Umair Riaz
Qamar-uz-Zaman: Editors

RICE PRODUCTION:

KNOWLEDGE AND PRACTICES FOR ENSURING FOOD SECURITY

ISBN: 978-93-87500-51-8

Austin Publishing Group

ISBN: 978-93-87500-51-8

Austin Publishing Group

Overview and Perspectives of Food Security in Connection with Rice Crop

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Published Date: January 08, 2020

Abstract

All over the world, rice is a significant food in general, and in Asia, about 90% of the world rice (*Oryza sativa* L.) is produced and consumed. More than half of the world's population is feeding on rice; however, >400 million people suffering from chronic hunger in the rice-producing areas of Asia, Africa, and South America. However, as the population of the world is increasing day by day the demand for rice as a food increases within the globe which is expected to rise by the further 38% within 30 years according to the United Nations. The rice production in the world stands at 454.6 million tons per annum, with an average yield of 4.25 ton/ha. Food security is the current emerging issues/problem in this era that scientists and policymakers are working it on four dimensions, e.g., Food access, convenience, constancy, and consumption. It exposes the statistic that rice is not only the critical food basis for > 4 billion people, but also the emphasis on composite rice ecosystems that disturb global apprehensions, like poverty mitigation, food security, sustainable development and security of cultural inheritance.

Keywords: Rice; Food security; Population; Global warming; Sustainable agriculture

Background Information

The awareness of the problem of food security in the world – by which is meant the level of availability and access to food of an individual (or population) – can be seen clearly from the statistics that reflect its effects on personal nutrition.

Based on population projections from the United Nations and income projections from the Food and Agricultural Policy Research Institute (FAPRI), global rice demand is expected to rise from 439 million tons (milled rice) in 2010 to 496 million tons in 2020, to 555 million tons in 2035. This is an overall increase of 26% in the next 25 years, although demand will decline over time as population growth slows and people diversify from rice to other foods. Asian rice consumption is projected to account for 67% of the total increase, rising from 388 million tons in 2010 to 465 million tons in 2035 despite a continuing decline in per capita consumption in China and India. Besides, 30 million tons more rice will be needed by Africa, an increase of 130% from 2010 rice consumption. In the Americas, total rice consumption is projected to rise by 33% over the next 25 years.

Worldwide, there are more than 150 million hectares of rice fields. Irrigated lowland fields make up over half of this area and produce 75% of the world's rice. These remain the essential rice production systems for food security –, especially in Asian countries.

Because land is scarce and expansion is unlikely, global rice yields need to rise faster than in the recent past if world market prices are to be stabilized at affordable levels for billions of consumers. Globally, farmers need to produce at least 8–10 million tons more paddy rice each year – an annual increase of 1.2–1.5% over the coming decade. This is equivalent to an average yield increase of 0.6 t/ha during the next ten years, taking into account the expected slowdown in global rice consumption in the longer term. However, yields will still have to grow faster because of pressure on rice lands in the developing world from urbanization, climate change, and competition from other, high-value agriculture. A Rice yield growth of 1.0-1.2% annually beyond 2020 will be needed to feed the still-growing world and keep prices affordable.

Projected demand for rice will outstrip supply in the near-to-medium term unless something is done to reverse current trends of slow productivity growth and inefficient, often unsustainable, management of natural resources. Steep and long-term price increases would wreak havoc on the lives of the poor and send dangerous reverberations throughout the political and economic landscapes of the world's most populous regions.

Rice will remain the dominant feature of the nutritional and agricultural landscape of many countries far into the foreseeable future. However, the way rice is grown will have to change. The massive 'water footprint' of some traditional cultivation methods is not sustainable in many parts of Asia, where scarcities of water and labor are becoming significant drivers of change. More efficient management systems are needed.

Scientific research has successfully increased rice yields in the past, and is also finding ways to protect ecosystems without compromising productivity. Under the Global Rice Science Partnership (GRiSP), more than 900 research and development partners are coming together to help increase the productivity of rice to meet food security needs.

Food Security; Introduction, History

During 2007-08 the awareness of food insecurity issue and its effect on the living standards of many people, especially the poor, have been triggered due to a sharp rise in global food expenses. In 1947, the food security concept was described as "all time and sufficient availability of basic diet products throughout the world to ensure a continuous extension of food intake and to balance variations in prices and production." The principle was to respond to transient food insecurity during the lean season like milk supply-demand gaps, and short-term food insecurity like shortfall production due to natural catastrophes [1]. There is an immense increase in the concerns given for the distribution and access to food instead of demand and supply side.

For this reason, a holistic approach to food security was offered at the World Food Summit in 1996: "The security of food exists once all individuals have continuous access to adequate, safe and nutritious food to sustain a healthy and dynamic life. This definition suggests that there should be four dimensions of food security, for example, food access, convenience, constancy, and consumption. In the last years, the increasing energy prices, the decreasing rate of the dollar and rising grain demand for biofuel not solely impel a pointy increase in grain costs but additionally worsen the scarcity in food and malnourishment of the poorer because of an enormous food share in their total expenses [2].

History

The agricultural ability to support the expanding population is a significant issue for ages, and it remains high on the international policy agenda. In 2000, the elimination of famine and poverty was incorporated as the United Nations Millennium Goals Development (UNMGD) part was accepted. One objective of UNMGD is to divide the proportion of individuals who experience the starvation from 1990 to 2015. The accomplishment of this security objective would be a noticeable challenge. Food safety performance forecasts have been part of landscape policies since Malthus's essay on the principle of population in 1798. From the last century, some specialists have shown concern for the ability of agricultural production to be alert of global food demands, while others predict that industrial expansion or growth will increase the volume of production to suit the growing request adequately. Up till now, desperate expectations of a worldwide food security calamity have been unsupported. In any case, crop yield and development has hindered in a significant part of the world as a result of decreasing investment in irrigation, rural infrastructure, agriculture research, and declining water shortage. New difficulties to the food safety have been presented by environmental variation and through HIV (human immune deficiency virus) causing mortality of humans. Numerous investigations predict that global supply of food will not be antagonistically influenced by modest environmental changes as they expect that the agriculturists will find a way to adapt to alteration in the atmosphere and additional carbon dioxide will increase yield.

Nevertheless, numerous developing states are expected to cost acutely. In tropical or hot climates, environmental variation can result in extreme precipitation among delayed desiccated periods and for irrigation, additionally more variable or decreased resources of water. These types of condition can stimulate plague and a pest in crops and animals, along with soil erosion and desertification. Increasing development in marginal areas may cause more risk of ecological degradation in these lands. HIV endemic is an additional worldwide issue that caused almost 42 million incidents globally by 2002, and 95% of these incidents are generally in underdeveloped nations. Besides health problems, financial and social impacts, the syndrome also influence food safety and nutrition. From affected family units, adult labor is removed regularly, and these families will suffer more to buy or produce food because of less capacity, as resources are often exhausted for burial or medical expenses. The basis of knowledge about agriculture will decrease as individuals that have experience of scientific farming will become ill with this syndrome. Quantitative models have been developed by several organizations that project global food demand and supply in the coming years. According to current strategies of IFPRI (International Food Policy Research Institute) and IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade), international production of cereals and livestock is likely to rise by 56 and 90%, respectively during 1997-2050. Rapid urbanization and rise in income are central powers that enhance request for best-esteemed produce like meat, fruit, and vegetable [3].

Food Security; Issues, Limits, and Measures

Issues

Remarkable advances in food production in the last half-century has allowed a severe decline in the world's population, which is starving instead of doubling the population. Nevertheless, more than one in seven people do not have access to sufficient proteins and energy from their food and undergo malnutrition. A set of numerous intersecting challenges has now been faced by the world as the world population will continue to expand, although it is about to reach 9 billion people by the mid of this century.

The main factors associated with the slowdown in population growth include increased income, improved purchasing power, and high consumption and demand for manufactured food, dairy products, fish and meat all of which increase pressure on the food system. Meanwhile, food producers face more competition for energy, water, and land, and the need to include many of the negative environmental impacts of food production is becoming progressively brighter. The first question of all these problems is the threat of climate change and the concern about how the mitigation and alteration methods can affect the food system. The world now faces several main challenges which include; matching the rapidly varying food demand to its provision to highly populated and prosperous societies by using socially and environmentally sustainable ways and ensuring that the world's deprived people do not starve.

These challenges involve extreme fluctuations in the preparation, storage, processing, distribution and disposal of foods, for example, during the agronomic and industrial rebellions of the 18th and 19th centuries and the 20th century's Green Revolution. Although the increase in production has an important role, it will be restricted by the limited resources provided by land and sea and the earth's atmosphere, which are unprecedented.

Limits

Some factors limit the ability of families to benefit from higher prices. For example, poor marketing infrastructure, along with unique transport links confine the capability of the Papua New Guinea Highlanders to supply food to the most significant urban centers where the demand for local food is very high. The similar situation happens in the islands of several countries. Inadequate funding coverage and research facilities to prevent farmers from receiving technical assistance to improve productivity. The potential for increasing agricultural production is also limited by the availability of inputs such as land, credit and planting material and the increased cost of fuels and fertilizer. These constraints are documented elsewhere [4]. With the continued growth of population, income, and biofuels, the continued existence of many problems is precarious to ensure food security from now until the middle of the century. Total factor productivity, a measure of GDP growth for all input indexes, has increased both in agriculture and in livestock farming over the past two decades [5,6]. However, there are concerns that crop yields from primary staple foods can reach their biophysical limits in some areas [7]. This could harmthe global food supply and prices. Climate change will also affect the future crop yield paths, though the precise effect is spatially heterogeneous and uncertain. Depending on the geographical location, the effects of climate change on temperature and precipitation may lead to higher or lower crop yields [8]. For instance, the effects of fertilization on the higher concentrations of carbon dioxide in the atmosphere can increase crop yield [9].

Measures

Several sessions are used to measure the regional distribution and overall status of global hunger. None of these sessions include all aspects and facets of the above-described insecurity. This also applies to the FAO under nourishment Index. However, the FAO measure has many advantages. First, it deals with two aspects of food security, access, and availability; second, the basic approach is transparent and straightforward. Third, the data and parameters required for FAO indicators can be readily available to previous estimates and can be drawn without further difficulties in the future.

Current Scenario of World Food Security

Risks, Management, Opportunities, Challenges

The thing important is that more food production does not certainly mean more food for those people who want it. Most experts agree that most of the increase in manufacture must come from an increase in production. Current productivity and production levels in agriculture have little to say about potential levels because they only present price and demand levels/market conditions. However, it should be noted that food production differs from food accessibility (production subtracted by imports plus exports), and total availability and capability to access food (food entitlements) are quite different. African roots and tubers have less productivity as compared to other parts of the world [10]. Although food production will undoubtedly affect food entitlements, the relationship is complicated, and there are other related issues. People's access to foodstuff depends on the purchasing power and non-market entitlements of their income, such as the land rights for foraging purposes and subsistence farming. Families who want to maintain food security levels can apply specific coping strategies to increase access to food. These comprise retention of standard income-generating patterns, adjustment by existing funds or liquidation of liquid assets through innovation, withdrawal of inputs such as stocks or land, excitement, destitution, and immigration.

Nevertheless, the market economy is not believed to grow promptly, and several non-markets entitlements are likely to be declined. The market often regulates the food entitlements of urban dwellers, and these entitlements often depend on the local production of the rural dwellers, especially the subsistence farmers. Food insecurity is a fundamental poverty problem, and whether it concerns access to safety nets and social networks or productive assets (land, capital and agricultural inputs), it affects social groups with most fragile or weakest food entitlements. Malnutrition can thus pose a threat to rural and urban dwellers for various reasons and at different times. Links between urban and rural areas often focus on food security, so the urban dwellers will retain land or rural contacts, to ensure food security in the event of loss of purchasing power, while the rural dwellers will be sustained by the urban contacts, in part to ensure that local food entitlements are not lost.

Food safety management ensures that all members have access to available food. The possible things must also be appropriate, and people must be prepared to eat, and that should be accepted as a favorite food. With the current growth rates, it is expected that the food shortage will increase to more than nine times as compared to the current gap in 2020 [11]. As a consequence of their trade history, position, and agree-ecology, African countries have a variety of food systems for staple food. This is a great benefit to the food security condition because many consumers will replace five significant categories of the staple, yams, cassava, plantain, tubers, rice, maize, and millet-according to tribal and national taste preferences as well as in relative prices. The most important indicator of monitoring food security around the globe is per capita consumption of food, measured at the countrywide level in calories by the average dietary energy supply (DES) based on the national food balance sheets (FBS) and populace data [12].

However, there are no comprehensive, internationally comparable data to track the evolution of access of individuals or populations to food within countries. Achieving food security requires investment and policy reforms on many fronts, including agriculture research, water resources, human resources, rural infrastructure, natural resource management, and community-based agriculture. Progressive political action should not only enhance agricultural production but must also reduce poverty and boost income in rural areas, where most poor lives. If we adopt this approach, we can expect about a 71% increase in cereal production and a 131% increase in meat production between 1997 and 2050. Subsequently, child malnutrition would diminish, the number of malnourished children would decrease from 33 million in 1997 to 16 million in sub-Saharan Africa in 2050 and 85 to 19 million in South Asia. In order to implement an agricultural revolution, we must need a collective action at the local level, and the participation of non-governmental and governmental organizations working at the community level. There have been many successful projects, including those with techniques for conservation and water harvesting. Another priority to increase yield in rain-fed agrosystems, especially in remote and dry areas is participatory plant breeding. Participation of farmers can be utilized in the early stages of selection of breeds to help find suitable crops for a variety of environments and preferences of farmers. It can be the only viable approach to grow crops in remote areas where the farm requires a high degree of crop diversity or for small crops that are ignored by formal breeding programs.

Food Security in Asia and the Role of Rice

In the upcoming decades, per capita, food consumption is expected to increase as incomes in developing countries increase. Over the years, Asian countries have established a relationship to attain food security through the establishment of emergency food reserves [13]. These relationships are established in agreements, declarations, and joint statements of intergovernmental organizations [14]. The result is to enhance and improve the stability and development of the Asian region.

To conclude the analysis of their effectiveness and implications of the following policies: Firstly, the current Asian Plus Three Emergency Rice Reserve Agreement (APTERR) share is not enough to achieve the goal. Parties must strengthen their financial support and cooperation for the APRERR. Secondly, after the disaster, all parties must increase response, coordination, and negotiation for the release of emergency and acute food aid. Thirdly, the parties must remove the requirement of consensus in the APTERR council decision in the dispute. Finally, the Parties must integrate a compliance and enforcement mechanism and comply with the decisions of the APTERR Board; otherwise, their decisions will remain major victories in transient foods, from local foods in the West [15]. As the population continues to grow in the future, competition for crop production between livestock feedstuffs and direct consumption, and raw materials to direct consumption in the food processing industry will increase. In the meantime, as global renewable fuel use increases, industrial request for crops is likely to increase, particularly for first-generation biofuels that require primary foods [16]. In the past 50 years, food supplies have increased significantly due to increased productivity in the agricultural sector. So far, global rice production has been capable of meeting the demands of the population. However, if proper action is not taken in the future, its ability to maintain this performance is challenging. Shortly, the key challenges facing rice production include; increased rice demand for population growth, limited opportunities to expand harvested areas, reducing rice production growth, and low profits for rice production. In the same year, more than 3.1 billion people consumed 100 kilograms or more of rice. In 2001, the demand for rice was significantly increased as the world's populace utilized more rice as compared to maize and wheat and two other significant grains during this year, higher than 3.1 billion people utilized 100 kg or more of rice. Rice production has almost doubled since 1970 (316 million tonnes) to 2001 (592.8 million tonnes). During this period, the average growth percentage of rice yield was 2.29% per year. Though rice growth in the world has been decreasing since 2000, which was lower than the worldwide rice consumption. In this context, the global population is expected to increase from 6.13 billion in 2001 to 8.27 billion in 2030. Rice demand is expected to increase from 571.9 million tonnes in 2001 to 771.1 million tonnes in 2030. The population of the world is continuously growing, while many rice growers and their families still live in poverty. There are around 800 M people in the globe who are malnourished, while the rice crop is facing issues of decreased yield due to adverse environmental impacts, reduced soil fertility, high production costs, and lower rice prices.

Although rice production has experienced high growth rates, it has caused environmental problems such as soil acidity and compactness [17]. Besides, the decline of biodiversity in agriculture, food price speculation and rural poverty have increased, indicating that current trends in rice production are not environmentally friendly, socially responsible and profitable [18-21]. Considering the current state of water and land resources, declining and the increased poverty in rural areas, tackling the challenge of achieving sustainable rice production and food security in the country is a significant challenge. Given these problems, the government has taken initiatives to limit these problems. The Department of Agricultural Extension (DAE) has implemented several ongoing and completed development projects to increase and develop the capacity of farmers through logistical, economic support, and training. However, because of limited resources, inefficient leadership, lack of inter-agency coordination, and weak extension services, these initiatives failed to achieve [22]. Mandal (2006) stated that most policy documents are based on fictional ideas and lack of experimental analysis, mainly due to clerical errors and the absence of reliable data [23]. A few years ago, the government provided fertilizer and irrigation subsidies, which were insignificant when compared to other countries like India [22]. Besides, research shows that subsidies are not very beneficial to small and marginal farmers, and fertilizer traders can get a large share of subsidies [24].

