by the crop plants when grown under varying environmental conditions.

Rice cultivation by transplanting

Rice is primarily grown by transplanting, and about 75% of the rice is cultivated by transplanting world over [21]. For TPR, seedlings are grown in a nursery for about 3-4 weeks (up to 4th leaf stage); they are pulled out and transplanted into puddled field. Transplanting is performed either manually or by machine. TPR gives higher yields and puddling minimises weed infestation. Moreover, transplanting ensures uniform plant stand in the field and provides a head-start to the crop over weeds. Transplanting may also favor crop intensification as the rice crop needs to enter in the main field about 3-4 weeks late. However, a number of problems (like scarcity of water, shortage of labor, and emission of greenhouse gases, etc.) are associated with the cultivation of rice by transplanting. TPR requires plenty of water starting from land (puddling) preparation, throughout the growing season, until maturity of the crop [22]. A larger portion of irrigation water is lost from the field through evaporation and percolation, which result in lower productivity of water. Moreover, the changing climatic conditions and increasing input costs are some of the threats to sustainable rice production [14]. In addition, TPR is considered to be a major culprit of greenhouse gas emissions globally.

Emission of greenhouse gas

Contribution of agriculture in the emission of greenhouse gases (GHGs, e.g., carbon dioxide, methane, and nitrous oxide) is significant (10-14% of global anthropogenic GHG emissions), which contribute to the global warming. Rice-based cropping systems play a major role in global warming potential primarily through emission of methane but nitrous oxide is also one of the culprits. Therefore, rice is considered to be an important target for mitigating GHG emissions. Rice cultivated by puddling and transplanting is one of the major sources of methane emissions because of prolonged flooding/anaerobic soil conditions, which accounts for 10-20% of total global annual methane emission. Anaerobic conditions in TPR are responsible for the activities of methanogenic bacteria and methane emission. Thus, alternate wetting–drying strategy in TPR can be adopted to minimize methane emission. DSR, an environment-friendly and resource-saving strategy, can help saving water and mitigating the emission

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of anthropogenic greenhouse gases.

Direct-sown rice

The water available for agricultural activities is declining rapidly because of the increasing population, lowering of the water table, declining water quality, inefficient irrigation systems, and competition with non-agricultural sectors for the use of water. With growing demand of water and increasing competition across water-using sectors, the world is now facing a challenge to produce more food/feed/fodder with lesser availability of water for agriculture. Presently, agricultural sector uses more than two-third of total freshwater globally. Some of the water-loving crops like rice compelling us to search for alternative crops or management practices which can increase water productivity and make it possible to grow more food/feed/fodder with the limiting availability of water for better ecological efficiency/integrity. Dry/direct sown rice (DSR) is one of the viable option to reduce unproductive water losses. This method is generally practiced in rainfed agricultural ecosystem. The seeds are sown directly in the field in dry soil rather than seedlings are raised first in nursery and then transplanted.

However, deficiency of micronutrients is one of the major concerns of adopting DSR. Increased pH, high carbonate and bicarbonates in calcareous soils under aerobic conditions affect Zn availability to aerobic rice. Similarly, Fe availability becomes limiting under aerobic rice, especially when soil pH is high. Moreover, nutrient uptake and use efficiency of plant get reduced because of the reduced soil water content. Therefore, appropriate nutrient management strategies would be essential while adopting DSR. Lodging is another pertinent difficulty faced while adopting DSR, which causes not only reduced yield and quality of the produce but makes harvesting of the crop a difficult task. Hence, the rice cultivars with lodging resistance, dwarf–intermediate plant height, more stem diameters, thick stem walls, high lignin content, thicker sclerenchyma/more vascular bundles at the periphery of stem and are preferred for DSR. Diseases (e.g., rice blast and sheath blight) and insect pests (plant hoppers and root-knot nematode) are some other problems associated with DSR. Poor stand establishment of crop, because of different abiotic stresses, is another important problem associated with DSR, which can be minimized by seed priming [23]. Although DSR faces several (abiotic and biotic) stresses during its growth, a comparative yield of DSR can be expected by adopting different cultural practices like use of suitable cultivar, appropriate sowing time, increased seed rate, proper abiotic/biotic stress and water management. We observed more vigorus seedlings of Nagina-22 (an abiotic stress tolerant cultivar suitable for direct sowing) with more number of surviving seedlings and better growth, compared to that of the IR-64 (a high yielding rice cultivar suitable for transplanting) seedlings grown by dry/direct-sowing (Figure 1). Moreover, differential expression of genes for growth-regulating factors, nutrient reservoir activities, transcription factors, translational machinery, and carbohydrate/nitrogen metabolism were observed in leaves of Nagina-22 rice cultivar when grown under dry/direct-sown conditions. Our observations on considerably up-regulated expression of TOR (target of rapamycin) pathway genes (serine/threonine-protein kinase) involved in phosphorylation of eIF3 and selective translation of a subset of transcripts corroborated with better performance of Nagina-22 under DSR conditions. TOR signal-transduction pathway (an evolutionarily conserved serine/threonine kinase) correlates nutritional status, cell division, growth, and development of plant with the environmental stresses. Thus, the TOR pathway integrates nutrient-, energy-, and stress-related signals to adjust protein biosynthesis in the cell [24]. Therefore, TOR pathway acts as a master regulator to coordinate various cellular activities to improve plant productivity even under unfavourable environmental conditions. Thus, considering the current scenario of global water-scarcity and increasing labour wages, DSR is one of the viable options for sustainable rice production without overexploitation of the natural resources.

