Water and Rice

Muhammad Naveed[1*], Shahzada Munawar Mehdi[2]; Umair Riaz[3]; Saifullah[4,5]; Muhammad Irfan Sohail[4]; Fatima Akmal[4]; Ammara Arooj[6]; Naveed Iqbal Khan[1];Muhammad Abubakar Amin[7]

[1]Soil and Water Testing Laboratory for Research, Lahore-53700, Pakistan

[2]Soil Fertility Research Institute, Lahore-53700, Pakistan

[3]Department of Agriculture, Soil and Water Testing Laboratory for Research, Bahawalpur-63100, Government of Punjab, Pakistan

[4]Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad

[5]Imam Abdulrahman Bin Faisal University, Saudi Arabia

[6]Key Laboratory of Jiangsu Province for Chemical Pollution Control and Resources Rescue, Nanjing University of Science and Technology, Nanjing, China

[7]Soil and Water Testing Laboratory for Research, Faisalabad-38000, Pakistan

***corresponding author:** Muhammad Naveed, Soil and Water Testing Laboratory for Research, Lahore-53700, Department of Agriculture, Government of Punjab, Pakistan. Email: naveed.2570ag@gmail.com

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Abstract

Rice is a major food source for more than half of the world's population and also major water consumer in the world. With impending Climate change, water availability has become a serious concern because it has a severe effect on rice production.Water availability will be one of the limiting constraints for crop production and food security. To cope up with the new challenge, two strategies can be implemented. First is to improve crop water productivity, which can be increased by adopting different water-saving irrigation practices. And second is to optimize different water management systems. Water saving technologies in rice production dramatically reduced the water consumption. Thus, using water-saving technologies along with effective weed, water, and nutrient management is to be practiced for better rice production. Paddy ecosystem (sink of pollutants) is susceptible to contamination for being stored because of its phytoremediation nature. Since rice isa staple food for half of the world's population, its intake directly manipulates the human health and biological systems.

Abbreviations: IT: Information Technology; RCT: Resource Conservation Techniques; LLL: Leaser Land Levelling; GPS: Global Positioning System

1. Rice

Rice is the world's single most and important staple food for a large part of the human population, also a food source for half of the world population. Out of 49% calories consumed by humans, 23% comes from Rice. Almost one fourth of calories consumption of world comes from rice. The major contributor to rice production in Asia, Latin America and West India. Among them, largest producer is China with 210.3 million metric tons production, following India is the second most rice producer of the world while the first inthe area under cultivation for rice. Other rice-producing countries are Bangladesh, Laos, Cambodia, Vietnam and Myanmar.

2. Taxonomy of Rice

Two species of rice are under cultivation currently, one of them known as Oryza sativa (Asian Cultivated) is worldwide grown, while the second Oryza glaberrima (African cultivated), is grown in the least scale in some part of West Africa. The cultivated rice belongs to Oryza genus, which probably originated 130 million years ago, and was spread in Gondwanaland as wild grass. Gondwanaland, at the end of the day, broke up and gave birth to Antartica, Australia, Africa, and Asia continents (Chang 1996). Thus, the reason forthe presence of Oryza specie in all countries except Antartica is explained. The sum total of wild species of Oryza is 22, among them nine are tetraploid while remaining are diploid. Common rice, Oryza sativa and African rice, Oryza glaberrima, are considered to be the examples of evolution in crop plants. About 9000 years ago, wild rice domestication started. Process of annuals development at different elevations in Western China, Southeast Asia, and East India, enhanced by periods of drought, temperature variations through the Neothermal age about 10-15 thousand years ago (Whyte 1972). While in Asia, domestication could have been occurred concurrently and independently at sites within or border of broad belt, which extends from plains below eastern foot hills of Indian Himalaya through upper Myanmar, northern Thailand, Laos, and Vietnam to southwestern or southern China (Roschevitz 1931; Chang 1976). The origin of O. glaberrima (African cultivar), belongs to Niger River delta. Swampy basin of upper Niger River is the primary center for the diversity of O. glaberrima (Porteres 1956). Evolutionary pathway for two cultivated rice species is given in **Figure 2**.