Sustainable Rice Production

For the population, sustainability means changing our way of life to make the best possible use of social and environmental conditions in order to preserve human safety, health, and well-being for an indefinite period. Notably, the flow of valuable services and goods in the ecosystem must be maintained. The contemporary motivation for exploring sustainability is evidence of the accumulation of human beings that threaten their long-term interests by living outside the earth, thus changing the composition of the atmosphere and depleting soil fertility, biodiversity, freshwater supplies, and sea fishing. Based on literature review [25,26], sustainability means conservation and improvement of natural resources (promoting environmental health), building social and human capital, increased agricultural profitability and productivity (increased economic viability) and benefiting society with public goods and services (promoting social development).

At present, agriculture and sustainable rice production are the major alarm for policymakers, and re-addressing these issues is essential in many relevant government documents, such as poverty reduction strategic 2008 [27] and the National Agricultural 2010 Policy [28]. The reasons for the potential of this problem are as follows: rice cultivation is very susceptible to climate change (e.g., Floods) [29], land has become a scarce commodity, decreasing by 1% per year [28], pesticides, fertilizer and irrigation fuel prices are increasing gradually [22], groundwater arsenic contamination and irrigation water crisis in the South Western region of the country [30], and the main non-cereals such as pulses and oilseeds are pushed out by rise-based monoculture [31] based on rice-paid crops.

Besides, increasing pressure of population and soils containing unfortunate organic matter, that is, most soils contain 1.5% organic matter, while good soils must contain 2.5% organic matter [32] in rice production areas that are on a serious threat tothe sustainability of rice production. At the same time, incentives and new policies to ensure the sustainability of the ecosystem and agriculture services will be essential if we have to fulfill the requirements of increased production without compromising the safety of the environment or public health [33].

The literature on evaluating the sustainability of rice products is not sufficient to attract main public policy inputs [34]. According to historical data, Baffes and Gautam [35] investigated the current production levels of rice per capita can be maintained by obtaining improved yields from high yield varieties (HYVs). Roy et al., [36], without looking at rice growing ecosystems in floods and salt farming, assessed the sustainability of rice cultivation and concluded that the rice “Boro” is the most sustainable. By the development of comprehensive indicators (CIs), Gowda and Jayaramaiah [37] compared the sustainability of the Indian rice production system and found that lowland rice is the best sustainable in the rain-fed areas, followed by irrigation systems. However, the method was not described in details in the latter study, and all CI development steps were not followed as recommended by the OECD [38].

Fortunately, innovations have emerged in the technology field. Varieties of rice with maximum return should be produced to increase regular agricultural production, thus increasing the total production of rice [39]. In the past, most rice varieties showed increased yields when nutrients and water were supplied in an adequate amount [40]. The Republic of China has played a leading role in the development of high-yield varieties using a hybrid, new plant and breeding methods of a semi-dwarf kind. "Super rice" breeding of Chinese programs has established F1 hybrid varieties like Xieyou 9308 and Liangyoupeijiuusing a combination of intersubspecific heterosis and ideotype approach [41,42]. The production of grain yield in the farm demonstration area of hybrid varieties is 12 tons per hectare, which is 8 to 15 percent greater as compared to control. From 1998 to 2005, commercially released 34 hybrid rice varieties "super" were grown on 13.5 million hectares and produced a surplus 6.7 million tons of rice in China [43]. Advanced newly developed hybrid rice varieties often break down production records.

Although, the physiological mechanisms on which high yield potential is based are not well understood in super hybrid rice. For these varieties, no crop management strategies have been developed to fully demonstrate potential yield while achieving high resource efficiency at the same time. Several growers utilize similar administration techniques for "super" hybrid and conventional rice varieties [44]. Therefore, regardless of whether "super rice" varieties are consistent with seasons and sites, it is not informal to attain maximum yields. Due to environmental issues and water scarcity, the task is to enhance the production of rice with a reduced amount of chemicals and water [40]. To achieve this task, novel techniques of breeding, such as genetic engineering, conversion, and marker-aided selection, must be effectively connected with empirical methods of breeding. Agronomists and physiologists input is critical to the success of this effort. The Chinese government is aware of the significance of supportable upsurge in the production of rice for attaining national food security. The increase in rice production is mainly determined by the increase in yield rather than the expansion of the farming area. It has become necessary for the government to spend more on rice production. We believe that technological and scientific innovations will keep on playing a vital part in enhancing rice production despite the alterations in physical environments, socioeconomic, and problems connected to the production of rice [45] announced the advancement towards developing Super Green variety of rice by assimilating molecular technology, genomic sources, and germplasm in China. These Super Green rice varieties will enhance resistance against leading insects and diseases; maximum nutrient use efficacy; resistance to abiotic stresses such as abnormal temperature, salinity and drought; and high crop yield with good quality. It is estimated that Super Green development of rice will consequence enhanced rice production with fewer inputs.

It reveals the fact that rice is not only the primary food source for more than 3 billion people but also the focus of complex rice ecosystems that affect global concerns, like poverty alleviation, food security, sustainable development and protection of cultural heritage.

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Rice Plant Growth and Development

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Published Date: January 08, 2020

Abstract

Rice (Oryzae sativa L.) belongs to the grass family Oryzeae and is one of the leading food crops in the world. It is one of the leading food crop feeding approximately one half of world population; it is reported to feed approximately one half of the world's population. it is a staple of over half of the world's population, mostly in Asia. It is the second most cultivated cereal after wheat. It provides 20% of the per capita energy, and 13% of the protein consumed worldwide. It is known as a semi-aquatic, annual grass plant and is found growing in a wide range of soil types and water regimes: irrigated, rainfed lowland, upland, and flood-prone areas depending on where it is produced. Although there are multiple types of rice production the principles of land preparation, planting, management, harvesting, and finally processing are similar throughout the world, apart from the obvious difference between wetland and dry land cultivation. There are various types of rice based on grain length, width, and chemical characteristics, those being a long grain, medium grain, and short grain. Rice grows in approximately 115 countries on every continent except Antarctica. Production practices range from very primitive to highly mechanized. This chapter will focus on the various aspects of rice growth and development under normal and stressed conditions.

Keywords: Cultivation; Rice; Growth; Annual Grass

Introduction

Higher plants have many specialized organs, tissues, and cells. All these components are derived from a single cell (fertilized egg, zygote) through several developmental events. In animals, developmental and differentiation processes are restricted mainly to a short period of embryogenesis [1].

In contrast, development continues in plants until the end of the life cycle. Apical meristems repeatedly differentiate lateral organs. Meristematic tissues are generated in a variety of organs with proper timing to achieve continuous development. Therefore, developmental studies of the entire plant life cycle are essential to elucidate the establishment of plant formation [2].

Rice belongs to grass family and one of leading food crop. It is rich source of energy and provide 13% of protein globally [3]. It is semi aquatic plant and grows on variety of soil having various moisture regimes. In other word it is found on wide range of areas from deeply flooded to dry flat fields or hilly terreced or non terreced slopes [4].

Growth and development of the rice plant involve continuous change. This means essential growth events occur in the rice plant at all times. Therefore, the overall daily health of the rice plant is essential. If the plant is unhealthy during any stage of growth, the overall growth, development, and grain yield of the plant are limited. It is essential to understand the growth and development of the plant [5]. The ability to identify growth stages is essential for proper management of the rice crop. Because management practices are tied to the growth and development of the rice plant, an understanding of the growth of rice is essential for the management of a healthy crop [6]. Timing of agronomic practices associated with water management, fertility, pest control, and plant growth regulation is the most critical aspect of rice management. Understanding the growth and development of the rice plant enables the grower to correctly time recommended practices. Keeping in view the importance of rice growth this attempt will focus on the diferent aspect of rice growth and development under normal and stressed conditions.

Growth and Development of Rice

Growth and development of rice grown as an annual from seed begin with the germination of the seed and ends with the formation of grain. During that period, growth and development of the rice plant can be divided into three phases: vegetative, reproductive, and maturation. These three phases deal with growth and development of different plant parts. It is essential to remember the growth and development of rice are a continuous process rather than a series of distinct events. Growth of the rice plant starts from seed germination and ends up at the formation of grain. This process can be divided into three phases of development:

1. Vegetative Phase

a) Emergence

b) Seedling development

c) Tillering

d) Internode elongation.

2. Reproductive Phase

a) Pre-booting

b) Booting

c) Heading

3. Maturation (grain filling and ripening)

Vegetative Phase

A. Emergence

Seed Germination occurs when the seed coat has imbibed adequate water to become soft and elastic. The coleorhiza (the sheath covering the radicle or embryonic primary root) elongates slightly, emerging through the seed coat, allowing the radicle to break through the coleorhiza and become anchored in the soil. The coleoptile or primary leaf then elongates. Thus, under dry seeded or aerobic conditions, the radicle emerges before the coleoptile. Under water-seeded or reduced oxygen (anaerobic) conditions, the coleop tile may emerge before the root (radicle or coleorhiza). This typically occurs within two days when temperatures are between 70° to 97°F. Below or above this temperature, germination requires more time. Germination occurs within the temperature range of 50° to 107°F with an optimum temperature of about 87°F [7]. The series of events the takes place during the process of emergence are described in the (**Figure 1**).

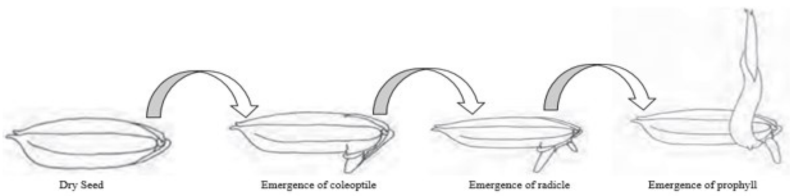

Figure 1: Events the takes place during the process of emergence

B. Seedling development

When the seed has imbibed water and germination begins, the seed radical emerges to anchor it in the soil, which subsequently leads to plumule emergence in the dry land, direct seeding. Seedling emergence is when the coleoptile emerges above the soil surface in dry-seeded rice or when it emerges from the water surface in the case of water-seeded rice. This occurs between 10˚C and 42˚C, optimum temperature 31˚C. This may take between 5 and 28 days based on the growing environment help the plant emerge faster. Planting depth is essential, particularly in the case of the semi-dwarf varieties, which should not be planted more than 3 cm deep, or they will not emerge [8]. A first leaf is not the individual leaf blade and generally of one inch or shorter in length, elongates from the coleoptiles. Developing leaf is based on the first leaf that acts as a protective layer. With the growth of seedlings elongation of next leaves occur. By the time this primary leaf grows further and develops into three different components, such as a sheath, collar, and blade, as mentioned in the (**Figure 2**).

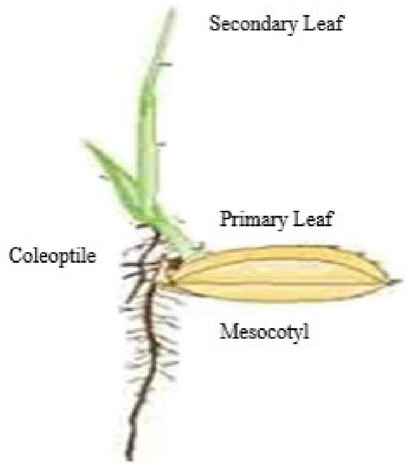

Figure 2: Germination and seedling development

C. Tillering

Tillering occurs when a sprout or stalk is produced from the crown, which forms just below the soil surface or from the axis of the lower leaves. Tillering usually begins three weeks after emergence, i.e., as the fourth-leaf fully emerges, and ends at the fifth leaf stage appears (approximately three weeks). A rice plant may develop from two to five tillers depending on the seeding method. Direct seeding may result in two to five panicle-bearing productive tillers while transplanted rice may have 5 to 30 productive tillers. It is from the surviving tillers that the potential panicles per unit area are determined, which has an impact on yield. The late tillers may die due to competition with the earlier established tillers. During tillering, the crown roots of each plant continue to develop growing downward, and it is only at the flooding that roots begin to develop laterally and vertically in response to the oxygen available on the water surface. For the duration of this period, second roots produce downwards till the flooding. After flooding, roots grow horizontally and vertically. The growth in horizontal direction depends upon the oxygen availability of water and soil interface [9].

Tillering amplifies in curve shape until the highest tiller number is attained. At this stage, there might be a difficulty to differentiate between culm and tiller. To increase the tiller population, nitrogenous fertilizers are the practical and standard tool, which enhances the amount of cytokinin inside the nodes of the tiller and also increases the germination process of tiller primordium [10].

The vegetative lag phase occurs as tillering ends, and the reproductive phase of plant development begins to be expressed in the plant. During this time, the number of tillers decreases while the plant height and stem diameter increase slowly. In short-season varieties (110-day maturity) this is not as evident as in longer-season varieties (150-day maturity). Since the plant is not actively growing during this period, it may appear yellow. In most cases, this is not due to a lack of nitrogen [11].

D. Internode elongation

Internode or stem elongation is directly linked with the growth period. In the early maturing varieties and medium maturing selections, it typically initiates approximately when panicle primordia start. However, in late maturing rice varieties it begins before the initiation of panicle primordia. In the photoperiod sensitive rice plant varieties, extensive photoperiod boosts up the total length and the number of internodes. On the other hand, in photoperiod insensitive plants varieties, it bears a zero influence on the elongation of the stem [9]. Unexpected environments, like deep water and deep seeding, stimulate the elongation of internode even at the very early growth phases. When the seed is placed 2 cm deep in the soil, it does not initiate the stem elongation, but when the same seed is placed deeper somewhere, 3-4 cm can stimulate elongation of internodes. In floating and rooted water rice plants, elongation of internode starts in response to the higher water depth. 2-10cm internode elongation per day is common, while the maximum rate is 23-25 cm per day [12]. **Figure 3** explains the plant structure at various leaf stages.

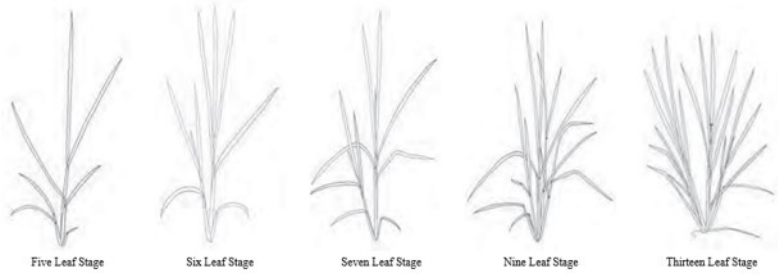

Figure 3: Rice plant at various leaf stages

Reproductive phase

The reproductive phase occurs from panicle initiation to anthesis and is characterized by a decrease in tillering activity, panicle initiation, then by internode elongation and jointing. The boot stage and flag leaf emergence are followed by heading and flowering. The reproductive phases of plant growth take 30 days depending on variety and environmental conditions. Panicle initiation starts when the panicle primordial begins to differentiate. The first sign of this is the "green-ring" stage when a bright green band is observed just above the top node. Once this stage concludes, the internode elongation begins. Panicle differentiation is a critical stage in yield build-up as the number of grains per panicle is set at this time.

A. Pre-booting

Prebooting refers to the interval after the onset of internode elongation and before flag leaf formation is complete. During prebooting, the remaining leaves of the plant develop, internode elongation and stem formation continue, and panicle formation begins uppermost branches first and progress downward. Because there are several panicle branches, development of florets within the panicle as a whole overlap. Florets at the tip of a lower branch might be more advanced in their development than florets near the base of an upper panicle branch. From a management stand point, panicle length defines plant development during this phase. A fungicide label, for example, might prescribe its application "from a 2- to 4-inch panicle". By the time the panicle is about 4 inches long, individual florets can be easily recognized on the most mature panicle branches [13].

B. Booting

Booting is the period during which growth and development of a panicle and its constituent parts are completed inside the sheath of the flag leaf. The sheath of the flag leaf is the boot. Booting stages are classified according to visible development of the panicle without dissection. For convenience, it is divided into three stages: early, middle, and late boot. It is based on the amount of flag leaf sheath exposed above the collar of the leaf from which it emerges, the penultimate (second to last) leaf [14]. The early boot is recognized when the collar of the flag leaf first appears above the collar of the penultimate leaf on the main stem and lasts until the collar of the flag leaf is about 2 inches above the collar of the penultimate leaf. Middle boot occurs when the collar of the flag leaf is 2 to 5 inches above the collar of the penultimate leaf and late boot when the collar of the flag leaf is 5 or more inches above the collar of the penultimate leaf. By late boot, the increasing panicle development causes the boot to swell, giving rise to the term "swollen boot". The boot becomes spindle-shaped; it is wider in the middle tapering to a smaller diameter at each end [15].

C. Heading

Heading occurs after the panicle begins to swell in the boot and as the panicle emerges from the boot. Panicle emergence may take 10 to 14 days depending on how many tillers there are on the plant. Heading date is when 50 percent of the panicles have emerged from the boot. There are several types of panicle emergence based on how much of the panicle exert from the boot, from well exerted to enclosed. Once exertion begins, anthesis/flowering are initiated. Anthesis is depicted when the floret opens, allowing the stamens to extrude, and the pistil becomes visible between the floret lemma and palea.

