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Corresponding Author
S. Vijayakumar
e-mail: vijitnau@gmail.com

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Sustainable Rice Production in India Through Efficient Water Saving Techniques

S. Vijayakumar[1*], V. Karunakaran[2], R. Gobinath[1], K. Basavaraj[1], B. Raghavendra Goud[3], Naseeruddin Sha[4], Vakada Manasa[1] and S. Aravindan[5]

Abstract

Decreasing irrigation water availability, declining ground-water table, emission of greenhouse gas, indiscriminate use of pesticides (insecticides & fertilizers), intensive rice-rice cropping system, declining soil fertility and other environmental problems due to practice of unsustainable rice production practices are of serious concern. Action to address these multiple issues associated with rice cultivation should be taken immediately to ensure sustainable agricultural development in the post-Industrial era. In this article, we discussed in detail the paradox of the Indian rice scenario, perceptions that are not true in rice cultivation, the various problem associated with rice production and finally proven technologies to address the multiple issues associated with rice production.

1. Introduction

India has only 3.83% of the total world's fresh water resource to feed the second largest population in the world (about 1.3 billion). Rice is a major food crop grown in India with an area coverage of 43 Mha and consume large portion (~35-43%) of fresh-water for irrigation (Vijayakumar et al., 2022). Among the field crops, rice has the highest water requirement (1140 mm) and its water and carbon footprint are also higher than any other field crop (Nayak et al., 2020). Rice crop consumes thousands of litres for every kilogram of production and it is the second-largest contributor to greenhouse gas (GHG) emission in the agricultural sector next to livestock. India also exports a large quantity of water (virtual water) through the export of rice (17.7 million tonnes). So it is high time to ensure sustainable water use in rice cultivation along with food security and environmental safety.

Author's Address

[1]Scientist, ICAR-Indian Institute of Rice Research, Rajendranagar, Telangana, Hyderabad, (500 030), India
[2]Assistant Professor, ICAR- Krishi Vigyan Kendra, Needamangalam, Thiruvarur, District, Tamil Nadu, (614 404), India
[3]Scientist, ICAR - National Rice Research Institute, Cuttack, Odisha, (753 006), India
[4]Assistant Professor, Acharya N.G. Ranga Agricultural University, Guntur, (522 034), India
[5]Scientist, ICAR-Indian Institute of Seed Science, Regional Station, Bengaluru, (560 065), India

1.1. Paradoxes of Indian Rice Scenario

In India, rice cultivation is associated with many paradoxes such as 1. Growing rice in high rainfall areas example Eastern and North eastern India and South India where it is hit by flood/drought/cyclone and the yield is low. 2. Growing rice in low rainfall areas example Punjab, Haryana and western Uttar Pradesh leads to groundwater depletion & contamination, declining soil fertility (Vjayakumar et al., 2022) & appearance of multi-nutritional deficiency although farmers get higher yields. 3. Regional disparity. For example, Andhra Pradesh, Karnataka, Punjab and Telangana are providing free electricity to their farmers for irrigation which encourages them to go for application of an excessive amount of irrigation while other states are not providing free electricity; Assured government procurement of rice only in very few states (Ex. Telangana, Punjab) with MSP (minimum support price) provide considerable economic benefits over other states where assured procurement of paddy is almost not available. 4. Virtual water trade through rice export. Though the amount of revenue generated through rice export (Approximately 65000 crores) is encouraging but then we calculate ecosystem services including GHG emission, groundwater depletion, soil nutrient mining, etc. then probably this is not going to be a very encouraging or heartening proposition.

1.2. Demand & Production of Agri-commodities in 2020-2021

If you look into the demand and production data of major agricultural commodities, it clearly shows the self-sufficiency in a majority of the agricultural commodity (Table 1). For example, the demand for rice in the year 2020 is 112 million tonnes (MT) while the production is 122 MT with surplus/excess production of 10 MT of rice. The demand for rice (except basmati) in the international market is low as a result the profit what we are getting through the export of rice is low. But the quantum of natural resource use especially water is huge in rice cultivation. This is the reason why policy makers are very keen on reducing the rice area in the country.