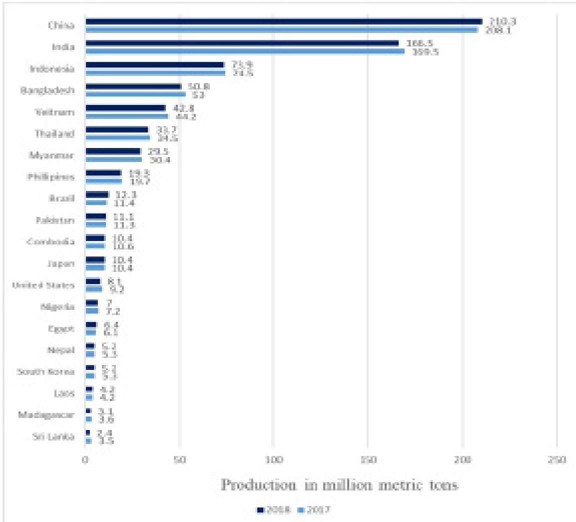

Figure 1: Rice production in million metric tons of rice producing countries
Source: Statista-2018 (https://www.statista.com/statistics/255937/leading-rice-producers-worldwide/)

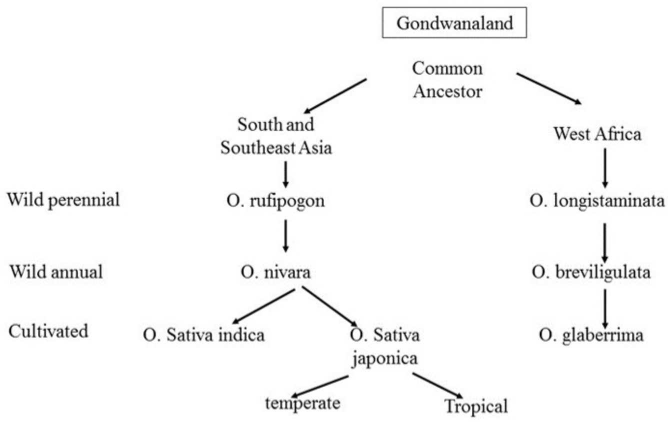

Figure 2: Evolution stages of Rice

3. Water and Rice

Rice is one of the major crops feeding the world population and is most important in South Asia and Africa. Large irrigation projects are often constructed to meet the water demand in rice production. As a result, rice is one of the largest water consumers in the world. This report quantifies how much fresh water is being used to produce rice globally, distinguishing between two different sources: irrigation water withdrawn from ground- or surface water (blue water) and rainwater (green water). It also quantifies the volume of polluted water related to the use of nitrogen fertilizers in rice production (grey water). Rainwater and irrigation water are necessary for rice growth in two ways: to maintain soil moisture and – in wet irrigation – to maintain the standing layer of water over the paddy field. In the major rice producing regions of the world, the crop is grown during the wet (monsoon) season, which reduces the irrigation demand by effectively using rainwater. As much of the standing water in paddy fields percolates and re-charges groundwater and surface water, there is a substantial contribution to the local blue water availability. Percolation can be seen as a loss to the paddy field, but for the catchment area, it is not considered as a loss, because the water can be captured and reused downstream [12]. In some irrigation systems in flood plains with impeded drainage or systems in low lying deltas, a continuous percolation can even create shallow groundwater tables closer to the surface (Belder et al., 2004). Although the report focuses on the estimation of evapotranspiration from rice fields, it also estimates percolation flows, because evapotranspiration and percolation are both parts of the soil water balance. Rice field management practices are responsible for rice field preparation, regardless of soil environments before cultivation. These practices lead to formation of specific horizons in soil as (I) Plankton formed due to presence of water on top layer and habitat for microbes, (II) Zone with changing oxidation states, (III) Puddled layer categorized as region with the absence of oxygen and (IV) hard plough pan where reducing states are stabilized (McDonald *et al*., 2006; Kögel-Knabner*et al*., 2010). Formation of hardpan below plough zone results in high losses of water through puddling, surface evaporation, and percolation. Water resources, both surface and underground, are shrinking, and water has become a limiting factor in rice production [2]. Huge water inputs, labor costs, and labor requirements for transplanting rice have reduced profit margins (Pandey and Velasco, 1999). In recent years, there has been a shift from transplanting rice to direct seeded rice (aerobic rice) cultivation in several countries of South-east Asia (Pandey and Velasco, 2002). This shift was principally brought about by the expensivelabor component for transplanting due to an acute farm labor shortage, which also delayed rice sowing (Chan and Nor, 1993).