In most cases, pollen is shed from the anthers first while the floret is closed and then sheds more after it opens [16]. The majority of pollen shed occurs between 9 am and 3 pm. Flowering proceeds from the tip of the panicle downward to the base of the panicle as it emerges from the boot. This takes six to 14 days. At this time, the second factor of yield, seeds per panicle, is set. Factors that may negatively impact the seed set at this point in the reproductive phase include temperature, wind, rain, and pesticide applications. If ambient temperatures are less than 10°C or greater than 35°C, some of the seed may be empty [17].

Maturation (grain filling and ripening)

During grain filling, florets on the main stem become immature grains of rice. Initially, the starch is white and milky in consistency. When this milky accumulation is first noticeable inside florets on the main stem, the stage is milk stage. Before pollination, the panicle in most varieties is green, relatively compact and erect. During the milk stage, the accumulation of carbohydrate increases floret weight. Since the florets that accumulate carbohydrate first are located near the tip of the panicle, the panicle begins to learn and eventually will turn down. The milky consistency of the starch in the endosperm changes as it loses moisture. When the texture of the carbohydrate of the first florets pollinated on the main stem is like bread dough or firmer, this stage of growth is referred to as the dough stage. As the carbohydrate in these florets continues to solidify during the dough stage, the endosperm becomes firm and has a chalky texture [18]. Grains capable of being dented without breaking are in the soft dough stage. As more moisture is lost, grains become chalky and brittle. During the grain filling stages, the florets develop and mature unevenly because pollination and subsequently grain filling occur unevenly. In the dough stage, only the florets on the main stem, which pollinated first, have an endosperm with the texture of bread dough. At the same time, the florets, which pollinated later, including those on the tillers, may be in the milk stage. These are the last florets to accumulate carbohydrate. As more and more florets fill with carbohydrate, the translocation of carbohydrate to the panicle starts to decline, and the final phases of grain filling occur. The panicle changes in color and form as the florets develop and mature. For most varieties of rice, the panicle changes from uniform light green at the milk stage to a mixture of shades of brown and green during the dough stage. As the color changes so do the grain shape as a consequence of carbohydrate accumulation in the florets. The weight of the carbohydrate causes the panicle to bend over and the panicle branches to be less compact around the panicle axis [19].

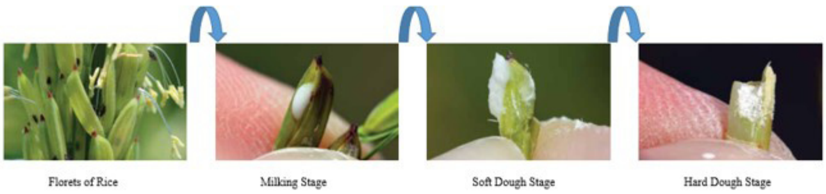

Figure 4: Reproductive Stages of the Rice Plant

At the end of the grain filling stages, the panicle on the main culm has a bent and slightly open shape and is various shades of brown and green. The bent and slightly open configuration of the panicle remains unchanged from dough to maturity. The ripening phase starts at the fertilization stage and prolongs up to 30-40 days through the filling of grain and ripening stages [3]. The grain filing takes place when the water and nutrients are carried from one area of the plant to other. This process may be affected by the number of nutrients, temperature, and water. The stage of grain filling, maturation, or ripening follows fertilization of ovary and is differentiating by the growth of grain. Within this period, weight and size of grain increases when the sugars and starch are transported from culms and sheath of the leaf, leaves of rice start to senesce, and the grain alters itscolor or color of straw at maturity [20].

Second (Ratoon) crop

Second crop stems originate from small axillary buds at the crown and stem nodes of the stubble remaining after harvest of the first crop. Generally, the second crop begins to initiate when the first crop approaches harvest moisture (18 to 21 percent). It is not uncommon to see second crop growth initiated before harvest of the first crop. Shoots develop in the second crop as they do in the first crop. New leaves emerge through sheaths of leaves on the first crop stubble; eventually, internode formation occurs, followed by panicle initiation and panicle differentiation, booting, heading, grain filling and maturity [21]. Development of buds on the crown is essentially the same process of tillering without the presence of a distinct primary shoot. Second crop growth is small and much more variable in all aspects compared with the first crop. There are fewer leaves and internodes per stem, a shorter maturation period (time from bud initiation to heading) and shorter mature plant height. There are fewer panicles per acre and per plant and fewer grains per panicle. Second crop yields are generally less than 40 percent of first crop yields. Second crop growth and development are limited by declining day length and falling temperatures at the end of summer and during the fall, which is opposite from the first crop that experiences mostly increasing day length and temperatures from planting to heading during the spring and early summer. The reduction in total sunlight translates to lower photosynthesis, which accounts in part for the lower yields. Reduced input costs often make ratoon cropping profitable despite lower yields [22].

Rice Growth under Stressed Conditions

Rice can be grown in different environments depending upon water availability and temperature conditions. Cold stress is a common problem in rice cultivation and affects global production as a crucial factor. Rice is a cold-sensitive plant that originated from tropical or subtropical zones [23]. When low temperature occurs during the reproductive stages, it can cause severe yield and yield components losses. The optimum temperature for rice cultivation is between 25°C and 35°C, and in temperate regions, rice growth is impressed by the limited period that favors its growth [24]. Exposure to cold temperature affects all phonological stages of rice and lower grain production and yield [25]. The low temperature in a vegetative stage can cause slow growth and reduce seedling vigor low number of seedlings, reduce tillering increase plant mortality increase the growth period and in the reproductive stage, it can cause to produce panicle sterility and lower grain production and yield [26].

Drought is abiotic stress, which affects plants at various levels and stages of their life period. This abiotic stress not only affects plant water relations through the reduction of water content, turgor, and total water, but it also affects stomatal closure, limits gas exchange, reduces transpiration, and disturbs photosynthesis [27]. Drought stress is characterized by reduction of water content, diminished leaf water potential, turgor pressure, stomatal activity, and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disturbance in metabolism, and finally, the death of plant [28]. It reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, respiration, translocation, ion uptake, carbohydrates, nutrient metabolism, and growth promoters [29]. The reactions of rice plants to water stress differ significantly at various organizational levels depending upon the intensity, duration of stress, plant species, and its growth stages [28].

Rice is affected by salinity during transplanting, after transplanting and flowering. However, it logarithmically endures salinity stress until ripening [30]. In the reproductive stage, salinity decreases the number of filled panicles, fertile panicle, the weight of 100 grains, and the percentage of rich grains and increases fertile tillers-influences of this pressure increase in warm weather and high evaporation. Without any regard to the seasons of the year, salinity decreases yield, the number of panicles, the weight of 100 grains and increases sterility in all rice cultivars and any growth stages but the most sensitive stage is panicle initiation [31]. Increasing salinity tolerance in rice could develop its production in regions where influenced by salinity, and they are not usable at present [32].

Contamination of agricultural soil by heavy metals has become a critical environmental concern due to their potential adverse ecological effects. Different heavy metals have a significant effect on the growth and yield of the rice crop [33]. Rice plants exposed to high levels of metals stress causes reduction in photosynthesis, water uptake, of plant growth, chlorosis in young leaves, nutrient imbalance, wilting of tops, and root injury and nutrient uptake [34-37].

Conclusion

Rice is a very important crop, and it is usually grown in approximately 115 countries on every continent except

Antarctica. From germination to final maturity, each stage has its role in the final yield of the crop. Anthesis and ripening are the most sensitive stages in rice for different stresses. Further experimental studies of the effects of transgressing threshold biotic and abiotic stresses on the rice responses can be included in crop impact and adaptation models.

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Rice Production Under Changing Climate scenarios

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Published Date: January 08, 2020

Abstract

Rice is a staple cereal crop for more than half of the global population. The changing climate, such as high Carbon Dioxide (CO_2), rainfall, and temperature have direct and indirect impacts on the soil-rice-plant atmosphere. Rice accounts for 2.7 percent of the value added in agriculture and 0.6 percent of Gross Domestic Production (GDP) in Pakistan. The optimum temperature required for growth of rice is 22-28 °C whereas, it is estimated that by the end of the twenty-first century, the surface air temperature will increase around 1.4–5.8 °C. This increase in surface means temperature during sensitive stages of rice production may reduce rice yields drastically. The high CO_2 levels reduce the rice productivity. These climatic impacts can be minimized through the proper management system and adaptation. The adaptation practices may include the shift of sowing dates, selection of appropriate stress tolerant variety specific to the agricultural zone, and water conservation strategies. The agronomic management suggests early sowing of rice cultivars or selection of early maturing cultivars to avoid high temperatures during grain filling. In this chapter, the threats of climate shift and climate change on rice characteristics, including its growth, quality, yield, and various other physiological, morphological, and biochemical mechanisms are discussed. The comparison of different management and adaptation practices and their limitations are also highlighted. The mitigation and adaptation strategies for food security dealing with climatic stressors under different rice simulation models are discussed.

Keywords: Climate; Temperature; Rice; Rainfall; CO2; Agriculture; climate shift

Abbreviations: CIAT: Climate-Smart Agriculture; CSA: Climate-Smart Agriculture; FACE: Free-Air CO_2 Enrichment Facility; FAO: Food and Agriculture Authority; FOT: Flower opening time; GDP: Gross Domestic Production; GHGs: Green House Gases; IPCC: Intergovernmental Panel on Climate Change; IRRI: International Rice Research Institute; LAI: Leaf Area Index; NGDP: National Gross Domestic Production; WG: Working Group

Introduction

The climate change refers to the variation in a climatic condition such as intensity and frequency of rainfall, temperature, and humidity level over some time. This change might be due to natural variability or as a result of anthropogenic activities [1,2]. Climate change in the form of higher temperatures, reduced rainfall, and increased rainfall variability, reduces crop yields and net farm revenues and threatens food security in low income-based economies, including African countries [3]. At the recently concluded 10th Session of IPCC WG II and the 38th session of IPCC in Yokohama, Japan, the world was warned that climate change impacts are leading to shifts in crop yields, decreasing yields overall and sometimes increasing them in temperate and higher latitudes. In light of these, some indigenous communities are changing seasonal migration and hunting patterns to adapt to changes in temperature

Climate Change Scenarios and Food Security

The simulation of climate change indicates a severe threat to the agricultural sector in developing countries [2]. According to the report of Climate-Smart Agriculture [4], the changes in monsoon and higher temperature are considerable challenges for the agriculture sector of Pakistan. This sector contributes 25% in National Gross Domestic Production (NGDP), involving 42% of the labor force [4]. About two third of the total population in Pakistan earn its livelihood through agriculture sector so the decline in cereal productivity may result in adverse impacts on their livelihood [2,5].

Pakistan is one of the most vulnerable countries of climate change due to its low adaptive capacity, and it is ranked 8th on the vulnerability index from 1995 to 2014 [6-8]. The productivity of major crops such as wheat, rice, cotton, and sugarcane is greatly affected due to climatic variations and extreme climatic events such as severe droughts from 1999 -2003, [5]. The global food security is threatened due to climatic changes, population growth, rapid urbanization, and a shift towards more meat consumption [6]. Pakistan is the 6th most populous country, and it ranks 78 out of 113 countries in Global Food Security Index. Therefore, the agricultural production needs to be increased by 70% by adaptive measures such as biotechnologies to create more productive crops and ensure food security (Brown and Funk, 2008; Tester and Langridge, 2010).

Effect of climate change on rice production

According to the [7], the climate change may cause tremendous damage to the rice production if it is not managed correctly. Less supply of rice with an increase in demand will not only create the food insecurity, but it will also affect the global food economy. Among the impacts of climate change are increase in temperature, increase in frequency, intensity, and duration of extreme climate events such as droughts, floods, and tropical storms; changes in the intensity, timing and spatial distribution of rainfall; soil degradation; and sea level rise resulting in loss of agricultural land and saltwater intrusion. Rising sea level may amplify soil salinity, displace areas for crop production, and reduce rice production in a sizable portion of the highly productive rice land in deltas. Drought affects all stages of rice growth and development. The strong effects of drought on grain yield are mainly due to the reduction of spikelet fertility and panicle exsertion. Frequent drought not only reduces water supplies but also increases the amount of water needed for plant transpiration. The most significant

Table 1: Critical temperature ranges required at various growth stages of rice

Growth Stage	Critical Temperature (^{0}C)		
	Low	High	Optimum
Germination	16-19	45	18-40
Emergence of Seedlings	12	35	25-30
Rooting	16	35	25-28
Leaf elongation	7-12	45	31
Tiltering	9-16	33	25-31
Anthesis	22	35-36	30-33
Ripening	12-18	>30	20-29

(Source: FAOSTAT, 1998)

Temperature

Increase in air temperatures during the grain-filling stage of rice will decrease grain yield and reduce its quality. Temperatures above the optimal growth temperature impair dry matter production due to reduced grain size [9]. Increases in both carbon dioxide levels and temperature will affect rice production. Higher carbon dioxide levels typically increase biomass production, but not necessarily yield. Higher temperatures can decrease rice yields as they can make rice flowers sterile, meaning no grain is produced. Higher respiration losses linked to higher temperatures also make rice less productive. The different predictions for elevated temperature, carbon dioxide levels, changes in humidity, and the interactions of these factors make forecasting future rice yields under these conditions challenging. IRRI research indicates that a rise in night-time temperature by 1 degree Celsius may reduce rice yields by about 10%. The effect of the expected rise in temperature as a result of reduced length of the growing season and increased maintenance respiration rates, such that the two factors canceled each other out [10-14].

CO_2 and other GHGs

The CO2 concentration in the atmosphere affects plant productivity in three significant ways, i.e. increase in photosynthesis, reduce in stomatal aperture and density which causes a reduction in stomatal conductance and transpiration and reduction of dark respiration [15]. Therefore, the increased CO2 levels are beneficial to vegetation [10].

Rice plants exhibit phenotypic plasticity in Flower opening time (FOT) in response to the concentration of atmospheric CO_2. Elevated [CO2] (E-[CO_2]) increases the temperature of rice panicles, which results in advance FOT. A study conducted by [16] indicates effect of E-[CO2] on FOT in rice using a Free-Air CO2 Enrichment Facility (FACE) where [CO_2] was increased by about 200 μmol mol^{-1}above the ambient level (A-[CO_2]) resulted in advanced FOT due to an increase in panicle temperature arising from a reduction in leaf stomatal conductance.

In rice plants, the respiratory CO_2 efflux and O_2 uptake in leaves change in response to the growth CO_2 concentration ([CO_2]). This degrees of change varies upon the cellular processes such as nitrogen (N) assimilation and accumulation of organic acids to growth [CO_2]. However, the underlying mechanisms remain unclear. A study conducted by [17] examined the respiratory characteristics of two rice varieties leaves with different yield capacities at different growth stages under ambient and elevated [CO_2] conditions at a FACE. The leaf CO_2 efflux rates decreased in plants grown at elevated [CO_2] in both varieties and were higher in high-yielding Takanari than in Koshihikari. The leaf O_2 uptake rates showed little change concerning growth [CO_2] and variety. The increased water temperature did not significantly affect the CO2 efflux and O2 uptake rates.

sea level rise

According to the International Rice Research Institute (IRRI), it is predicted that sea level may rise on an average rate of 1 m by the end of the 21st century due to the melting polar ice caps and glaciers. Rice production is vast in low lying deltas as well as the coastal regions of Asia, sea level rise. Predicting the effect of high sea-level on rice production in vulnerable areas is involved as the entire hydrology of the delta will be affected; sediment discharge and shoreline gradients will also be changed.

Flooding

Rice is unique in its characteristics as it can thrive in wet conditions where other crops fail to grow. However, the uncontrolled flooding is a problem, because rice cannot survive if I submerged under water for long periods. Flooding caused by sea-level rise in coastal areas and the predicted increased intensity of tropical storms with climate change will likely hinder rice production. At present, about 20M hectares of the world's rice-growing area are at risk due to the flooded at submergence level, especially in major rice-producing countries such as India and Bangladesh.

Climate change is likely to increase the frequency and intensity of flooding events in rice-growing areas. Currently, those areas which are not exposed to flooding, are predicted to experience floods.

Water Scarcity

An abundant amount of water is required for proper growth of rice. Low levels of rainfall or no rainfall for a week in upland paddy areas and for about two weeks in shallow lowland paddy fields can reduce rice production. According to the findings of IRRI (2018) average, rice yield reduction in rainfed, drought-prone regions has ranged from 17 to 40% in severe drought years, leading to a loss in production, food scarcity and related economical loses.

In South and Southeast Asia, water scarcity directly affects approximately 23 million hectares of rainfed rice production regions. In Africa, drought affects about 80% of 20 million hectares of rainfed lowland rice. Moreover, the climatic studies predict that drought also affects rice production in Australia, China, USA, and other countries.