Table 1: Demand and production of major agricultural commodity

Commodity	Demand (MT)	Production (MT)
Rice	112	122
Wheat	99	110
Coarse cereals	43	51
Pulses	22	26
Food-grain	277	309
Fruits & vegetables	244	300
Milk	148	208
Fish	9	15
Sugar	34	31

1.3. Facts of rice production in India

1. Rice cultivation consumes 35-43% of the total irrigation water.

2. Rice is grown in areas where annual rainfall is <500 mm and >2500 mm.

3. Only in very few states irrigation is free and energy use efficiency is low, whereas in many states it is costly and highly energy efficient.

4. Water levels in paddy field largely determines the quantum of methane emission, besides organic matter content, soil & canopy temperature, *etc.*

5. Cost involved in the irrigation and procurement of inputs determines the profitability of rice cultivation.

2. Rice & Water: Perceptions & Problems

2.1. Perceptions that are not true in rice cultivation

2.1.1. Rice needs submergence. Rice is the only crop that is adapted to all the ecosystems (Figure 1). There are many success stories around the world that prove the fact that rice crops can be grown in aerobic conditions (Direct seeded rice, drip irrigated rice, System of rice intensification, aerobic rice without submergence) and yields as good as transplanted rice.

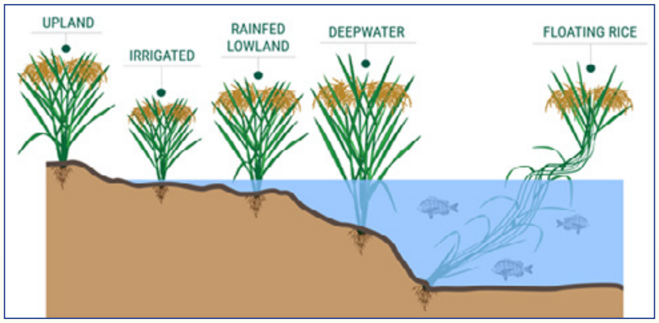

Figure 1: Different types of rice ecosystem

2.1.2. Rice has high water use and demand. The water footprint of a region or crop provides information about the quantity of total water consumed in the region or by a particular crop. Rice actually consumes <2500 L water to produce 1 kg grain but farmers apply 2500 to 5000 L water to produce 1 kg grain which actually rice does not require (Vijayakumar et al., 2022). Similarly, rainfall received during the crop periods is more. Rice doesn't need higher water to produce 1 kg grain, actually it needs less than 1/2rd of this.

2.1.3. Rice plant produces methane

Let us make it clear that rice plants as such don't emit methane. It is the soil management practice *i.e.* organic manure application, irrigation management, land levelling, *etc.* which facilitate or trigger methane emission in paddy cultivation. Methane emission is high under the waterlogged condition with high soil organic matter whereas it is very low in the aerobic rice field with the best organic nutrient management.

2.1.4. Rice has a high environmental footprint because of high water, high energy and more fertilizers

This is again because of inefficient management practices. The environmental footprint of rice cultivation is going to be less, if we can cultivate rice without applying more water, with optimum use of energy and fertilizers (Nayak et al., 2020).

2.1.5. Indian rice yield is very low compared to many other Asian countries. Yield in India is reported in terms of milled rice (after removing hull) whereas in China and many Asian countries it is reported in terms of coarse rice (without removing hull). So, if we convert our country's productivity to coarse rice, the per hectare productivity will be higher by at least 30%. Of course, our country's average rice productivity is comparatively less compared to China but if we look at the state level productivity, ex. Punjab, Haryana, Tamil Nadu, Telangana the average productivity is almost ≥5 t/ha which is almost equal to China's per hectare productivity. In many states, rice yields are low, because it is grown under un-favourable conditions like rain fed, flashflood, saline/alkaline etc.