4. Climate Change and water-rice system

Rice-water system usually consumes more delta of water for production and is being affected by the availability of water, which is being affected due to climate change. Since climate change has also been a major concern over the last few decades and is affecting considerably over the availability of water for the rice-water system.

4.1. Climate Change and Water Availability

It is known that water resources play a vital role in human prosperity and crop productivity. The world's agriculture, hydroelectric power, and water supplies depend on different components of the hydrological cycle, including the natural replenishment of surface and groundwater resources. Water availability issues include how much water can be diverted when the water can be available and how much water can be stored in surface and ground-water reservoirs. Assessment of seasonal and long-term water availability is not only important for sustaining human life, biodiversity, and the environmen but also helpful for water authorities and farmers to determine agricultural water management and water allocation. Climate change is one of the greatest pressures on the hydrological cycle along with population growth, pollution, land use changes, and other factors [3]. Water availability is under threat from changing climate because of possible precipitation decrease in some regions of the world. In the light of the uncertainties of climate variability, water demand, and socio-economic, environmental effects, it is urgent to take some measures to use the limited water efficiently and develop some new water resources [4]. If the water resources are replenished by snow accumulation and the snowmelt process, the water system will be more vulnerable to climate changes (Guo et al., 2009).

4.2. Climate Change and Crop Water Productivity

Climate change impacts on crop water productivity in the 21st century, global agriculture has met the new challenge, namely, to increase food production for the growing population under increasing scarce water resources [5], which can be achieved by improving crop water productivity [4,6]. Water productivity is a concept to express the value or benefit derived from the use of water and includes essential aspects of water management such as production for arid and semi-arid regions [7]. Increasing water productivity means either to produce the same yield with fewer water resources or to obtain higher crop yields with the same water resources [8]. While Bouman (2006) suggested that just "increasing water productivity" may not solve the dual challenge, so it is necessary to understand the latent mechanism of increased water productivity. The existing studies show that climate is the single most important determinant of agricultural productivity, basically through its effects on temperature and water regimes [9]. Climate change impacts on crop water productivity are affected by many uncertain factors [10], of which one of the most important factors is the uncertainty in global climate model predictions, especially regarding climate variability. The other factors include soil characteristics such as soil water storage [11], long-term condition in soil fertility [12], climate variables and enhanced atmospheric CO_2 levels [13] and the uncertainty of the crop growth model, which is connected with biophysical interactions. All of these factors will affect the estimation of climate change impacts on crop productivity. As long as the researchers reduce the effects of uncertain aspects, it is possible to obtain more accurate predictions about climate change impacts on crop productivity.

Water productivity concerned with water-saving irrigation is dependent on the groundwater level and evapotranspiration [14]. Crop water productivity is an important index to evaluate water saving and water investments for farmers and scientists. Meanwhile, it is inversely related to vapor pressure [4]. Crop water productivity can be increased significantly if irrigation is reduced, and the crop water deficit is widely induced. Climate change will influence temperature and rainfall. In the decreased precipitation regions, the irrigation amount will increase for optimal crop growth and production, but this may decrease crop water productivity. Therefore, it will be a big challenge to increase crop water productivity at all levels