Salinity

Salinity is associated with higher sea levels. As this will bring saline water further inland and expose more rice-growing areas to salty conditions. Rice is only moderately tolerant of salt and yields can be reduced when salinity is present. As sea-level rises, the effects of salinity can permeate throughout the whole deltas and fundamentally change hydrological systems. Higher salinity has indicated negative effects on rice productivity [18,19]. A number of studies have been conducted to analyze the impacts of higher salinity on various components on rice growth cycle including establishment, panicles, tillers and spikelets per plant, Leaf Area Index (LAI), floret sterility, individual grain size, and timing of heading [20,21]. Severely salt-stressed rice seedlings have smaller and lesser tillers; less root mass; and shorter, thinner, paled (less chlorinated) leaves compared to control plants not exposed to salinity [21]. [20] found a decrease in the LAI in different varieties of rice with an increase in salinity level. Research indicates that the percentage of sterile florets in panicle increases with increasing salinity, which results in a reduction of rice yield [21,22]. Salinity is also associated with the delay in flowering and reduction of productive tiller number, fertile florets per panicle, weight per grain, and overall rice grain yield [22].

The scarcity of irrigation water is recognized as a global threat in rice cultivars, which forces them to adopt irrigation water management systems that may result in increased salinity and yield reductions. While salt concentrations in field water have been shown to vary depending on water management, the distribution and build-up patterns of dissolved salts are unclear.

Adaptation and mitigation of climatic Impacts through smart climate agriculture

According to the Climate Smart Agriculture (CSA) report of 2019 rice alone accounts for 50 % of total GDP. It is simulated that in upcoming years (2020-2050) the percentage points will increase by 23.6%. Rice is the third most cultivated crop in Pakistan, followed by wheat and cotton and accounts for 8% of the total area harvested with a productivity of 5802 kg/ha (FAO, 2017). According to the studies until 2050, the total rice harvested area will increase by a factor of 3. However, the rice productivity will decrease by 5.7% mainly due to the increase in temperature.

According to the Climate Smart Agriculture (2017), the proposed adaptation techniques to overcome the climate change impact on wheat productivity includes:

i. Direct Seeding

ii. Measurement of correct timings for harvesting and

iii. Alternate Wetting and drying

These changes are being analyzed (Adopted) only by less than 30% of Punjab and Sindh predominantly by large scale farmers. The direct seeding and correct timing of harvesting (measuring proper grain moisture) lead towards 1.6 and 1.1 ranks on Climate smartness level (out of 10).

Table 2: Smartness assessment for rice ongoing CSA practices by production implemented in Pakistan

CSA Practices	Region and adaptation ratio (%)	Predominant farm scale	Climate Smartness	Impact on CSA Pillars
Direct Seeding	<30%	Large	1.6	Productivity: Increase yield by maintaining optimum conditions for plant development Adaptive: promotes the efficient use of scarce resources such as water Mitigation The practices may contribute to reactions in GHG emissions by reduced use of fossil fuel
Correct timing of harvesting (measuring proper grain moisture)	<30%	Large	1.1	Productivity: Increases in household income and profit due to higher yield. Adaptation: Reduces the risk to extreme climate conditions, without compromising production and quality of produce. Mitigation: Provides moderate reduction in GHG emissions per unit of food produced

Conclusion

There is Climate change has adverse effects on rice production, especially in South Asian countries. Several factors such as a rise in temperature, rainfall intensity, increase in GHGs, and salinity of soil can lead to a decrease in rice production. The water scarcity and flooding will also decrease rice production. These challenges will become more intense in the future as the simulation of mid-century and end-century shows that climatic patterns will be intensified. Therefore, appropriate adaptation and management plan is required to overcome these climatic challenges. The smart climate agriculture suggests that adaptation and mitigation practices such as direct seeding, measurement of correct timings for harvesting and alternate wetting and drying can increase rice production and also reduce GHGs.

Future Aspect

Agro-climatic modeling is used for the simulation of related climate impacts on future crop production. These simulations are run on the bases of different management practices such as the application of fertilizers, pesticides, insecticides, use of different irrigation techniques, and many other factors. Several experimental studies have been conducted to analyze the impact of modifications in the environment and their effects on productivity. However, there is a need to explore the future trend in the productivity of rice, especially from the economic point of view. Moreover, the study of climatic trends may also indicate which areas are more suitable and increase the productivity of rice.

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Rice Production Systems

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Published Date: January 08, 2020

Abstract

The rice is the third most grown crop in the world among maize (corn) and sugarcane crops. Rice cultivation started in China thousands of years ago and then went throughout Asia to the rest of the world. Today the 9 out of 10 top rice producing countries belong to the Asian continent. There are more than 115 countries cultivating rice around the world in varying agro-ecological zones. Rice production systems have been classified over many years differently depending on different factors. In this chapter, the rice production systems have been classified based on cultivation methods, and some other factors influencing the efficacy of these methods. Some other factors, like resources used, total crop production, emerging challenges, and research areas to be studied, have been summarized. There are two well-established rice growing systems in the world: (1) transplanted rice (TPR) producing system and (2) direct-seeded rice (DSR) producing system. The DSR can further be categorized as (a) dry-seeded rice producing system, (b) wet-seeded rice producing system, and (c) water-seeded rice producing system. The System of Rice Intensification (SRI) is another intervention. Both systems have similar productivity depending on how you overcome the challenges. There is a wild shift in adopting DSR producing system in developing countries due to water scarcity and climate change. Due to the unavailability of labor, transplanting has been shifted from manual to mechanical trans-planters. Some new horizons of research in rice cultivation systems have emerged to improve the productivity of rice.

Keywords: Information technology; Modern farming; Rice; Satellite technology; GIS; Remote sensing

Introduction

Rice (*Oryza sativa* L.) is an vital staple feeding the billions in the world and accounts for 20-70% of the calorie intake [1]. About 58.6% of rice produced in Asia is irrigated and uses more than 50% of the agriculture water supplies. Growing water scarcity is threatening the irrigated rice production in this area, and global rice demand is still in the rise [2]. In Pakistan, rice is an important cash crop and exportable commodity and accounts for approximately 13.5% of the total cultivated area. Total rice production in the country remained 6883 thousand tones with an average yield of 2387 kg ha^{-1} during last season [3].

In Pakistan, mostly rice is cultivated by transplanting of nursery nurtured seedlings into the puddled field which is kept flooded throughout the growing season. Poor drainage and low water table are usually responsible for this continuous flooding and believed for maximizing rice yield. However, decreasing water availability and lower water tables are not sufficient to meet the projected rice demand of growing population in the country [4] and irrigated rice in Pakistan may experience physical water shortage by 15-20% [5]. Also, the high labor cost required for also transplanting constraints the economic feasibility of conventional rice production [6].

To reduce the water inputs and improve water productivity in rice, several water-saving technologies, i.e. alternate wetting and drying (AWD) and aerobic rice, are being practiced. Decreased water inputs in these rice systems have been achieved by reducing the unproductive seepage and percolation flow at field level [7], to some or less extent through weed management, and avoiding non-beneficial transpiration and reduced evaporation at plant level [8]. The AWD system reduces water inputs by 5-35% without sacrificing yield even maintained or high rice yield. Under certain conditions, reduced water inputs of 50% with some yield penalty in loamy and sandy soils with lowered groundwater tables are also reported [9]. Nonetheless, the system has high adaptability and is being successfully adapted and practiced in China, India, and the Philippines. Likely decreased water inputs of 50%, higher water productivity (60%) and lower labor use (55%) than flooded rice have been reported [10] in aerobic rice systems. This harvest in water use is also accompanied by 20–30% lower yield in aerobic rice than flooded with a higher yield. However, switching from saturated to aerobic or alternate wetting-drying soil three conditions may affect the processes determining nutrient availability, mode of their uptake, and associated losses [11]. This review sums up the most recent experiences, potential advantages, associated problems, and likely patterns of the different rice production system.

Constraints to Rice Production

Rice ranks second staple after wheat, important cash crop and also an important export item of the country. This contributes 6.4% of the total value added in agriculture and 1.4% in GDP. The total area under the crop grown during 2008-09 and 2009-10 has been declined 17.1 and 8.4% with similar proportion to percent change in yield by 21.7 and 1.3% respectively [3].

Drawbacks of Rice Transplanting System

In the traditional transplanting system (TPR), puddling creates a hard pan below the plow-zone and reduces soil permeability. It leads to 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 [12]. Massive water inputs, labor costs, and labor requirements for TPR have reduced profit margins. In recent years, there has been a shift from TPR to DSR cultivation in several countries of Southeast Asia [13]. This shift was principally brought about by the expensive labor component for transplanting due to an acute farm labor shortage, which also delayed rice sowing [14]. Low wages and adequate water favor transplanting, whereas high wages and low water availability suit DSR [15]. TPR has high labor demands for uprooting nursery seedlings, puddling fields and transplanting seedlings into fields.

Increasing Water Scarcity

Rice is grown as wet season crop in Pakistan from April to November and depends on irrigation supplies from Indus River melts of Himalayan glaciers. Traditional cultivation system with continuous flooding is followed in major rice-growing areas of the country. This requires higher water and labor inputs, particularly at critical crop stages, increasing higher energy and production costs [16]. Puddling in rice is usually done to create standing water conditions and reduce deep percolation and water inflows. This facilitates in ease of transplanting, reduce weeds pressure, and considered advantageous in terms of yield stability due to better rice growth and increased availability of some nutrients [17]. Ground and surface water are the primary source to meet the rice crop demand. But over drafting, falling water tables, low quality of groundwater supply, water logging and salinity, increased competition from industrial and urban usage, non-availability of irrigation water at critical crop stages, inefficient irrigation techniques and least development in water storage reservoirs are reasons for depleting groundwater resources [18]. Reduced water availability has been the major constraint affecting rice production in the country and fresh irrigation water supply to produce irrigated rice is further to be reduced due to physical water shortage [5]. Per capita, water availability has been reported to decrease from 1066 to 858 m3 and is to be aggravated by 15-54% by 2025. Pakistan has been declared as water-stressed country, and global climate change has significant impact on rice production [19]. Although the area under rice cultivation has increased and total production in 2009-2010 was 6.883 m. Tones and country rank 14th for rice production and 6th for export in the world. Efforts have also been made for better infrastructure of groundwater resources, favorable environmental conditions, and increased support price to farmers.

However, since the last decade, extreme weather conditions, acute water shortage, and onset of drought conditions due to variability in rainfall occurrence greatly affected the rice production from 2000 to onwards [20]. Change in temperature and rainfall has potential impacts on glaciers melts, drought and flood events and change in rainfall pattern and rice production is most vulnerable to these effects in the country [21]. Thus under escalating water crisis, growing rice under submergence conditions is not a viable option and necessitates making efficient use of available irrigation resources by alternative methods of rice production [22]. And development and assessment of water-saving rice can increase crop water productivity.

Water saving Rice Production

Rice production in Asia is in the transition towards water saving cultivation, and several water saving technologies are being successfully practiced to reduce water inputs and improve rice water productivity [23, 10]. These technologies include raised beds, a system of rice intensification [24], alternate wetting and drying (AWD) [25] and direct seeding under aerobic culture [26]. Water savings in these rice systems mainly have been achieved by reduced unproductive water losses of seepage and percolation, non-beneficial transpiration, and to some extent by evaporation [8].

Direct- Seeded Rice (DSR)

Rice can be established by three principal methods: Dry-DSR, Wet DSR, and water seeding. These methods differ from others either in land preparation (tillage) or CE method or in both. Dry-, wet-, and water-seeding, in which seeds are sown directly in the main field instead of transplanting rice seedlings, are commonly referred to as direct seeding. Direct seeding is the oldest method of rice establishment. Before the 1950s, direct seeding was most common but was gradually replaced by puddled transplanting [27]. As it often happens, essential prototype technologies, when introduced to farmers' fields, undergo various modifications to suit local needs and also to optimize the benefits [29]. There is now much confusion in the terminology used for various versions of direct-seeding practices. Therefore, standard terminology is essential to communicate better among different groups of stakeholders.

Dry direct seeding

In Dry-DSR, rice is established using several different methods, including (1) broadcasting of dry seeds on unpuddled soil after either zero tillage (ZTdry-BCR) or conventional tillage (CT-dry-BCR), (2) dibbled method in a well-prepared field (CT-dry-dibbled R), and (3) drilling of seeds in rows after conventional tillage (CT-dry-DSR), reduced tillage using a power tiller-operated seeder (PTOS) [RT (PTOS)-dry-DSR], zero tillage (ZTdry-DSR), or raised beds (Bed-dry-DSR). For CT-dry-DSR and ZT-dry-DSR, a seed-cum-fertilizer drill is used, which, after land preparation or in zero-till conditions, places the fertilizer and drills the seeds. The PTOS is a tiller with an attached seeder and a soil-firming roller. It tills the soil at shallow depth (4–5 cm), sows the seeds in rows at adjustable row spacing, and covers them with soil and lightly presses the soil for better seed to soil contact, all in a single pass [30]. For Bed-dry-DSR, a bed-planting machine is used, which, after land preparation, forms a bed (37-cm wide raised bed and 30-cm wide furrows), places fertilizer and drills the seed on both sides of the bed in a single operation [6]. The seedbed condition is drying (unpuddled), and the seed environment is mostly aerobic; thus, this method is known as Dry-DSR. This method is traditionally practiced in rainfed upland, lowland, and flood-prone areas of Asia [27]. However, recently, this method has been gaining importance in irrigated areas where water is becoming scarce. Drill seeding is preferred over broadcasting in irrigated or favorable rainfed areas in both developed and developing countries as it allows line sowing and facilitates weed control between rows saves seeds and time and provides better CE. In Dry-DSR, land preparation is done before the onset of monsoon, and seeds are sown before the start of the wet season to take advantage of pre-monsoon rainfall for CE and early crop growth.

Wet direct seeding

In contrast to Dry-DSR, Wet-DSR involves sowing of pre-germinated seeds with a radicle varying in size from 1 to 3 mm on or into puddled soil. When pre-germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic, and this is known as aerobic Wet-DSR. When pre-germinated seeds are sown/drilled into puddled soil, the seed environment is mostly anaerobic, and this is known as anaerobic Wet-DSR. In both aerobic and anaerobic Wet-DSR, seeds are either broadcast [CT-wet-BCR (surface)] or sown in-line using a drum seeder [CT-wet DrumR (surface)] [31] or an anaerobic seeder [CT-wet-DSR (subsurface)] with a furrow opener and closer [32]. In CT-wet-DSR (subsurface), seed coating with calcium peroxide to improve oxygenation around germinating seeds can be used. When manual broadcasting is done, seeds are soaked in water for 24 h followed by incubation for 24 h. However, when motorized broadcasting is done, the pre-germination period is shortened (24-h soaking and 12-h incubation) to limit root growth for ease of handling (easy flow of sprouted seeds) and to minimize damage, as is the case when a drum seeder is used for row seeding [32]. A drum seeder is a simple manually operated implement for sowing rice seed on puddled soil. It consists of six drums, each 25 cm long and 55 cm in diameter, connected one after the other on an iron rod having two wheels at the two ends [30]. For the motorized blower, a 3.5-hp mist blower/duster is used, attached with either a 1-m-long blowpipe or a 20- to 30-m-long shower blowpipe.

Water seeding

Water seeding has gained popularity in areas where red rice or weedy rice is becoming a severe problem [33]. Aerial water seeding is the most common seeding method used in California (United States), Australia, and European countries to suppress difficult-to-control weeds, including weedy rice. This method is also becoming popular in Malaysia. In this method, pre-germinated seeds (24-h soaking and 24-h incubation) are broadcast in standing water on puddled (Wet-water seeding) or unpuddled soil (Dry water seeding). Usually, seeds, because of their relatively heavy weight, sink in standing water, allowing good anchorage. The rice varieties that are used possess good tolerance of a low level of dissolved oxygen, low light, and other stress environments [32]. In addition to irrigated areas, water seeding is practiced in areas where early flooding occurs, and water cannot be drained from the fields.

Alternate wetting and drying (AWD)

Alternate wetting and drying involve transplanting of 2-3 weeks old nursery seedlings into puddle field and kept flooded for 10 d with water enough for 3-5 d. After which field is allowed to dry for 2-4 d before re-flooding and the number of days without 15 ponded water varies with soil type, climatic conditions, and groundwater depth. At panicle initiation and flowering, the field is kept flooded, and AWD cycles are continued until harvest [34]. Water inputs can be further reduced, and water productivity values are increased if soil drying periods are prolonged and slight drought stress is imposed, but this substantially occurs at yield penalties [7]. For practicing AWD as a safe guide, irrigation can be applied when soil water potential of -20 kPa is achieved at 10 cm depth [35]. Reduced water inputs of 5-35 and 50% have been found when AWD is practiced in loamy and sandy loam soils with water tables deeper in India, China and Philippines respectively. Although increased yields with AWD are also reported [36] but with recent studies yield reductions by 20% or in some cases maintained or even increased yields as compared to flooded rice are also found [9]. AWD is a mature technology and widely practiced in China, Philippines, and India and can be commonly practiced in lowland rice in any country of the world [37]. However, further quantification studies in AWD are needed with water outflows, i.e., evaporation, seepage, and percolation. Recent studies suggest that AWD reduced seepage and percolation with some effects on evaporation [38] and reduced water evaporation losses by 2-33% compared with flooded conditions are reported. Very little research has been done to quantify the impact of AWD on the different water outflows: evaporation, seepage, and percolation. The little work done so far suggests that AWD mostly reduces seepage and percolation flows and has only a small effect on evaporation flows. Cabangon et al. (2004) calculated that evaporation losses were reduced by 2-33% compared with fully flooded conditions.