2.2. Problems associated with rice production

2.2.1. Decreasing water availability

The availability of fresh water for irrigation is decreasing drastically in recent years due to increasing demand and withdrawal from other sectors. Also, the groundwater table in many rice growing regions is lowered at an alarming rate and created a sustainability threat.

2.2.2. Increasing irrigation cost

To minimize the yield loss and crop failures under changing climate, farmers started depending more on artificial irrigation through irrigation pumps and in recent decades it shows a tremendous increase in number. This in turn increased the irrigation cost.

2.2.3. Increasing rainfall variability & intensity

Climate change brought a shift in rainfall patterns which in turn brought delays in sowing and transplanting. Climate change also brought more frequent droughts and floods (Vijayakumar et al., 2021).

2.2.4. Increasing water pollution

Indiscriminate use of fertilizers in agriculture leads to increased water pollution in many rice growing areas. For example, in Punjab, the nitrate concentration reached above the safe level due to the leaching of nitrogen fertilizers to ground water table and other surface aquifers.

2.2.5. Increasing C and energy footprints

In recent decades the production of rice become highly carbon and energy intensive due to indiscriminate use of inputs, energy and other resources (Vijayakumar et al., 2019).

2.2.6. Virtual water trade

Virtual water export through rice is only expected to increase in the future if corrective efforts are not taken as soon as possible, and the impact on future generations will be far worse. The estimates show that the exports of virtual water alone can lead to loss of water sustainability and may affect food sustainability from regional to global scale. Virtual water trade may disturb the water budget of exporter's country as well as the economy. Therefore, there is a need to rethink sustainability policies on virtual water export as there are not many effective policies for virtual water export.

3. Technologies to Solve the Problem in Rice Cultivation

3.1. Direct-seeded rice

Direct seeded rice (DSR) is a crop establishment technique for rice crops in which seeds are sown in the field directly in the main field rather than by transplanting seedlings from the nursery to the main field. Direct seeding is done by either sowing pre-germinated seeds in puddled soil (wet direct seeding) or well prepared non-puddled seedbed (dry direct seeding). If proper weed management is not adopted the yield losses may go up to 85% in DSR (Saravanane et al., 2021). The risk associated with DSR is given in Figure 2. Water stress must be avoided during critical stages of seedling emergence,

Figure 2: Multiple Issues with DSR

active tillering, panicle initiation, and flowering. The carbon and water footprint DSR is significantly lower than conventional transplanted rice.

4. Is DSR a Water Saving Technology?

Yes - When water is managed appropriately

No - When water is managed similar to puddled field

4.2. Alternate wetting & drying

Alternate wetting and drying (AWD) is a water-saving technology that saves up to 15-30% water with no/little yield loss (upto 5%). The most efficient and accurate way to implement AWD is through the use of a 'field water tube' or 'pani pipe' of 30 cm length and 7-10 cm diameter to keep vigil the water depth. After a few days of application of irrigation, when the water level drops below 15 cm from the soil surface, the field should be re-irrigated. However, during the sensitive stages (flowering) a thin layer of water of about 5 cm is always advocated. AWD improves water use efficiency (upto 1.2 kg m^{-3}) and reduces greenhouse gas emissions by 30-50% (Nayak et al., 2020a). Indian peasants are not reaping the full benefit, though in many countries rice farmers are getting carbon and water credit for practicing DSR and AWD (Vijayakumar et al., 2021b).

4.3. Precision water use

Drip irrigation has proved its superiority over other methods of irrigation due to the direct application of water and nutrients in the vicinity of the root zone (Subramanian et al., 2021). Because of its low water use with a reasonable yield, drip irrigated rice has greater scope in areas where water availability is limited especially in well-irrigated areas. Internet of Things (IoT) based irrigation systems are found to be more accurate in supplying irrigation to the rice crop. Similarly, several sensors are now available for the accurate measurement of moisture in the field (Vijayakumar et al., 2022a).