4.3. Climate change and Food Security

Food security is defined by the Food and Agriculture Organization (FAO) (2002) as a "situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." The definition involves four aspects of food security, namely, food availability, food stability, food access, and food utilization [15]. However, the existing studies are focused on the climate change impacts on food availability, scarcely referring to the impacts of a potential increase in climate variability, frequency, and intensity of extreme events on food stability. The FAO [16] mentioned that biotechnology could be an approach to improve food security and reduce the environmental pressure. Meanwhile, modified crop varieties, resisting drought, waterlogging, salinity and extreme climate can expand the crop planting area such as in the degraded soils, consequently, to increase food availability in the future. Global food security threatened by climate change is one of the most important challenges in the 21st century to supply sufficient food for the increasing population while sustaining the already stressed environment [17]. Climate change has already caused significant impacts on water resources, food security, hydropower, human health especially for African countries, as well as to the whole world [18]. Studies on climate impacts and adaptation strategies are increasingly becoming major areas of scientific concern, e.g. impacts on the production of crops such as maize, wheat and rice [19,20], water resources in the river basin catchments [21,22], forests [23], industry [24] and the native landscape [25]. Crop productivity and soil water balance have been studied with crop growth models by using parameters from different climate models. Meanwhile, climate variability is one of the most significant factors influencing year to year crop production, even in high yield and high-technology agricultural areas. In recent years, more and more attention has been paid to the risks associated with climate change, which will increase uncertainty with respect to food production [4]. Water availability will be one of the limiting constraints for crop production and food security. Fujihara et al. [26] pointed out that water scarcity will not occur if water demand does not increase; however, if the irrigated area is expanded under present irrigation efficiency rates, water scarcity will occur. Therefore, it is urgent to determine the impacts of climate change on crop production and water resources in order to develop possible adaptation strategies.

5. Recent Water Saving Technologies in Paddy Production

With the extensive increase in the world's population, the water demand has been intensified for both industrial and household use. In addition, looming water scarcity due to climate change, make it quite evident that there is a severe crisis of agriculture water resources. Rice is the major consumer of water resources, accounting for 34-43% of total irrigation water globally [27]. Throughout the rice-growing countries, lowland rice production has been recognized as a sustainable system for centuries. But the impending water crisis compels the farmers to adopt alternate water saving techniques for better rice yield with less water.

Alternate water saving techniques have been increasingly adopted by farmers in recent years because there is a great potential in saving a substantial amount of water during rice production. Sujono [28] showed that alternate wetting and drying (AWD) and semi-dry cultivation lessen irrigation water usage by 55.4% and 38.5% respectively. Likewise, in China, water saving techniques saved up to 10-30% of irrigation water in comparison to traditional rice cultivation method [29,30]. Different water saving technologies in rice production are as follows:

5.1. Direct Seeding

Direct Seeding is a suitable alternative to transplanted rice in both rains fed and irrigated conditions. Direct seeding is extensively practiced in America and under optimal conditions; it proved to be a cheaper and efficient method than rice transplantation.

5.1.1. Dry Direct Seeding for Aerobic Rice

Dry direct seeding has been an optimal option, to grow crop by sowing seeds in non-puddled and unsaturated field conditions. In recent years, researchers extensively tested dry direct seeded rice (DDSR) practice and their results on yield production and water-use efficiency. This practice is approached for aerobic and upland rice [31,32,33].

Aerobic rice cultivation is a promising technique of saving labor and water and suitable for both rainfed and irrigated conditions. It maintains water at just soil saturation level to minimize water losses accompanied by traditional practice, which have made this approach widespread in water-scarce regions [33]. The success of aerobic rice dramatically depends on practical and timely herbicide application along with nutrient supply (efficient nutrient management practice with organic amendments).

Aerobic rice cultivation is an eco-friendly, cost-effective technique which saves water and labor and maintained soil structure and improved soil health [34]. The yield attained by aerobic rice varieties is twice or thrice (4.5 to 6.5 tons per hectare) than attained with upland rice cultivation, but lowered than lowland rice varieties yield by 20%-30% [2,35]. Thus, there is a need for breeding efforts in developing better aerobic rice varieties for the sustainable aerobic system.

5.1.2. Dry Direct Seeding for Aerobic–Anaerobic Rice

Riceis established by sowing seed in a well-prepared dry filed. This method has become very popular due to less input usage. The farmers of India, Thailand, and the Philippines are increasingly shifting from the conventional method of rice cultivation to DSSR due to progress in weed control methods, development of nutrient management techniques and improved varieties.