System of Rice Intensification (SRI)

Intensification of irrigated double- and triple-crop rice systems in Asia since the mid-1960s involved an increase in the number of crops grown per year and greater yield per crop cycle. Higher yields resulted from the combination of increased yield potential of modern varieties, improved crop nutrition made possible by fertilizer application, and improved host-plant resistance and pest management. Growth rates of yield and total irrigated rice production have, however, slowed down in recent years due to lower rice prices and a slowdown in demand growth, but the concern was also raised about resource degradation [39]. In many large irrigated rice production domains, where farmers were early adopters of modern technologies, yields have stagnated since the mid1980s [40]. At issue is how rice yield growth in Asia can potentially be re-energized. In several recent publications, Uphoff (2001) [41], Stoop et al. (2002), and Uphoff et al. (2002) [42] described the system of rice intensification (SRI), which mainly evolved through participatory on-farm experimentation conducted in Madagascar during the 1980s and 1990s. They suggested that SRI represents an integrated and agro-ecologically sound approach to irrigated rice cultivation, which may offer new opportunities for location-specific production systems of small farmers. They also proposed that such approaches could unlock currently untapped production potentials of rice, allowing farmers to realize yields of up to 15 Mg ha-1 or more with reduced irrigation and mineral fertilizer inputs [43]. Many development-oriented organizations have, therefore begun to evaluate the SRI system or some of its components in other regions, including major rice-growing areas of south and southeast Asia [44]. However, although most published and unpublished reports on SRI tend to be optimistic, they are incomplete in their coverage of the existing scientific literature, and there is a general lack of detailed field research following high scientific standards. Both Uphoff (2001) and Stoop et al. (2002), for example, do not report research data that would allow a thorough examination.

Key elements of SRI

Stoop et al. (2002) and Uphoff et al. (2002) provide a detailed overview of the rationale and critical components of SRI, and they also discuss its scope for adoption. Therefore, only a summary will be given here. SRI is understood as a set of principles and a set of mostly biophysical mechanisms. It originated in the humid highlands of Madagascar with rainfall mostly ranging from 1000 to >2000 mm [45], mostly on poor soils with low pH, low CEC, low available P, and high concentrations of soluble Fe and Al. Major SRI principles include (1) raising seedlings in carefully managed nurseries, (2) careful transplanting of single, young (8–15 days old) seedlings at wide plant spacing (starting at 2525 cm, but going up to 5050 cm), (3) intermittent irrigation to avoid permanent flooding during the vegetative growth phase, (4) addition of nutrients to the soil, preferably inorganic forms such as compost instead of chemical fertilizer, and (5) intensive manual or mechanical weed control without herbicide use.

It should be noted, however, that SRI is not a ‘‘standard package’’ of specific practices, but rather represents empirical practices that may vary to reflect local conditions [24]. Variants of SRI have also been tested in which only some of the basic components were practiced. The key physiological principle behind the principal SRI measures is to provide optimal growing conditions to individual rice plants so that tillering is maximized and phyllochrons are shortened, which is believed to accelerate growth rates [46]. It was also observed that tiller mortality is reduced. Furthermore, intermittent irrigation is believed to improve oxygen supply to rice roots, thereby decreasing aerenchyma formation and causing a stronger, healthier root system with potential advantages for nutrient uptake [41].

Conclusion

On the face of global water scarcity and escalating labor rates, when the future of rice production is under threat, direct seeded rice (DSR) offers an attractive alternative. A successful transition of rice cultivation from transplanting system (TPR) to DSR culture demands to breed of particular rice varieties and developing appropriate management strategies. Because of the water-, labor-, and energy-intensive nature of this system, and rising interest in CA, dry-seeded rice (Dry-DSR) with zero or reduced tillage (ZT–RT) and SRI has emerged as a viable alternative for the rice production a system. Projections and trends seem to suggest that Dry-DSR will likely be a significant rice culture in many countries in the future.

Future aspects

A successful change from the traditional flooded to aerobic rice production requires the breeding of unique aerobic rice varieties and the development of appropriate water and crop management practices. Therefore, to combine novel regulatory systems for the targeted expression with useful genes, more effective and rational engineering strategies must be provided for the improvement of rice for higher water productivity. Different strategies need to be tested experimentally to genetically improve the water-use efficiency and drought stress tolerance in rice. Different strategies need to be integrated, and the genes representing distinctive approaches be combined with increasing rice water productivity substantially. Extensive hybridization using hardy wild rice species is another area to be emphasized. Moreover, combining the transgenic with traditional breeding methods may be a practical approach to develop abiotic stress tolerant rice cultivar.

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Austin Publishing Group

Nutritional Management in Rice: Recent Advances for Sustainable Production

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Published Date: January 08, 2020

Abstract

Owing to unique biological values, rice (*Oryza sativa L.*) is not only a staple diet for more than three billion humans, but it is also a significant bulwark to the economy of rice growing countries. According to FAOSTAT, the 740.9 million tons paddy was harvested from 159.8 million ha in 2016, and 24.14 million metric tons of fertilizers were applied. The rice grain demand is projected to be double in 2050 to ensure the global food security for more than 9 billion faces. The exclusive morphologies, physicochemical properties, and biological characteristics of the paddy soils require special attention due to low fertilizer use efficiencies. Nutrient mining, stagnation, and deceleration of rice productivity and loss of soil health are the results of imbalance fertilization. To increase productivity through increasing the yield, potentials can only be achieved through proper nutrient management. The indispensable role of recent smart technologies like (remote sensing), quick fertilizers, smart delivery systems, site-specific nutrient management, and 4R strategy is suggested for achieving the food security. Therefore, this chapter will highlight the recent advances focused on enhancing nutrient use efficiency as sustainable management tools to enhance the rice production. The best agronomic practices resulting in yield enhancement will also be highlighted in this chapter.

Keywords: Food security; Rice (Oryza sativa L.); Nutrient losses; Efficiency; Management

Abbreviations: AVHRR: Advanced Very High-Resolution Radiometer; AWD: Alternate wetting and drying; BMPs: Best management practices; Ca: Calcium; CRFs: Controlled released fertilizer; EPA: Environmental protection agency; FAPAR: Fraction of absorbed photosynthetically active radiation; GIS: Geographic Information System; GPS: Global Positioning System; IPNM: Integrated plant nutrient managements; IRRI: International Rice Research Institute; Fe: Iron; LAI: Leaf area index; LLC: Leaf color charts; Mg: Magnesium; MLC: Maximum likelihood classification; MH: Million hectares; MT: Million tonnes; MODIS: Moderate Resolution Imaging Spectroradiometer; NNI: N nutrition index; NT : Nanotechnology; NIR: Near infrared region; N: Nitrogen; NDVI: Normalized difference vegetation index; NUE: Nutrient use efficiency; P: Phosphorus; PGPR: Plant growth promoting rhizobacteria; PNC: Plant N concentration; PNU: Plant N uptake; RVI: Ratio vegetation index; RE: Relative error; RS: Remote Sensing; RMSE: Root mean square error; SSNM: Site-specific nutrient management; SI: Spectral index; S: Sulfur; SAR: Synthetic aperture radar; TPC: Total phenolic content; UN DESA: United Nations Department of Economic and Social Affairs; Vis: Vegetation indices; YGs: Yield gaps; Zn: Zinc

Introduction

Among the sturdy challenges to global food security and sustainability are; how to feed increasing human population while improving and sustaining the natural resources without exerting any hazard for the environment [1-4]. The urbanization is also among potential pressures on agriculture, which is not only engulfing productive lands but also degrading useful quality land resources [5]. The lack of best management practices (BMPs) to bring sustainability in the production of food to counteract the threat of global food insecurity. Poor management of crop husbandry is not only leading to low yields but also land degradation, ecosystem imbalances, climate change, and adverse impacts on human health. Moreover, the agriculture industry will be compelled to feed about 9.6 billion faces by 2050. The balanced fertilization is a crucial hindrance to increase the crop productivity [6]. Rice (Oryza sativa L.) is not only staple diet of approximately 50% of the global population [7], but it is the backbone for GDP based nation's economy in many developing countries [8]. Rice is among most diversified crop in kingdom Plantae, and it is spread across the globe [9]. It is cultivated on low and uplands ecosystems. Rice inhabits more than 57 M ha in South Asia only. Rice cropping systems comprises continuous rice-rice cropping, rice-wheat rotations, maize-rice rotation are followed in lowland rice ecosystems [5, 10-13]. Rice production systems differ widely in cropping intensity and yields ranging from single crop rainfed lowlands and uplands rice with small yields to three times higher crop yields in irrigated systems. Irrigated rice ecosystem in combination with lowland rice systems shares about 80% of worldwide harvested rice area and 92 percent of the total rice productions. The upland rice cultivation accounts only 8% of the global production. Overall, to meet increasing population growth, about 25% more production is required in the coming 20 years. The typical global yield of irrigated rice is 5t ha^{-1} per cultivation, but the regional and seasonal yields may vary with climatic conditions and adopted agronomic practices.

In recent decades, with the upsurge of the world population, the sustainability in paddy production has been questioned with yield stagnation [14,15]. Recently, significant development has seen in estimating rice production-yield gaps (YGs) with the help of crop modeling and data based on field experiments [3, 16-20]. There is a scarcity of information for the heterogeneity prevailing at farm-scale which causes the YGs. The distinctions and quantification of agronomic and environmental factors (e.g., climatic) affecting the YGs sustain as a significant trial [21]. The existing evidence indicates that inappropriate crop husbandry practices are the root cause of YGs [3, 8, 17, 22, 23]. Yield is significantly dependent on regional climate and soil properties [8, 24-28]. Fertilizer is a prime input to get sustainable production of rice and act as a backbone role in achieving food security. The global research experiences in rice cultivation have explained that rationalization of fertilizers is the primarily efficient and significant practice for increasing rice production [29,30]. About 30-50% rice yield is attributed to the application of commercial fertilizers [31]. Above all the challenges in rice production around the world, the low fertilizer/ nutrient use efficiencies remained a challenging issue not only for farmers but as well for the scientific community to deliver sustainable solutions [8,32,33]. Unsynchronized application of fertilizers with rice plant demand and exclusive losses of nutrients from paddy soil is the chief cause of low fertilizer use efficiencies [34]. Among the mineral nutrients, nitrogenous fertilizers have the lowest use efficiency and high environmental costs under paddy soils [4, 35-38]. The nutrient use efficiency (NUE) of conventional fertilizers barely surpass 30–35% for N, 18–20 % for P, and 35–40 % for K. Moreover, these efficiencies of nutrient are persistent for the past several decades [39].

Significant recommendations for enhancing NUE has been published since the introduction of mineral fertilizers, and farmers have gained benefits, but these recommendations are based on data from small regions with a similar climate. Among the conventional ways to boost the fertilizer use efficiencies, the 4-R practices are widely recommended and well appreciated for general farming practices, yet the paddy fields need special attention even 4-R works with the same efficiency in paddy fields as it benefits in aerobic soils. In "paddy soils nutrient management system," specific novel strategies, i.e., "fertilizer application without standing water condition" and "stimulation of N transport with water flow" are suggested to enhance NUE. Split applications, deep placements or foliar applications are among the best practices to improve NUE. Research has explored that placement of urea and ammonium bicarbonate fertilizers to appropriate depths has enhanced the yields up to 11.6%, compared with the routine surface broadcasting method.

Moreover, nitrogen use efficiency was also enhanced up to 12.8%. Balanced application of N, P, K, with other secondary micronutrients guarantees a sensible supply of essential elements for lucrative paddy yields. Due to intensive developments in science and technology, modern techniques and methods are being applied to boost paddy production. Contradictory to conventional practices, new strategies like "site-specific-time nutrient management (SSNM)," controlled release nano-fertilizer (CRF), site-specific precision nutrient management based on satellite sensing, and use of nitrification inhibitors have significantly assured to enhancements in NUE [29]. The integrated plant nutrient managements IPNM is also a holistic approach to optimize plant nutrient supply with an overall objective of adequately nourishing rice crop as efficiently as possible and achieving sustainable soil health while minimizing potential adverse impacts to the environment [30]. Moreover, the use of polymeric materials like biochars as carrier materials or bio-fertilizer is increasingly trending for enhancing nutrient release and nutrient use efficiencies under paddy soils [39,40].

Shortage and surplus of mineral nutrient in plant body result in stress-induced responses, therefore understanding the nutrient status of soil, as well as plant, become prerequisite for wise fertilization. Site-specific nutrient recommendations based on optical sensing using chlorophyll is being adopted at farm levels [32, 41]. Singh et al. [42] presented that excellent yields with high N use efficiency in puddled transplanted rice can significantly be gained through application N fertilizer in moderate quantity at the phase of transplanting which efficiently meets the N demands during the period of active tillering and panicle initiation. The use of optical sensing devices is hugely helpful in measuring N requirements. To deliver reliable and accurate status of nutrient at farmer fields to entire agro-ecological system, has only become doable due to inventions in the field of space-borne remote sensing measurements. Recently, the geo-informatics is among the fastest emerging sciences, surrounded with modern tools of global positioning system (GPS), remote sensing (RS), artificial intelligent simulation modeling and Geographic Information System (GIS). Such technologies provide an effective and accurate way of obtaining real-time data. The GIS delivers the chance to catalog the variability in data and maps of different nutrients [6,43].

The era of science dealing with the materials having dimensions in the array of 1-100 nm, termed as "Nanotechnology." This science of using nano-materials (NMs) has transformed every aspect of life, including the agriculture. However, applications of nanotechnology in the agricultural sector is still on its way to completely overtake the traditional inputs. Nanotechnology seems yielding a promising and sustainable solution to nutrient losses from paddy fields through the synthesis of advanced/slow released fertilizer and nutrient delivery systems in the plants [44]. NM is having the vast surface area, and suitable sorption properties that can reduce the losses by decreasing the runoff and controlling the release kinetics. Precisely, the NMs could also protect active ingredients from degradation or enhance uptake into the plant body. Nano-fertilizers are planned to improve the NUEs by manipulating the exclusive properties of NMs. The nano-fertilizers are being widely produced by fortification of nutrients wither singly or in conjugation/doping with other materials. Physico-chemical approaches are deployed to synthesize NMs. Nano-fertilizers are well-known for active release of nutrients with suitable rates, which helps in improving the NUE without yielding any hazards. The release can be synchronized with crop stage and growth patterns, therefore reducing the environmental issues too [45]. Current rapid growth in population demanding higher rice yields is continuously stimulating the scientific community to invest resources and directions in enhancing the yields. Nutrient management poses the most severe challenge under the rice-production system. Highly efficient strategies for the optimization of nutrient management practices are direly required. Therefore, in this chapter, the recent advances being developed to enhance nutrient use efficiency in rice system and modern agronomic practices have been highlighted.

Table 1: Nutritional components per 100 g rice of various categories [59].

Rice type	Energy	Water	Protein	Lipids	Carbohydrates*	Fibers**
	kcal	g				
Raw-white/long-grain	365	11.62	7.13	0.66	79.95	1.3
Raw-white/medium-grain	360	12.89	6.61	0.58	79.34	-
Raw-white/short-grain	358	13.29	6.50	0.52	79.15	-
Raw-brown/long-grain	367	11.80	7.54	3.20	76.25	3.6
Raw-brown/medium-grain	362	12.37	7.50	2.68	76.17	3.4
White/flour	366	11.89	5.95	1.42	80.13	2.4
Brown/Flour	363	11.97	7.23	2.78	76.48	4.6

2.0. Rice production, global food security, and human health

2.1.0. Why is rice a staple food for over three million people?

Rice is the second most cultivated cereal in all the continents except Antarctica. The high demand for the rice consumption is related to its exclusive nutritional values [46,47]. The food and agriculture organization (FAO), states that a staple food is one that which is eaten habitually and, in such quantities enough to establish the significant part of the diet with the substantial supply of a chief proportion of energy and vitamins/nutrient requirements. Whole rice grain has substantial quantities of protein, carbohydrates, fibers, and vitamins: especially vitamin B complex (B_1, B_2, B_3, B_5, B_6, and B_9) and vitamin E along with other bioactive components [48,49,50]. However, the chemical composition and nutritional value of rice vary significantly, with the difference of variety (genetics), production technology, environmental conditions (geographical location), storage duration and primarily with the milling degree [48-51]. The typical proximate analysis of rice grain has been presented in **Table (1 and 2)**. The edible portion of rice or whole rice grain contains rice bran, the embryo (germ) and endosperm [52,53]. Minerals, fat vitamins and dietary fibers are a prominent part of rice bran while germ of the rice caryopsis has a significant portion of proteins and fats along with minerals and almost all the vitamins [54,50].