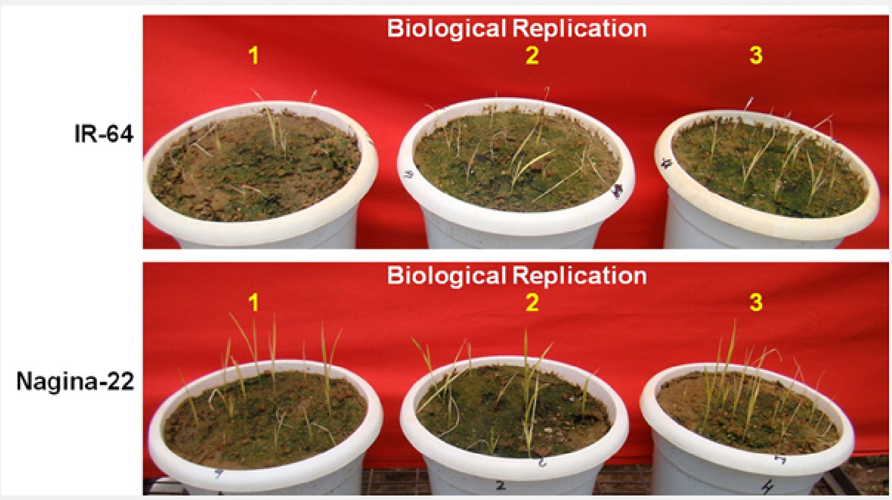

Figure 1: Seedling-vigor of contrasting rice cultivars (Nagina-22 and IR-64) grown by dry/direct-sowing in pots.

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Future Perspectives

Water is extremely important for survival of living organisms. Resources for fresh water are decreasing continuously due to the change climatic conditions, unpredicted rainfall, global warming, misuse of water and its pollution. Air, water, and soil are the basic components/natural resources required to ensure continuity of life. Using and protecting the natural resources is necessary to avail them in an efficient manner for ecological integrity. Excessive use of one of the components or for any one species of an ecosystems may lead to imbalance in the ecosystem and reduced ecological efficiency. Therefore, it is absolutely necessary to use and protect the natural resources (air, water and soil) for continuation of life on the earth. With conscious use of water, we can save water, prevent its pollution and depletion of the water resources. We need to remember that the existence of future generations depends on the availability of sufficient potable water for them, which is in the hands of the present generation. A prerequisite for this would be to save potable water and maintain ecological integrity for the future generations.

Replacing maximum of TPR with DSR would not only result in higher water productivity towards realization of the slogan "*Per Drop More Crop*" and saving/conserving water for ecological integrity but this would also minimize the emission of anthropogenic greenhouse gases. Understanding the master regulators coordinating cellular activities might help improving crop productivity under unfavourable environmental conditions. Deciphering the epigenetic and epitranscriptomic regulation of gene expression under environmental stresses [25,26] would also be required. Identification of QTLs, candidate genes, and molecular markers for DSR traits might help improving rice varieties for dry/direct-sowing. Modern tools and techniques of molecular biology like RNAi and epigenome editing [27,28], in addition to the conventional physiological and genetic approaches, might be helpful in confirming the role(s) of the genes for DSR traits. Replacing TPR with DSR may help mitigating the effects of global climate change and emission of greenhouse gases for ecological integrity.

Conclusion

Water, being vital for all living organisms, is essential for survival, growth, development and productivity of most of the organisms. Therefore, saving water is essential for making it available in pure form to the organisms for ecological integrity and to maximise ecological efficiency. Water is not only necessary for human beings but equally important for agricultural and industrial activities, in addition to its requirements for many of other organisms. Hence, saving water is our prime responsibility to maintain/improve ecological integrity/efficiency. Agriculture being one of the largest consumers of fresh water, it is necessary to use irrigation water in a prudent manner for realization of the rightly framed slogan *Per Drop More Crop*. As per the estimations by different researchers, paddy crop (when grown by transplanting) requires 2000-5000 liters of water (depending on the varying environmental conditions and soil type) to produce one kilogram of rice (grain), which clearly indicates very low water productivity of TPR compared to that of DSR as well as many other crops. Water productivity of DSR is higher by >25% compared to that of the rice grown by transplanting. Some of the farmer-friendly, easy and economical strategies like seed-priming might be a promising approach to overcome certain problems (e.g., poor crop establishment) associated with DSR. More importantly, the need of the day is to produce food in safe and sustainable manner for the more informed/choosy consumers. Identification of quantitative trait loci (QTLs), candidate genes for DST traits, and their pyramiding in suitable genetic background using the modern tools and techniques of molecular biology while avoiding the biosafety issues [29,30] might help developing suitable rice cultivar for DSR. If suitable crop varieties are developed/used for crop husbandry, along with the efficient use of natural resources like biofertilizers, biopesticides [31,32] and irrigation water, these would help improving ecological efficiency and integrity.

The views expressed herein are those of the author only, and these may not necessarily be the views of the institution/ organization the author is associated with.

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