This shift substantially reduced the greenhouse gas emissions, weed biota, soil organicmatter turnover, and crop water and labor requirements. In coming years, it is anticipated that the development of improved rice varieties more apt with DSSR will persuade the farmers to adopt the technology on larger scale.

5.2. Wet Direct Seeding

In Wet direct seeding (WDS), pre-germinated seeds (soaked in clean water for 24 hours and incubated for 24-36 hours) are seeded via broadcasting or line sowing (using drum seeder or anaerobic seeder) on the surface of puddled soil (aerobic seeding) or drilling into puddled rice field (anaerobic seeding) [36,33]. WDS is gaining popularity due to efficient water use, shorter crop period, lower labor requirement and improves resource use efficiency and system productivity [37,38]. The method proved useful for both irrigated and rainfed regions. WDS is widely practiced in Malaysia, Sri Lanka, and Viet Nam.

Weed infestation, the most problematic factor in WDS, can be controlled by efficient use of weedicides. Chauhan et al. [37] used different strategies for rice weed management in WDS method andresulted in higher rice yield (6.27 - 8.27 t ha-1) in two consecutive years, respectively. In WDS, weed problem is low as compared to DDSR, but water savings is higher in DDSR because puddling needsa water supply. With proper weed and water management, it is suitable for farmers to adapt to WDS profitably.

5.3. Alternate Wetting and Drying

Wetting and Drying (AWD) refers to water-saving technology in which rice is produced with less water (applying water 3-5 days after the disappearance of ponded water) to obtain flooded condition. The AWD practice maintained the aerobic condition of soil with no standing water. So even without standing water in the field, rice roots remains saturated by accessing the water from sub-surface soil. Consequently, 20-25% less water is used in comparison to continuous flooding. The AWD system focuses on efficient water management and also mitigating the environmental footprints of the rice sector (reduce greenhouse gas (GHG) emissions). It assists farmers to save up to 30% of water and mitigates 30-70% of methane emission without yield loss (Annual report of IRRI, 2017).

Safe AWD is endorsed because sometimes mild drought stress is observed by using this method, which leads to yield reduction. The recommendation is to irrigate the field when the water level has dropped to 15-centimeter depth, re-flood the field to 5-centimeter above the surface. Keep the field flooded for 10 or 20 days after transplanting or direct seeding respectively, besides 1-week flooding both before and after flowering. By following these recommendations, the same results are attained as in transplanted rice with low water input by 15%–30% [1,39,40]. In the context of water scarcity, environmental concern, and energy crisis, AWD is the most appropriate technology which can potentially make rice cultivation profitable.Generally, most of the rice varieties developed for flooded irrigation do not perform well under non-flooded conditions, thus there is a need to develop new verities which apt with AWD conditions.

The traditional method of flooded-rice is labor intensive and needs ample quantity of water. Water scarcity is prophesied to be more severe by 2025; therefore,the management of available water is indispensable. Water saving technologies are developed to economize water scarcity and environmental safety. Apart from water and labor savings, these water saving methods mitigate the greenhouse gas emissions (GHG) of rice fields. Effective weed, water, and nutrient management are, therefore, to be practiced for the adoption of water saving technologies. And the development of new rice varieties which has a better adaptation to water saving technologies.