Table 2: Nutrition contents of brown rice (100 g^{-1}) at 14% moisture [46]

Protein	Crude fat	Available carbohydrates	Fiber			Crude ash	Energy
			Dietary	Water insoluble	Lignin		
(gN x 6.25)	(g)	(g)	(g)			(g)	(kcal)
7.3	2.2	71.1	4.0	2.7	0.1	1.4	384

Rice bran, as defined by FAO, is "a by-product of brown rice polishing, consists of the pericarp, aleurone layer, germ, and some endosperm" [51]. This aleurone layer is enriched with lipophilic antioxidants (tocopherols and γ-oryzanol) and phenolic acids [52,55]. The lipid content in bran ranges from 19.4-25.5% [55] while γ-tocopherol is major vitamin E component. These substances act as a defense against chronic cardiovascular diseases, help to capture the free radicals, and have anticancer effects [52]. Polyphenolic compounds present in rice grains specifically in rice husk are considered as the most effective natural antioxidant and prevent against chronic diseases such as atherosclerosis, diabetes, and obesity as well as cancer and cardiovascular problems [53,50]. One popular product extracted from bran is "bran oil" used for cooking in many Asian countries [55]. Rice embryo, also known as rice ger, has considerable quantities of vitamins B_1, B_2, B_6, and fiber. The critical component of vitamin E in the germ is α-tocopherol, that is five times higher than in bran, and lipid content of germ is about 34.1-36.5% [52,55]. It is estimated that about three-fourths of the fat and nearly fourth of the protein of whole rice grain are present in rice germ [54]. All these components together possess anti-inflammatory, anti-hyperglycemic, and anti-hypercholesteremic properties as well as antioxidant effect [52,54]. Milled white rice mainly consists of the starch and protein as the only endosperm is left. In endosperm, about 90% starch (including amylose and amylopectin) with 5-7% proteins and only 0.8-1% lipid content is present accompanied by trace quantities of vitamins and minerals [54,55].

Rice is processed before marketing and consumption. From harvesting to the production of polished and graded white rice, the whole practice is known as rice processing [52]. Harvesting and threshing processes yield paddy rice as a product with a moisture content of 20% that is then dried down to approximately 14% moisture content [56]. The paddy rice is passed through several milling processes to yield brown rice (husking) and white rice (whitening and polishing) together with other by-products like husk, bran, and germ. Rice straws, produced as a by-product of per kg harvested paddy, ranges from 0.41 to 3.96 kg depending on cutting-height of the stubbles, variety and moisture content. While the husk, bran, and white rice production range from an ideal milling process are established to 20%, 8-12%, and 68-72% respectively, depending on the variety and milling degree [52].The husk is removed to make rice edible, yielding brown rice, and process is known as husking or hulling [50,52]. Brown rice are subjected to whitening (removal of bran) followed by polishing (removal of remaining bran particles and kernel's exterior polishing) in order to increase shelf life of rice and to meet the consumer preference for white rice over brown rice like softness, digestibility, appearance, lightness and shorter cooking time [48]. Oil contents present in bran reduce the storage life of rice by making it rancid [57]. However, this process results in a significant loss of nutrients, as stated in the table (3). Other pre-consumption operations like washing and cooking using ample water volumes also reduce the mass of nutrients, thus making rice a diet with low nutrition level [48,56]. Other problems associated with rice consumption are exposure to toxic substances such as heavy metals like arsenic and cadmium, pesticides residues like organochlorines and whitening agents added during the process of polishing like chlorine dioxide [49].

Table 3: Nutrients loss during normal milling process

Nutrient	Loss (%)
Vitamin B complex (B_1)/Thiamin (B_2)/Riboflavin (B_3)/Niacin (B_5)/Pantothenic acid B_6/pyridoxine (B_7)/Biotin (B_9)/Folic Acid	 68-82 57 64-79 51-67 43-86 86 60-67
Vitamin E (α, β, γ, δ-tocopherol, tocotrienols)	82
Protein	10-16
Fibers	63-78
Fats	77-82

2.2.0. Global rice production; an overview

United States Department of Agriculture Statistics revealed that about 50% population of the world is using rice as their chief food source [58]. Rice, a semi-aquatic annual grass plant, belongs to genus (*Oryza)* that in which 24 species of rice are included, from which only two are cultivated, i.e., *Oryza glaberrima, and Oryza sativa L*. The leftover 22 are wild species [46,52,60]. The *sativa* Sp. is commercially cultivated in more than 112 countries globally because of its high adaptability to a wide range of climatic conditions from dry hilly slopes to deeply flooded lands, whereas *Oryza glaberrima*, which is highly tolerant to heat and iron toxicity, is grown only in the West Africa [46,52]. The global annual production for the previous 10 years is presented in table (4). Data indicates that global rice production is increased considerably in contrast to the cultivation area. Approximately above than 90 percent of the total rice is produced only in Asia [46,52,58]. China being the top producer and India as the second largest contributor in global rice production, collectively shares about 50% of total rice output [52,56]. While Indonesia, Bangladesh, Vietnam, Myanmar, and Thailand, together produce 30% of total global rice production [61, 62]. Other prominent rice producing Asian countries are the Philippines, Republic of Korea, Indonesia, Cambodia, Japan, Pakistan, Nepal, and Sri Lanka. Non-Asian countries which are contributing about 5% of total rice output include Brazil, Egypt, Madagascar, Nigeria, and the United States. The total production of top 10 rice producing countries in 2016 with per unit yield is given in table (5). Despite such a large production, the export quantities of rice are meager because rice is consumed usually in the same countries where it is produced, so, the global rice trade is about 7% of total rice production [56].

Table 4: Global Paddy Rice Production (million tons) from 2007-2016 in comparison to harvested area (million hectares) and per unit yield

Year	Production	Area	Yield
	(MT)	(MH)	(kg/ha)
2016	740.96	159.80	4636
2015	740.08	160.76	4603
2014	742.42	162.91	4557
2013	741.98	164.53	4509
2012	736.26	162.18	4539
2011	726.37	162.71	4464
2010	701.10	161.67	4336
2009	685.65	157.79	4345
2008	687.05	160.07	4292
2007	656.55	155.31	4227

Source: (62) FAOSTAT, 2018 (http://www.fao.org/faostat/en/#data/QC)

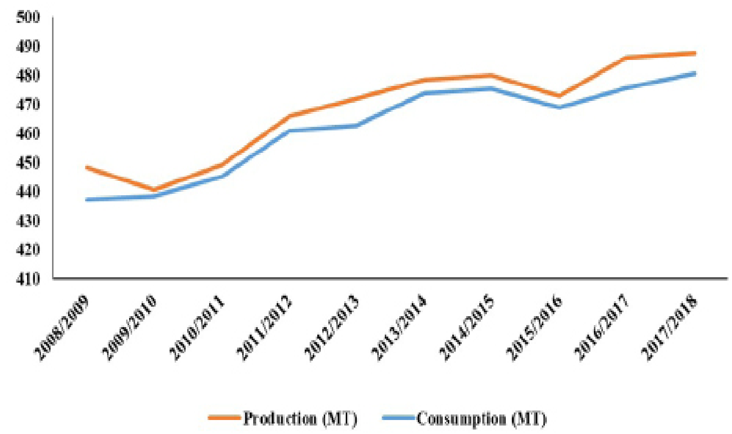
Table 5: Top 10 highest rice producing countries in 2016

Country	Production	Area Harvested	Yield
	(MT)*	(MH)**	(kg/ha)
China	211.090	30.449	6932
India	158.756	42.964	3695
Indonesia	77.297	14.275	5415
Bangladesh	52.590	11.385	4619
Vietnam	43.437	7.783	5581
Myanmar	25.672	6.723	3818
Thailand	25.267	8.677	2912
Philippines	17.627	4.556	3869
Brazil	10.622	1.943	5464
Japan	8.044	1.479	5439

2.3.0. The current yield-demand gap in rice production:

Until now, the gap in rice demand and production was not so wide because the average rice production of the world increased proportionately to the growth of population during the era of the green revolution [56,61]. Such as in the years 1966-2000, paddy rice production amplified by 130% while during the same period, the population of developing countries increased by 90% [56]. This rise in yield, along with technological advancements, improved verities, and increased fertilizers input, is also attributed to the expansion of cultivated area [61,63]. However, from the last decades of the 20th century to onward, no significant rise in rice yield has been observed as compared to the period of the green revolution [47,54]. Annual rice production and consumption data are given in figure (1). Despite the fact that consumption is lower than production, still, a huge number of populations is suffering from the supply-demand gap of rice such as those living in poor Asian countries, i.e. Afghanistan, North Korea, Vietnam and Nepal [61]. Global climate change, extreme weather conditions, water scarcity, soil salinity and low nutritional status of soil along with increasing population have potentially affected rice production in terms of quantity and quality [54]. Micronutrients deficiencies specially of calcium, iodine, iron, zinc and vitamin-A are reported in many people who are using rice as their main food source [54,64,65]. Conditions are going to be adverse with time as farmers must grow rice in the coming decades with a lesser amount of water and inputs on less existing lands for more population [66]. Estimation shows that at least, additional two million tons of rice per annum are required to fulfill the increasing demand of top rice utilizing countries where the population is rising at a rate of 1.5% annually [47]. Approximately 75% of global rice and 90% of rice in Asia is cultivated under flooded/submerged puddled soils [63]. In such type of systems with irrigation, about 2672 L of water is needed to produce about 1 kg of rice.

Figure 1: Year wise data of global milled rice production and consumption
Source: Statista – The portal for statistics (www.statista.com/statistics)



Overall per capita, rice consumption is also increasing with time such as in 2000, Asian annual per capita rice consumption was 81 kg, which exceeded to >110 kg in 2014. Per capita consumption has been presented for some regions in the table (6). Likewise, Asia, annual per capita rice consumption in other continents is also increasing with years, for instance, in South and North America it is recorded to reach 45 and 70 kg in 2014 from 31.1 and 11.2 kg in 2000, respectively [56,67]. According to the United Nations Department of Economic and Social Affairs, the presented that the global population of 7.6 billion is expected to touch 8.6 billion in 2030 and 9.8 billion in 2050 [68]. International Rice Research Institute states that to feed one billion people, about 100 million tons of paddy rice are required [69]. So, net demand for milled-rice is expected to touch 481.9 MT in 2025 and 525 MT in 2050 [61]. According to an estimate, the demand of rice in Asian countries will be increased by 70% in the next 30 years with rising in population while the rice production should be increased by 40% before 2030 to meet the demands of a growing population [54,56]. For growing such a large quantity, the same land area is required as of today with less water and chemical inputs [54].

Table 6: Per capita rice consumption in different regions of world [56,67]

Country/Region	Annual per capita consumption (kg)	
	Year-2000	Year-2014
Asia	81	>110
South America	31.1	45
North America	11.2	70

3.0. Soil sufficiency levels of mineral nutrients for proper rice production

Soil sufficiency of mineral nutrients is a relative term which is mostly expressed in nutrient concentration range. This range lies between the extremes of critical deficiency to nutrient toxicity. Determination of soil sufficiency level is a pre-requisite for efficient usage of amendments and thereby improved crop production. Soil sufficiency level of mineral nutrients varied greatly from site to site. Application of balanced fertilizer (NPK) in soil improved both the agronomic and recovery efficiency while imbalanced application leads to micro-nutrients deficiency. Deficiency of zinc (Zn), phosphorus (P), or iron (Fe) is reported in rice fields of Asia, which further limits rice production [12]. In about 179 rice fields of China, India, Vietnam, Indonesia, and the Philippines, the recovery efficiency of nutrients was as; N (33%), P (24%) and K (38%) [70]. While globally compiled data documented, 46% was the average recovery efficiency of N [71]. In modern rice production technology, the use of proper nutrient management has an important role in enhancing the crop yield by enhancing the agronomic efficiency of crop. These practices strived to accomplish nutrient management in the form of balanced fertilizer recommendations, proper timing of fertilizer application, their placement, and methods of application [72].

3.1. Why paddy soils need high attention to nutrient management

Efficient nutrient use and appropriate management have become important tools to achieve higher rice productivity. Use of proper organic and inorganic nutrient amendments, appropriate fertilizer inputs, efficient methods, soil pH and water management, high yielding varieties and keeping the timing of fertilizer application in consideration can provide large potential in improving crop productivity. Therefore, nutrient management has supreme importance in enhancing rice yield and profitability [72].

3.1.1. Nutrient management for lowland rice

In lowland rice production of the aerobic environment of the root zone is converted to anaerobic, which significantly affected the availability of nutrients. The flooded condition in lowland rice cultivation showed minimal nitrogen use efficiency because most of the N applied is lost via leaching and denitrification [73]. Therefore, N appropriate application for optimal production and losses should be maintained by following different management options. Thus, it is important to choose the appropriate N fertilizer and formulation and added in soil with the judicious amount with proper placement at the right time [78]. For low land rice production, an ammoniacal form of N is recommended such as urea. Ammoniacal form of N contains NH^{4+} which may be fixed to soils cation exchange complex near to its placement, thereby enhanced the N use efficiency [73]. The fertilizer use efficiency of nitrogen in rice varies greatly with the time of application and fertilizer source. Nitrogen fertilizer recovery efficiency in rice is 20-80% [74] with 30-40% average range [75]. The nitrogen not accounted in recovery efficiency may be lost through leaching, denitrification and/or volatilization, while a small amount of this nitrogen becomes part soil organic carbon by incorporated in microbial biomass. The recovered N from organic fraction generally ranges from 16-25% [76]. The shift from blanket recommendation to site-specific demands is management practice to be considered critically for the improvement of synchrony between supplies of N to the actual demand of plant [72]. Guo et al. [77] surveyed 735 farmers and conducted 6 experiments; the results showed an increase in crop yield by adjusting the application timing of fertilizer and controlling the N rates.

In the United States, the recommendation for P fertilizer is 10-40 kg P ha^{-1} for maximum rice production [79]. In Asia, to obtain maximum rice yield, 26 kg has^{-1} is recommended [80] and for high fixing capacities of soil, the input of 97–175 kg P ha^{-1} is required for optimum growth [81]. The rate, method, and timing all have a significant role in improving P use efficiency. According to Massawe and Mrema, [82], 60 kg P ha^{-1} should be applied to avoid P depletion with time from the soil as well as to ensure the build-up of P in soil. The management of P is focused more on keeping the soil adequate P level to ensure the crop productivity [83]. The residual effects of P fertilizers from all input sources should also be kept in mind during nutrient management to avoid unbalanced fertilizer addition [83]. The broadcasting of nitrogenous materials earlier to the tillering stage is mostly subjected to losses due to the low requirement of paddy crop. While at the tillering stage and panicle initiation stage N is excessively and quickly taken up. To obtain optimum rice yield under flooded condition, 50 kg K ha^{-1} is recommended to apply in the rice field [80]. Fairhurst et al. [83] suggested that 25 kg K ha^{-1} must be applied in a rice field for each increase in a ton of target yield. The incorporation of crop residues also added a substantial amount of K back into the soil. According to Pillai [84], recommended "NPK" rates for lowland rice production in different geographical regions are as given in **Table** (**7**):

Table 7: Recommended "NPK" for rice production in lowland ecosystem of different countries

Region/Season	**Country**	**Recommended fertilizer level (kg ha^{-1})**		
		N	P	K
Haryana	India	125	11.4	41.5
Pattambi, Kerala		90	19.6	37.3
Wangdipho-drang	Bhutan	75	21.8	0.0
–	Egypt	100	16.2	0.0
Muridke	Pakistan	120	11.4	0.0
Dera Ismail Khan		135	17.5	30.7
Dry season	Indonesia	140	15.3	24.9
Wet season		80	7.9	24.9
West Java		115	10.9	33.2
Nueva Ecija	Philippines	90	12.2	23.2
Guadalupe, Laguna		100	13.1	0.0
Tarlac		80	21.8	24.9
–	Sri Lanka	73	25.3	48.1
Hyogo Prefecture	Japan	170	53.3	141.1
MUDA	Malaysia	80	13.1	24.9
Hathazari	Bangladesh	80	12.2	14.1

The anaerobic environment developed by flooding leads to reduced redox potential or oxidation-reduction which ultimately converted the unavailable Fe^{3+} and Mn^{4+} form to available Fe^{2+} Mn^{2+} form. Thus, the concentration of Fe and Mn increase by reduction. The reduced paddy soil condition results in the improvement of some nutrients like (Ca, Mg, Fe, Mn, Mo, and Si) [85].

3.1.2. Nutrient management for upland rice

In upland rice growing, extensive N deficiency is reported due to soil acidity, erosion, low organic matter, N fertilizers high cost and low usage, low N use efficiency, imbalanced fertilizer usage, and insects, disease or weeds infestation.

Appropriate application of N fertilizers along with efficient N varieties of rice provided better N use efficiency and higher yield of the crop [86]. High P sorption capacity of the soil or innate P low concentration in the soil makes deficiency of P in soil. To cope with P deficiency, appropriate P application, placement of P in bands in high P adsorbed to soil, and low P content soil, us of advance and productive genotypes improve the mycorrhizal association and lime usage in acidic soils [9]. In upland rice production regions, K deficiency is not common, but still, soil K reserves will be insufficient for the long run. Keeping in view, the economic feasibility applies K fertilizer in soil along with the following two management practices. First practice is to incorporate the remains of crop into the soil as 70-80% of K taken up by rice and wheat is remained in shoots. In this way, substantial K amount can be recycled. The second practice is to improve K use efficacy by using K efficient varieties [9]. Calcium (Ca) and Magnesium (Mg) deficiencies in upland rice cultivation are alleviated by the use of dolomite lime and efficient Ca and Mg rice cultivars (87). Sulfur (S) deficiency is not common in upland rice regions because the fertilizer applied for N and P contain the content of S as well. But in the long run, the use of fertilizers which do not contain S content could lead to S deficiency in the soil. Malavolta et al. [88] reported that 10 mg kg^{-1} is the critical value of S in upland rice soil and showed increased yield of rice with S application.