4.4. Renewable energy

Most farm machines are driven by fossil fuels, which contribute to vehicular GHG emissions. Renewable resources such as solar, wind, biomass, tidal, geo-thermal, small-scale hydro, biofuels and wave-generated power can mitigate GHG emission. This will minimize use of non-renewable resources, such as natural gas for fertilizer production or fossil fuel used in diesel generators for water pumping. Solar photovoltaic water pumps and electricity, greenhouse technologies, solar dryers for post-harvest processing, and solar hot water heaters are economically viable and climate-friendly options (Nayak et al., 2020a). Solar-powered water pumps are an excellent alternative to diesel-powered pumps because of the geographical position of India. They are eco-friendly, as they do not release any harmful gases that pollute the environment. Because of the inadequate supply of electricity in rural areas, there is greater scope for solar-powered water pumps, sprayers and weeders. The government of India has launched different schemes to encourage the harnessing of solar power by the installation of solar power operated water pumps.

4.5. Biotic and abiotic tolerant varieties

There are several improved high yielding cultivars are developed for various ecology and location. These varieties also possess tolerance to various biotic and abiotic stress Table 2.

4.6. Managing Water as Stakeholders Need

Stakeholder engagement in every step of planning is a powerful tool to address the irrigation water problem in rice cultivation. However, the goal of every stakeholder in rice farming is highly different. For example, farmers want their field should be kept watered always, while irrigation manager wants to implement scientific irrigation scheduling and policy makers wants to reduce the water footprints in rice cultivation. Due to the difference in target between the stakeholders the implementation of appropriate water saving technology in rice cultivation is difficult.

4.7. Growing rice crop without degrading natural resources, with minimum GHG emission

Cultivation of rice account use of 38-40% of fertilizers and 17-18% of pesticides of total consumption. Balanced fertilization, soil test based fertilizer applications are not adopted in major parts of rice growing areas which leads to nutrient mining and declining soil fertility. About 8 M ha of rice soils are deficient in Zn and K mining was

Table 2: Abiotic stress tolerant rice identified /released by ICAR and SAUs

Drought	DRR Dhan 54, DRR Dhan 54, Sahbhagi Dhan, Satyabhama, Ankit, Vandana, Anjali, CR Dhan 40, DRR Dhan 42, DRR Dhan 43, DRR Dhan 44
Submergence	Swarna Sub1, IR64 sub1, TDK1 Sub1, CR Dhan 401, CR 1009 Sub1, Samba Mahsuri Sub1, and BR11-Sub1, Ranjit Sub1, Bahadur Sub1
Cold	CR Boro Dhan 2, CR Dhan 601, Chandrama, Rajalaxmi (Hybrid)
Heat	N22, Annapurna
Stagnant Water	CR Dhan 502, CR Dhan 503, CR Dhan 505, Varshadhan, Durga
Saline	CSR 46, CSR 56, CSR 60, CSR 23, CSR 13, Lunishree, Luna Suvarna, Luna Sampad, Luna Barial, Luna Sankhi, TRY-1 and TRY-4
Mild water stress	CR Dhan 205, CR Dhan 206
Aerobic rice	CR Dhan 200 / Piyari (suitable for Odisha), CR Dhan 201 (suitable for Chhattisgarh and Bihar), CR Dhan 202 (suitable for Jharkhand and Odisha), CR Dhan 204 (suitable for Jharkhand and Tamil Nadu), MAS 946-1, DRR Dhan 42, DRR Dhan 44, DRR Dhan 46
Lowlight stress	Swarnaprabha, Rajalaxmi (Hybrid)
Low N	Swarna, Ranjit, Sarjoo-52, Bejhary, Pranava, Salivahana
Low P	Kasalath, Rasi, Dullar, RPA 5929, MTU 2400, Vikramarya, CR Dhan 801
Low Zn	CSR 10, Sarjoo-52, Vikas, IR-30864
Fe toxicity	Mahsuri, Phalguna, Dhanrasi