5.4. Rice-Breeding:

World population continues to increase by 75 million people a year, an annual growth rate of 1.3%, with 90% of this increase occurring in the developing countries of Asia, Africa, and Latin America. Providing for population growth now requires an expansion in world grain production of 26 million tons per year. Moreover, owing to rising living standards, food habits are changing in many countries, particularly in Asia, and people are eating more high-value foods such as meat, eggs, and milk. This is driving the demand for grain at a rapid rate. A kilogram of beef produced in the feedlot requires 7 kg of grain, a kilogram of pork needs 4 kg, and a kilogram of poultry needs just over 2 kg (Brown 1997). More than a billion people in developing countries live below the poverty line and have poor access to food. As poverty-alleviation programs in developing countries make an impact, the purchasing power of poor people will increase, as will the demand for food grains. Based on population projections and improved consumption patterns in developing countries, it is estimated that rice production must increase by 40% during the next 20 to 25 years or at the rate of about 1.1% a year. This increase will have to be achieved from less land, with less water, less labor, and fewer chemicals. To feed 5 billion rice consumers in 2025, we have to develop rice varieties with higher yield potential and more excellent yield stability. Crop cultivars with higher yield potential are the key to increased productivity. Conventional hybridization and selection procedures will continue to be employed, but breakthroughs in cellular and molecular biology will be increasingly used in rice improvement. Transformation techniques allow us to introduce novel genes from unrelated sources to accomplish breeding objectives not possible through conventional breeding approaches. For example, none of the rice varieties or related wild species has beta6 P.K. Subudhi, T. Sasaki, G.S. Khush carotene, a precursor of vitamin A, and rice varieties with vitamin A could not be developed. Ye et al. (2000) introduced three genes, two from the daffodil (Narcissus pseudonarcissus) and one from the bacterium Erwinia uredovora into rice variety Taipei 309. This led to the establishment of a biosynthetic pathway for the production of beta carotene in rice endosperm. This so-called "golden rice" will have a significant impact on alleviating vitamin A deficiency among poor rice consumers.

6. The fate of Organic and Inorganic Pollutants in Paddy Soils

Paddy soils are being recklessly polluted by accretion of various pollutants into the soil by anthropogenic means which eventually contaminate the soil-water ecosystem. Since rice being stapled food for half of the world's population, directly manipulate the human health by the intake of contaminated food. Paddy ecosystem is most susceptible to contamination for being stored and potential phytoremediator of pollutants [41]. For example, studies in various countries showed that Cd even at a minor concentration in soil adversely affected the human health, as it is readily taken up by rice and translocated to shoot and then grains [42,43].

6.1. Organic Pollutants in Paddy Soil

Persistent organic pollutants (POPs) are the most toxic ones among numerous organic pollutants. These pollutants are non-degradable, transported over long distances, and persist in soil for more extended period of time [44]. Organic pollutants have been becoming alarmingly relevant since the industrial revolution. Despite being prohibited, organic pollutants are still found in environmental samples (Eremina et al. 2016). The universally recognized organic pollutants are; Persistent Organic Pollutants (POPs), 2Polychlorinated Biphenyls (PCBs), Polychlorinated Dibenzodioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs) and Pesticides. Ding et al. 2013 reported that concentration of polycyclic aromatic hydrocarbons in rice grains reached a toxic level in some parts of China, i.e. 13.2–85.3 ng/g. These pollutants can be bioaccumulated and tend to biomagnified having a potential adverse effect on human and ecosystem.

6.1.1. The fate of Organic Pollutants in Paddy Soils

Diffuse contamination is perceived as a danger of soil quality, constitutes natural toxins (POPs) and heavy metals. POPs are profoundly risky as they remain in the soil long after the application in bioavailable form and find hazardous to humans and biological communities [45]. Some of these POPs are carcinogenic in nature and impervious to microbial degradation. Since the prohibition of PCBs, their level in the soil is declining while all other important organic pollutants like PCDD/DFs and PAHs are found in substantial in soil [46]. Therefore, the ecological danger of organic pollutants in the environment needs widespread consideration.

POPs are taken up by plants from soil (via roots) and air (via foliage). In rice, the primary pathway of POPs entry into the plant is from soil [47,48]. In paddy soil, these POPs are present via adsorption in unmodified and untreated structures by having strong or weak linkages with organic and inorganic colloids of soil [49]. The critical environmental issue regarding POPs is their bioavailability in soil. As we know aging of POPs, a portion of POPs are entrapped in micropores or tightly adsorbed on soil organic matter. Tao et al. [50] reported that only loosely bound or water-soluble POPs are bioavailable. Though, tightly adsorbed POPs are considered to be not available [51,48]. After absorption, these organic pollutants have toxic effects on plants like abnormal cell ultrastructure, disturbed DNA, Disturbed cell biosynthesis, and disrupted membrane stability [52]. In south-east Asian countries, rice is an important cereal crop used as a staple food, and its straw is used to feed the livestock; POPs could possibly enter into the food chain via ingestion of contaminated rice or meat of animal raised on contaminated straw [47].