Zinc (Zn) is widespread in upland rice cultivation and contributes a limiting factor in crop production. The most common practice to deal with deficiency is the application of Zn with other fertilizers. The required/pre-available quantity is measured through the amount of Zn in soil, organic matter content, pH, soil base saturation, and cultivar to be used. In upland rice grown regions, application of 5 to 10 kg Zn ha^{-1} via zinc sulfate is an adequate amount to overcome the deficiency. Zn deficiency can also be resolved through the foliar treatment of 0.5% liquid. The amount of application depends on deficiency severity. In the selection of Zn sources, the solubility of the source should be kept in mind because it is effective for the crop if the used fertilizer source is 40% water-soluble [89]. Iron (Fe) deficiency is most common in calcareous soils with high pH. The plant available form of Fe^{2+} usually is present in Fe^{3+} form. Thus reduction of Fe is an obligatory step for plant uptake. Liming is another factor contributing to Fe deficiency in upland rice grown regions. As compared to soil application, foliar application proved more effective in ameliorating Fe deficiency. Foliar application of 2% solution by Iron sulfate corrected the deficiency. A n, The number of applications, depends on the severity of the condition (90).

3.2. Farmer practice in rice-producing regions

According to the classification system presented by the international rice research institute (IRRI), There exist four agroecosystems for rice production, which are recognized as:

- Irrigated ecosystem/farming
- Rainfed lowland ecosystem/ farming
- Upland ecosystem/ farming
- Deepwater ecosystem/ farming

The cultural practices varied from condition to condition. Like in irrigated areas, both transplanting and direct seeding of rice establishment is in practice. That's why one set of cultural practices do not work efficiently in all rice ecosystems. According to Meera et al. [91], four ecosystems were developed and currently exist in India. The choice of method depends upon a topography of the land, the pattern of rainfall, type of soil, availability of labor, availability of water, etc. [92,93]. The methods for rice establishment are:

- Dry/semi-dry upland cultivation
- Wet/lowland cultivation

In general, direct seeding and seedling transplanting are the most common methods for rice cultivation. In direct seeding, seeds are sown directly in the field either by row seeding on by broadcasting in dry or wet soils. While, in transplanting, seedlings are grown on seed beds before transferring to the main rice field. Direct seeded rice (DSR) follows major three methods principally described by Thakur et al. [94] and Balasubramanian and Hill, [95]:

- Seeding in dry soil (sowing seeds in dried soil)
- Seeding in wet soil (Transplanting of pre-sown seedlings in soil having puddled conditions)
- Seeding under entirely submerged soils (dry or pre-germinated seeds grown in standing water)

DSR production is becoming popular because transplanting method needs intensive water, labor, and energy and have adverse effects on soil physical properties and the environment by methane emission [96,97]. Direct seeding is a commonly adopted method in America, Europe, and Australia and to some extent in Japan and South Korea. Onaverage, 23% of rice is grown by the direct seeded method. In , china, the proportion of direct seeded cultivation increased by 10 % (98). Transplanting methods are divided into 2 categories [99].:

- Manual transplanting
- Mechanical transplanting (growing nursery in matt nursery by self-propelled rice trans-planter)

Transplanting method ensure less weed problem and high yield. Seedlings raised from seeds and grown in a nursery for 4-6 weeks, then transplanted in puddles soil, which in consequence ensure uniform plant stand [93]. The direct-seeded rice production area has been enlarged from 2 % to 11 % in 2000 and 2009 respectively. At the same time, the mechanical transplanting practice has increased from 2 % to about 13% [100].

3.3.0. Soil-plant nutrient analysis: a pre-requisite for nutrient management

The uncertainty faced by farmers in determining how much and at what time fertilizer to be added in soil, is important factors limiting nutrient efficiency. Therefore, synchrony of supply-demand must be attained by fertilizer management keeping in focus the field to field variability. Within a small recommendation domain, the amount, timing, and a number of splits of nutrients varied considerably. Thus, soil-plant nutrient analysis is a pre-requisite for nutrient management. In term of N, the doubt can be suppressed by keeping correct information on soil N supplying capacity which in result improve grain yield by 7% and N-use efficiency by 30 to 40% in 179 rice fields of Asia [41]. Excessive N application and inefficient N splitting are some other major reason for low N-use efficiency. Recovery efficacy of N was improved from 31 to 40% when rice cultivated in field-specific management [101]. Buresh, [102] focused onthe application of N inappropriate time using crop and soil specific needs. In many developing countries, the practice of blanket recommendation of N on broad-based is a common practice for N management. This fixed rates and timings for variable fields cannot provide beyond limit relief in improving N-use efficiency [103]. No doubt, blanket recommendations could provide optimum production compared to low nutrient supplies in any region. It is a simple adoption with no expense on soil analysis, but the variation in soil fertility is not kept under consideration as fertilizer wastage in some fields.

For synchrony of site-specific nutrient demand with the demand for rice, soil and plant analysis are done. But these analyses are time-consuming and do not consider the weather variation during the crop season. Mostly, the farmer used leaf color as an indicator in rice for the need for N fertilizer. Diagnostic tools which can help in assessing the real N requirements at the specific growth stage of the plant originates from spectral characteristics of rice leaves are "leaf color charts" (LCC), ground-based remote sensors, digital, aerial, and satellite imageries, and chlorophyll meters. Among these, LCC, Green Seeker optical sensor and chlorophyll meters have been widely used for more than a decade in improving N-use efficiency. For example, the use of chlorophyll meter as N management significantly improved N-use efficiency of different rice fields [104,105]. Compared to chlorophyll meter, LCC is simple, inexpensive, and easy to use that measures greenness of leaf by visually comparing with the LCC and proved beneficial for low-income farmers of Asia [106]. LCC used two major approaches

- Real-time approach
- Fixed splitting pattern approach

For P fertilizer recommendation, calibrated soil tests provide the best estimate while on the other hand, routine soil tests may not deliver the authentic criteria for P requirement to lowland rice. Because in flooding, the reduced condition aggravated the accessibility of P to rice and reduced the P desorption. For example, soil test showed low P values for growing lowland rice but either responded to P fertilization or not [107]. Likewise, many extractants under or overestimated the P availabilit, and this prediction is further compromised by anaerobic condition used for lowland rice production. Sanyal and De Datta [108] reported that measurement of P through "Olsen method" is commonly used method which gives accurate and reliable estimation of available P. Extractable K from soil is significant pointer to gauge the quantity of available K in paddy soils, but their levels showed immense changes under strong K fixation and in aerobic-anaerobic soil conditions. In rice soil, 0.17– 0.21 cmol K kg^{-1} is generally accepted a critical level in rice soils for 1N ammonium acetate extractable K. In US, K fertilizer is recommended when soil exchangeable potassium is <60 mg K kg^{-1} [109]. Zn deficiency in lowland rice production is a limiting productivity phenomenon [110]. The critical soil Zn concentration ranges from 0.5-2.0 mg Zn kg^{-1} and up to 3.0 mg Zn kg^{-1} for DTPA and Mehlich-1 extraction, respectively [111]. Fe deficiency is identified by different analysis of plant and soil. 5 mg K kg^{-1} is the critical soil Fe level in upland rice when DTPA is used as an extractant, and for plant analysis interpretation 70-300 mg K kg^{-1} is the Fe-sufficiency range of dry plant tissues (tops of rice plant collected at the tillering stage) [112].

4.0. Role of balance fertilization for optimum rice yields

Imbalanced use of mineral fertilizers in paddy field has led to decreased quality and productivity of rice [113]. Efficient use of fertilizer is not only pre-requisite to fulfill the food security but also necessary to maximize farmers' profits. Truth can't be denied that imbalanced availability of mineral nutrients not only results in reduced yields and quality of grain but also leads to depletion/mining of nutrient reserves in the soil and subsequently resulting in soil degradation. Such condition also results in low NUE of applied fertilizers, mainly NPK [114]. Balanced use of inorganic fertilizers is a key to improve quality, increased yield, and disease and stress resistance for rice crop. Imbalanced, inappropriate and overuse of fertilizers are a significant cause of low rice productivity in developing countries, especially in Asia [115]. This unbalanced and excessive use of inorganic fertilizers not only environmental issues but also a nutrient imbalance in agricultural areas [116]. The notion of "balanced fertilization" is simple and was developed about 150 years earlier [114]. Balanced fertilization is related to optimal usage of inorganic and organic fertilizers of good quality in appropriate quantities to supply a balanced ratio of nutrients and ensuring the soil capacity to maintain profitable yields in a sustainable way. Balanced fertilization strategy is primarily designed to supplement limiting nutrients. Although the benefits of balanced fertilization in rice have been logged by the research community, cases from farmer fields are scarce.

In recent years, indiscriminate application of N, P, K fertilization has been practiced either due to subsidized prices of N fertilizers or high prices of P and K fertilizers (like south Asia and other countries around the globe. Lack of basic agriculture training and knowledge to small scale farmers in developing countries is also leading to imbalanced fertilization practices. The decreasing of "factor of productivity" or "response ratio" in rice crop mainly due to imbalance fertilization to 6 kg is another alarming situation [117]. In the post green revolution era, multiple nutrient deficiencies, including micronutrients, being one of the crucial problems making systems unsustainable [118]. Moreover, deficiency of Zn is very frequently being reported under rice-based cropping system [119]. The current micronutrient mining, especially the depletion of Zn in paddy soils, is the result of unbalanced fertilization. The nutrient harvested by the crops very far exceeds the quantities replenished by applied fertilizer, causing a much greater strain on the indigenous resources of soil and its productivity. Nitrogen is the element which confines the most the rice production, and it is the topmost applied element in paddy soils. In Asia, above than 90 percent of global rice is produced. About 60% of N-fertilizers are consumed only for rice production. The N loss as ammonia volatilization or nitrate leaching from a flooded rice field can be as high as 50% of the applied N [120]. Optimum, N-fertilizer application is essential for higher rice yield but overdose of fertilization by farmers has reduced nitrogen use efficiency in many paddy soils, consequently causing low yield and socio-economic harms (1, 121). This excessive N fertilization also causes a non-point pollution source [122]. Despite the overdose of N fertilizer in the last three decades, rice yield remains stagnant, which leads to decreased nitrogen recovery efficiency [113,123]. Mostly, in conventional methods, N is applied in three splits to rice, e.g., one basal dose and two top dressings. This inappropriate application results in N loss in shape of ammonia by volatilization and leaching attributes.

Phosphorus is a crucial nutrient for photosynthesis and energy transfer processes in plants [124]. Phosphorus deficiency is common around the globe, which affects plant growth and metabolism and leads to a reduction in leave numbers, delayed maturity, and disease resistance [125]. Phosphorus availability under many tropical and sub-tropical paddy soils has been decreased. Application of phosphorus in rice field will go for substantial fixation or lost by runoff or leaching attributes. This P fertilizer loss can be minimized by applying different strategies, e.g., P source evaluation, time, and method of P application. For a better understanding of rice phosphorus nutrition, the response of applied P to rice growth, P availability, and adsorption in paddy soil is important before the addition of phosphatic fertilizers [126,127]. Potassium is the major plant nutrient found in soil, but its appropriate application is neglected by farmers. Addition of the right dose of potassium in paddy field helps in decreasing nutritional disorders and increasing plant resistant against pest and diseases [128]. Potassium is found in soluble and exchangeable forms in soil and inadequate application results in depletion of soil fertility. There is a big gap between addition and removal of all essential nutrients and been increasing day by day. For 1 ton of rice grains production, 9 kg potassium is required for maximum yield [129].

Together with macro mineral elements including (N, P, K, Ca, Mg and S), the eight other essential nutrients (Cu, Zn, Fe, Mn, Mo, B, Ni, Cl) also need significant attention. Moreover, the scientific debate on the essentiality of Si, Se, and Na is going on but the fact which can't be denied that plant gets benefits from these nutrients [124]. Si has been ranked as agronomically essential for rice crop in Japan and Brazil [130]. Collectively, these nutrients not only play also play crucial roles in plant physiology but also in humans. Micro-elements have a direct metabolic role in growth and development and support our immunity system to respond to several diseases. Most of the enzymes, proteins, and many other biological structures in our body functioning vital process could be stopped due to micronutrients deficiencies. "Hidden hunger" presents the deficiencies of micronutrients present in daily diets. Soil-micronutrient deficiencies are globally spread phenomenon [131,132]. Yet, soils contain substantial quantities of micronutrients, but deficiencies could occur depending upon the physiochemical characteristic of soil. Availability microelements can be delimited through manipulation of soil physical, biologica, and chemical features. Micronutrients are highly dynamic, and their mobility is usually controlled by soil pH and ionic strengths. These cationic nutrients usually show strong attraction for complexation with anionic nutrient like phosphates and carbonates [124,133-135]. The application of micronutrient either applied as soil fertilizers alone/ combination with major fertilizers or foliar dressing have been seen to increase yields. Shivay et al. [136] confirmed that Zn application along with urea in rice, promoted the biomass, grain yield, and grain Zn nutritional quality up to 20, 29, and 57%, respectively. From a 41-year field experiment conducted by Shahid et al. [137] consisted of rice-rice cropping system aimed for balanced fertilization demonstrated that micronutrients with manures in combination with mineral fertilizers yielded a positive balance of nutrients (Fe, Zn, and Cu) but the Mn-balance was reported negative. The highest positive balance computed for Fe in "NPK + FYM treatment." The results claimed that the balances nutrients were harmful in treatments having no manure or any kind of fertilizer application. Manures and phosphatic fertilizer application increased the concentrations of all micronutrients. Many studies concluded that applying micronutrient through foliar application in rice results in profitable yields [138,139].

5.0. Nutrient regulation to enhance nutrient use efficiency (NUE)

The statistical data available for the year 2010 presents that globally, about 15% of nitrogen and 13% of P/K of fertilizer were used in rice cultivation [140]. Fertile soil, in combination with favorable climate and good management practices leads to high nutrient use efficiency and maximum yield. To narrow down the yield gap between research and farmer's field, there is a need to improve nutrient use efficiency by improving the agronomic practices. Thus, location-based solution and technologies need to be addressed to nutrient use efficiency.

5.1.0 Site-specific nutrient management

The concept of "Site-specific nutrient management (SSNM)" for rice cultivation came to practice from the middle of the 1990s as a best management practice and alternative approach to synchronize the fertilizer applications in field-specific needs [41]. The SSNM strongly emphases on evolving a nutrient management program that considers the following features into considerations [70,141].

- Temporal variability in land originated due to any factor (Season specific etc.)
- Indigenous soil nutrient supply capability at each site (site specific etc)
- Medium-term fluctuations in soil nutrients (N, P, K supply) based on the cumulative nutrient balance or the cultivar differences.
- The physiochemical characteristics of soil (drainage capacity, water holding capacity, etc.)
- The edaphic factors/ environmental factors.

5.2.0. Integrated nutrient management (INM)

Integrated nutrient management (INM) is a point to discuss. either this is a new concept or old one, but this concept has directed the crop production towards the sustainability. Many of our crop production snags (increasing cost, declining yield, loss of soil productivity) is resulted due to poor nutrient use efficiency. INM combined the nutrient cycle keeping in consideration of crops, livestock, organic recycling, soil, use of organic manures along with inorganic fertilizers and biological N fixation [142]. INM focused on preserving the atmosphere for the future by improving the agriculture production. In this approach, the combined application of organic and inorganic fertilizers is applied to preserve soil degradation, enhance crop production and most importantly maximizing the future food supply requirements [143]. Proper fertilization and application methods such as split application of fertilizer at important phenological phases of the crop. Combined application of organic and inorganic fertilizers and use of slow release fertilizers are also important for enhanced crop production. Ding et al. [144] performed a meta-analysis to quantify the effects of substitute fertilization techniques, i.e. slow-release nitrogen fertilizer (SRF), organic fertilizer, (OF), straw return (SR), green manure (GM) secondary/micronutrient fertilizer. Alternative fertilization gives better yield as compared to conventional fertilizers. Increasing order of yield: OF (7.8%)>SRF (7.4%)>GM (6.7%)>SR (5.4%)>SMF (4.6%). Nitrogen recovery efficiency 6.0-34.8% and the partial factor productivity of nitrogen were increased by 4.7–6.9% when alternative fertilization options were used.

INM can be reflected in an effective way to ensure global food security and improving the quality of the environment by minimizing the run-off, improving plant uptake and nutrient use efficiency [100,145,146]. INM significantly enhanced the yield of rice, and the application of azotobacters significantly enhanced the availability of P and N [147,148]. Jha et al. [148] also depicted that INM significantly decreased the rates of N-application; while improved rice yield and soil nutrient resource. Nath et al. [149] suggested that INM treatments resulted in the significant increase of grain yields of rice (3.68 t ha^{-1}) even over the 100% inorganic NPK treatment. INM strategy was also helpful in increasing the organic carbon, bacterial populations, microbial biomass carbon, and soil enzymes. Sharma and Sharma [150] reported that INM augmented straw yields 0.7–2.3 t ha^{-1}, grain yield 1.2–1.3 t ha^{-1}, uptake of N 38–45 kg ha^{-1}, P uptake 7–10 kg ha^{-1}, and K by 25–42 kg ha^{-1}, available N by 6–24 kg ha^{-1}, available P by 7–8 kg ha^{-1}, and K by 7–32 kg ha^{-1} and organic C content of soil by 0.09–0.15%, of rice-wheat system. Singh et al. [151] documented that average grain yield of rice (3.2 t ha^{-1}) and wheat (2.9 t ha^{-1}) and subsequent wheat yield was also improved from 43.1 to 48.9% when INM practices were applied. NPK pool of soil was increased under INM treatments. Utilization of indigenous and regionally produced resources like press mud, compost, industrial by-products, etc. or neem cake could be cheaper sources of nitrogen and other nutrient and their application in combination with urea or other inorganic fertilizer in the ratio of 5:1 could result in improved NUE. Long term fertilization investigation conducted dhad concluded that the efficiencies for P and K increased noticeably when both were applied in combination with any organic additives [142,152,100,153].