reported across the rice-wheat cropping system of IGP (Vijayakumar et al., 2019a; 2021a). Many improved technologies like android app based nutritional disorder detection, water saving technologies viz., DSR, AWD, drip irrigated rice, sensor-based IoT tools for irrigation, drone-based pesticide application could solve the problem of natural resource degradation and reduce GHG emission (Vijayakumar et al., 2020; 2022b).

4.8. Eco-regional Crop Planning for growing rice crop in suitable eco-regions

The cultivation of rice should be encouraged in a region which has adequate rainfall of >1000 mm, Clay content of >25% and Congenial temperature <32°C. In Punjab, Haryana, Rajasthan and western U.P, rice is grown in light textured soil (sandy loam) which is actually not suitable and environmental friendly. Thus, identification of alternate profitable crop and promoting it through appropriate policy and scheme is highly important.

4.9. Upscaling of Resource Conserving Technologies (RCTs)

Though several resource conserving technologies are available to solve the problem of water crisis in agriculture (Figure 3), the adaption of these technologies in the farmer's field is not upto the mark of expectations.

No-tillage. Zero till drill sowing of rice is found effective in Indo-Gangetic Plains (IGP). The field level adoptions found increasing tremendously in recent years especially in Punjab, Haryana, and Western U.P. Both central and state governments should promote the adoption of zero-till drill sowing in suitable areas through popularizing the improved tools and technologies and providing subsidies.

Laser land leveling. Precision land levelling is very important for the uniform application of irrigation water. Adoption of this technology is not reached upto the expectation. This is mainly due to the high cost of laser land levellers. So it is highly needed of the hour to make this instrument available to farmers through custom hiring or farmer's producer organization.

Direct seeding of rice. The area under DSR showing tremendous growth in recent years. It saved labour requirement by 20% in terms of working hours (Subramanian et al., 2021). However, the scope of DSR is remain untapped in many states. State agriculture departments should take lead in spreading this technology in every suitable area.

Micro-irrigation. The potential for micro-irrigation is enormous in India. Few states like Tamil Nadu and Maharashtra showed a successful implementation of micro-irrigation. Drip irrigation based rice cultivation saved 20% irrigation water (Subramanian et al., 2021).

So in other states also it should be promoted through appropriate intervention.

Crop diversification. Cultivation of rice in non-suitable areas should be converted to other suitable crops through crop diversification. This will solve the problem of water crisis and ground water depletion in many regions (Nayak et al., 2019). Cotton and maize is the suitable alternative crop for rice in *Kharif* season

Figure 3: RCT to solve water crisis in agriculture

4.10. 5Ms for Water-smart Rice Production

Mapping: Suitable rice growing zone, water availability zone for rice cultivation should be mapped at block levels.

Monsoon: High precision weather forecasting & weather services will minimize the inefficient application of irrigation and facilitate effective utilization of rainfall for crop growth.

Mechanization: Automation (Internet of Things based irrigation), custom hiring service. It helps in reducing the drudgery of agricultural operations.

Management: Matching the supply & demand of agricultural inputs including variety, nutrients, *etc*.

Manpower: Capacity building programs like training, field day, should be conducted at regular intervals to all the stakeholders.

5. Conclusion

Sustainable rice production technologies should be practised on a large scale to address water scarcity and environmental pollution arising out of conventional rice cultivation methods. The potential of several new technologies has remained untapped in most parts of the country. Government initiatives in terms of policy, subsidy, extension service, training, etc. are highly required to upscale these improved technologies. Also government and other organization like NGO should take initiative to materialize carbon credit and water credit to all the farmers across the country for practicing DSR and AWD.

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