Pesticides are used to kill harmful organisms from the field, but many of them are injurious to another organism, even human being. Organochlorinated pesticides are being used for many years and have a prime disadvantage of high stability and persistence in soil [53,54]. In paddy soils, the amount of pesticides depends on how tightly adsorbed on the colloid surface and how rapidly microbial activity degraded it. And the factors involved are; the moisture content of the soil, clay content of soil and ionic or neutral colloidal behaviors [55,56]. The sorption characteristics of lindane, methyl parathion, and carbofuran pesticides in paddy fields are determined by the organic matter and clay content of soil [57].

6.2. Inorganic Pollutants in Paddy Soils

Heavymetals (Pb, Cr, As, Zn, Cd, Cu, Hg, and Ni) are hazardous in nature and mostly generate due to anthropogenic activities like effluent and waste disposal, mining, etc. among these heavy metals, some are required by plant in small quantity (Fe, Zn, Mn) as a micro-nutrient while others pose serious threat to living entity [58]. Heavy metals pollution is the most pervasive problem of agricultural field, and they enter the food chain via a soil-crop-food pathway, and the remaining plant part is used as fodder of livestock or added into the field [59,60]. Heavy metals are the major pollutants of the paddy field as they bioaccumulate in the system by having long persistence than discharge rate [61]. Typically, heavy metals such as Cd, As and Pb are found in paddy soils and can be assessed and screened from farming soil. The fate of heavy metals in paddy soil depends on organic matter content and pH of the soil [62].

6.2.2. The fate of Inorganic Pollutants in Paddy Fields

Among the broader list of paddy soil pollutants, heavy metals especially As, Pb, Cd are highly toxic. The human activitiescontribute major share in annual addition of heavy metals into paddy soil. For example, phosphatic fertilizer application and irrigation water are foremost anthropogenic sources of Cd contamination in the rice field [63]. As case, the use of As-based pesticides and irrigation of As-polluted water are a source of As addition to rice fields [64].Thus, heavy metal minimization in rice is an increasing demand for sustainable rice production and food safety.

The bioavailability of heavy metals in plants depends upon various soil factors, plant genotype, climatic factors, and agronomic practices [65]. For example, increasing the soil pH by liming decreased the bioavailability of Cd and thus rendering less Cd available for plant uptake [66]. Likewise, agronomic practices could play an important role in heavy metal mitigation. The selection of low heavy metal-accumulating or resistant rice cultivars, adjusting planting patterns and crop rotations and water management could be used to minimize the exposure of humans to Heavy metals by rice [67,68,69].

The behavior of As is readily effected by soil surface, speciation, redox potential, and Fe–Mn oxides. As is more mobile in arsenite (AsIII) form as compared to arsenate (AsV) form by the result of reductive dissolution [70]. Fe–Mn oxides act as a sorbent of As and in aerobic conditions the chances of oxyhydroxides bond with As increased while in reduced condition, As become more available than to oxygen-rich condition [71,72]. In paddy soils, As has a positive correlation with dissolved organic matter (DOC), the mobility of As is enhanced by DOC [73]. Biochar addition in paddy soil contaminated with heavy metals reduced the concentration of heavy metals like Cd, Pb, and Zn but on the contrary increased the As the concentration of rice shoot by 3.3 folds and As soil solution concentration by 14.2 folds [74,75].

7. Conclusion

Shrinkage of water resources with climate change, and massive contamination of paddy fields cause severe threats to human health as well as food security. Rice grown in flooded condition use excessive water, and thus surplus water is lostmainly by unproductive seepage and percolation. In addition, the mass accumulation of pollutants in rice also leads to extreme risks. Thus to cope with these challenges of water scarcity and pollutant accumulation, appropriate adoption is proposed. Management practices like water-saving technologies, varietal improvement, fertilizer and weedicides application, and improvement in irrigation water practices exhibit the great potential in saving a substantial amount of water during rice production. Future research work is required to develop appropriate management strategies and genotypes better adapted to integrated stresses, i.e. heavy metal, water, salinity, drought, submergence, etc. under future climate change.

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