5.3.0. Inorganic and organic fertilization

Imbalanced fertilization and exhaustive cultivation in soil-plant environment system posed a disastrous impact on soil fertility and worsened the crop production sustainability. Addition of organic matter in the form of manure as a nutrient source is rejected substantially. In addition to that, repetitive and excessive addition of few inorganic fertilizers into the soil leads to lower soil fertility, micronutrient deficiency, and thereby resulted in unsustainable crop yield. Among the various organic manures, the compost produced by earthworms (vermicompost) and FYM ismain sources of macro and micronutrients. Due to increasing prices of chemical or inorganic fertilizers, most the Asian countries have encouraged organic materials as nutrient sources for rice production. Plant uptake nutrient in inorganic form, so the application of organic material first decomposes (by soil microbes) and releases nutrient in an inorganic form that can uptake by roots of rice crop. Nutrient releases from organic material decomposition cannot meet the demand of paddy for all yield-limiting nutrients as well as can surpass some nutrients than a requirement. Wei et al. [154] explored thirty- two long term experiments conducting in China, evaluatethe yield of rice and SOM contents and their time by nutrient management responses (TNMR). Treatments in these trials involved in chemical fertilizers, organic materials, and a combination of organic and chemical fertilizers. Combine application of fertilizer, and organic amendments give better results as compared to only chemical fertilizer application. Organic matter application either alone or combined with chemical fertilizer, can increase SOM and their TNMR over fertilizers applied alone.

Nitrogen requirement of rice cannot cover only with organic fertilizers, so to eliminate N deficiency integrated use of fertilizers is necessary. Mi et al., [155] reported the results of 4-year field experiment applying inorganic fertilizer in contrast with the combined application of organic manures (mushroom compost, green manure, cattle manure, rice straw) and inorganic on rice grain yield, the rice grain yields for 2014 under the NPK + cattle manure and NPK + rice straw treatments were 11.4% and 9.3% higher, respectively, compared with the NPK alone treatment. Organic material, including crop residues addition into the soil can have injurious effects. They can accelerate the modifications in soil constituents. This can speed up the transformation of sulfate to sulfide which in return precipitate Zn and consequently reduced its uptake to rice plants and enhance production and release of methane and increase organic acids formation that can affect unfavorably affect rice growth. The hazardous effect can be reduced by soil drying and aeration. The high concentration of NPK and other nutrients are present in oil cake, which can increase growth and productivity [156].

5.4.0. The 4R strategy

4R Nutrient Stewardship; demonstrates outline for right nutrient source, applied at the right time, right rate and in the right place, to accomplish improved sustainability. 4R Nutrient Stewardship involves the execution of best management practices that elevate the fertilizer use efficacy. The area of fertilizer best management practices is to supply nutrients in accordance with crop demands to maximize yield while decreasing nutrient losses. An assortment of management practices varied with crop type, soil and climatic conditions, site, management system, and other site-specific factors. The principle of 4R nutrient stewardship is applied in all conditions wherever fertilizer is used for the productivity of crop [157].

5.4.1.0. Right source

Appropriate fertilizer source must be understood like fluid nitrogen fertilizer gives N; half of total N of urea and a quarter of nitrate and ammonium. Soluble fertilizer addition in early irrigation would lead to leaching of nutrient and in late irrigation leads to poor circulation in the soil which further promote the growth of algae as it left N in irrigation line [158]. For wetted soil, fluid nitrogen fertilizer proved best in solution form when added to irrigation water in the middle of the irrigation cycle of drip irrigation Hanson et al [159]. Fluid nitrogen fertilizer will be applied near the irrigation system ina buried drip system to allow fertilizer to accumulate near greatest root density.

5.4.2.0. Right rate

Proper rate of fertilizer application according to plant and soil requirement can enhance efficiency. In-season fertilization rates can be refined by using various symbols (e.g., leaf color charts) or sophisticated analytical monitoring tools. For example, electronic sensors can track soil nitrate concentrations and plant tissue status, thereby allowing farmers to improve nitrogen application.

5.4.3.0. Right time

Time of fertilizer or nutrient application is significant. Application of N in split form is nowndays, a recommended practice. Rice crop mostly grow in submerged conditions. Application of full N dose at the time of transplantation can increase the risk of nitrate loss. Fertigation aptitudes let farmers respond in accordance with proper nutrient application timing that is coordinate with the requirement of the crop.

5.4.4.0. Right place

Placement of nutrients or fertilizers in the root vicinity is the promising technique to increase the efficiency of fertilizers [160]. In shallow-rooted crops, heavy irrigation can easily leach many important nutrients below the root zone; inthis scenario; fertilizer placement plays an important role.

5.5.0. Decrease in nutrient losses through water management

Irrigated rice ecosystems inhabit about 58% of the total cultivated rice area around the globe and yields more than 75% of rice supply to the world [161]. Single rice crop in a year is grown in some temperate regions and high-altitude of tropics. Continuous rice cropping limited to two, and/or occasionally three crops in a single year is seen in irrigated plains of Asia. Generally, a significant decrease in submergence can enhance N, P, and K requirements fora targeted yield. In aerobic soils, lower BNF and lower nutrient mineralization could lead to higher N requirement compared to submerged conditions. Very high needs for P fertilizer can originate from low solubility and bioavailability of native P in submerged condition [162]. The K requirement is inclined by poor management of crop residues and low K inputs. Similarly, the paddy soils are often subjected to Zn deficiency. The alternate wetting and drying cycle have a significant effect on Zn availability, especially in submerged acid soils [163]. The iron availability is also a subject of discussion for high-pH soils [164].

5.6.0. Managing water and fertilizer for sustainable agricultural intensification:

Rate of fertilizer application for a specific region must be adjusted earlier, considering the water-limited grain yield of rice [165]. The use of safe alternate wetting and drying (AWD) practice for rice production on puddled paddy soils without loss of rice yield results is an important management and skill, but the extent and duration of soil drying phase must be critically evaluated, and it must be a mild phase. The current research never suggested that a significant change in SOM and macronutrients availability for safe AWD as compared to continuous incubation phase. The BNP are the same for rice grown with AWD and continuous soil incubation unless the AWD is leading to soil crusting or some other degradation [166]. The AWD might favor gaseous loss N and soil N by the sequential nitrification-denitrification process [73], or it may also favor the contaminant uptake if soil possesses significant levels of contaminants [167]. Application of urea through broadcasting immediately before irrigation spread can help to ensure the vertical movement of N into the soil, but the event of high flooding can result in loss of N depending upon the physical properties of soil [73]. The "coupling effect" due to the combination of nutrient and water at the same time is usual in paddy soil. Few studies [168-173] have highlighted that there was a marked interaction between N application and water management on N uptake and utilization by rice grain.

6.0. Recent technologies for enhancing NUE and nutrient management

6.1.0. Remote sensing and geographical information system for rice management

The Geospatial Information Systems (GIS) and Remote Sensing (RS) techniques are among novel strategies which efficiently contribute knowledge and understanding to food security through helping in precision agriculture. These strategies include techniques which examine local food environments, assess changes in land use and land cover, identify areas of importance in specific regions to determine the relationships between biophysical and socioeconomic attributes, and the use of 3D models to demonstrate landscape and construct methods to sustain our food sources [174-178]. The recent trends and race among developing countries in launching the remote sensing satellite (RSS) have enhanced the capabilities for better utilization of this technology. Significant progress has been made in soil and land cover mapping, assessment of crop conditions, crop acreage, and production estimates [179].

RS is the science of acquiring information about an object through the analysis of data obtained by a device that is not in contact with the object [180]. Remotely sensed data take many forms, including variations in force distribution, acoustic wave distribution or electromagnetic energy distribution using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the plant/earth's surface. The data can be obtained from a variety of platforms, such as satellites, aircraft, unmanned aerial or underwater vehicles, and hand-held radiometers. Remotely sensed data be gathered by various devices such as sensors, cameras, and video recorders [180]. From the point of view of interaction mechanisms, the wavelengths (visible infrared) from 0.3 μm to 16 μm can be divided into three regions. The spectral band from 0.3 μm to 3 μm is known as the reflective region. In this band, the radiation reflected by the plant/earth's surface is sensed by the sensor. The 8 μm to 14 μm band analogous to the atmospheric window is known as the thermal infrared band. Thermal emission from the earth surface is the energy behind this band for remote sensing. In the intermediate band from 3 μm to 5.5 μm, reflection and self-emission are important.

Successful crop production is dependent upon effective nutrient management that includes identifying nutrient deficiencies and excesses [181]. Reliable nutrient recommendations are dependent upon accurate soil tests and crop nutrient calibrations based on extensive field research. Spatial variability of soil properties is inherent in nature, and it always exists whether it is observed in large-scale or small-scale. A better understanding of the spatial variability of soil nutrients is important for refining the nutrient and agronomic management practices for paddy soils. Quantification of soil spatial variability is also important in ecological modeling, environmental prediction, precision agriculture, and natural resources management. Similar, the chemical concentration of vegetation traditionally has been measured by chemical analyses of field samples. Sampling can be logistically difficult in wetlands/paddy soils, and often, data collection is restricted to a small area. Remote sensing of foliar chemistry potentially provides a method to assess ecosystem function on a range of spatial scales and in locations that are difficult to sample. The information on accurate demands and supply for the soil-plant system could easily be achieved through the utilization of RS based real time methods with extensive area coverage. Therefore, timely detection or forecasting of nutrient imbalance/stress can help the growers avoiding mineral deficiencies and thus the yield losses [182]. RS provides the essential technology and methodology to monitor, map, and observe rice-growing ecosystems over large areas, at repeated time intervals, to interpret rice-growing areas under a variety of aspects. The RS technologies can support the assessment and measures plant health and nutrient status based on the reflectance of light from the rice crop at two different wavelengths, visible and near infrared. Spectral reflectance data is inversely related to leaf chlorophyll level and relies on the interaction that occurs when light penetrates plant tissue, where it will be absorbed, reflected from the surface or transmitted through the leaf. These optical spectra are dependent on the leaf pigment content of different absorption wavelengths. Chlorophyll is used to determine N requirements in rice crop because it provides an indirect indicator of N status, especially in optical reflectance-based variable-rate nitrogen application technology.

Most of the passive remote sensors can provide information about soils from reflectance spectra in the visible (0.40 μm to 0.70 μm), near infrared (0.70 to 1.10 μm) and short-wave infrared (1.10 to 2.50 μm) regions of the electromagnetic spectrum. Besides this thermal infrared regions (3.0 to 5.0 μm and 8.0 to 12.0 μm) do provide diagnostic information about soils. Plant chlorophyll concentration provides valuable farmer information regarding potential crop yield. Variances in leaf's coloration and synthesis of different biochemical molecules under the deficiency or toxicity of any mineral element like (N, P, K and S etc) within plants body yields changes in the pattern of spectral reflectance of crop canopy. The variation in absorption bands related to structure or molecules can be paired as follows: (i) 460 and 670 nm for chlorophyll a and b, (ii) 530 nm for carotenoids and (iii) 1500 nm for N–H bonds. This information is highly helpful in nutritional monitoring through RS. A chief absorption characteristic of di-sulfide bonding within plant body is available to visible (VIS) region (500–600 nm) for RS sensors [182] However, the reflectance spectrum of a rice canopy is yielding a highly complex relationship among biophysical and biochemical characteristics. Alterations in one or more circumstances of growth like climate change, water stress, and clouds covers, or nutritional stresses may significantly affect or disturbs the reflection bands and patterns. Even if, such conditions are similar then the varietal differences of rice crop may show similar temporal spectral results [183-185]. RS can provide timely and consistent information on rice based agricultural systems, like:

- Monitoring and mapping of rice ecosystems
- Rice crop health, nutritional and growth assessment
- Quantification of disease incidence or climatic perils
- Climate-change estimation by estimating relevant methane emission
- Evaluation of the efficiency of rice-based cropping pattern/systems
- Quantification of rice crop vigor and other indices like leaf area index etc.
- A basic tool for the precision rice farming helping in yield predictions, fertilizer/pesticide requirements.
- Environmental hazards like land degradation and soil quality/salinity
- Moisture sensing for the hydrologic or irrigation modeling.

Hyperspectral reflectance gathered from crop canopy has the ability to sense typical plant population nutrition status rather than individual/each leaf or plant [186]. Processing of hyperspectral RS data can be characterized into major three groups (i) Narrowband or hyperspectral vegetation indices (VIs) (ii) multivariate data analysis and (iii) hyperspectral data which is base for wide band VIs. New RS sensors are swiftly producing a massive amount of data in higher resolutions as well as are cost effective. For fertilizer management and stress mapping procedures, images (both Hyperspectral and multispectral) are inferred in term physical parameters like crop health, the moisture of soil or crop cover and are useful for operations such as stress mapping, fertilization management [187-189]. Nutrient contents of different crops such as wheat [188,190], paddy rice [191], sorghum [192], corn [193], broccoli [194], citrus [195], grape [196], apple [197] have also been assessed using hyperspectral and multispectral RS data. Regarding the work procedure and methodology of RS for mapping and monitoring of rice fields, the selected procedures/methodology strongly depends on the type of sensor being used in the RS device. For low to medium resolution data, "maximum likelihood classification (MLC)" is the one of most general approach [198,199]. On the contrary, hyperspectral RS of rice areas emphases on the recovery of an ideal number of bands which are best suited for mapping. Therefore, the favored methodology is based on various "multiple regression models" [200]. MLC is unsuitable due to the severe variability which is easily handled by "synthetic aperture radar (SAR)" approach [201, 202]. Low spatial resolution sensors like "Advanced Very High-Resolution Radiometer (AVHRR)," "Moderate Resolution Imaging Spectroradiometer (MODIS)," and SPOT VEGETATION is also equipped with high temporal resolution and broad swath width, which provides coverage for extensive areas at low cost [203].

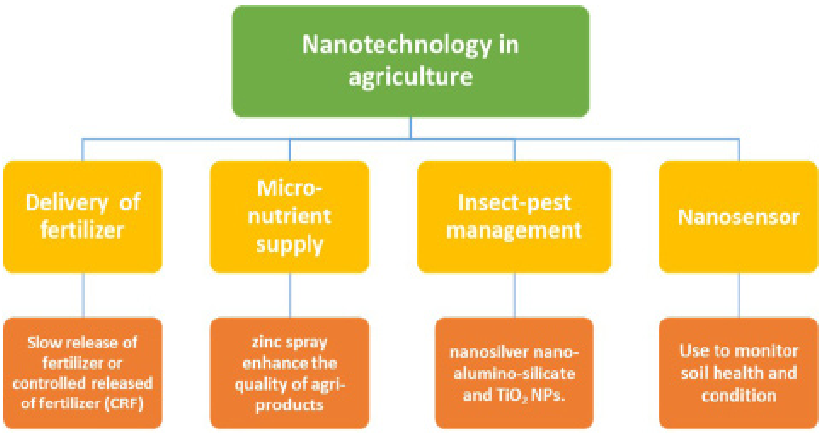
Using time-series data collected from MODIS for mapping of the rice ecosystem and nutrient management is widely recommended and reliable technique. Time series data from spatial resolution composites of images from the MODIS-sensors are widely used for the production of rice maps and other characteristics, i.e., intensity of rice cropping etc. The surface reflectance product based on MODIS collected from the "Terra platform (MOD09A1)" are highly suited for monitoring rice ecosystems on a continental scale. The bands of reflectance data resolution of about 15 arcs/500 m, conjugated with highly-repeated frequencies, are capable of capturing the seasonal variations in rice vigor, and rice plant moisture, and soil surface water which are also the key indicators for rice growth status considering the differences in stages of rice transplanting/ cultivations. The "reflectance data" undergo several preprocessing and treatments, i.e., algorithms for climatic factors correction etc. Moreover, the rate of observation, coverage area, view angle, cloud intensity or cloud shadows on canopy, smog, and aerosol are assessed on a "pixel-by-pixel" to ensure that each pixel covers best observations. In rice cropping systems, application of RS has been trending. Some fields reports have been summarized here as follow; Zhang et al. [204] explored the relationship between rice canopy spectral reflectance and N supply. It was concluded that marked variations in N concentrations of canopy present at different stages of growth. A significant relationship among N status, the visible, NIR ranges of the spectrum was found. Subsequently used NDVI and RVI analysis also predicted the N status. Xue et al. [205] also confirmed similar findings relating the seasonal canopy reflectance, different ratios in bands and NDVI with N status and N accumulation in rice during different treatments of N. NIR and the green band were in the ratio of (R810nm/R560nm). A linear relationship of N accumulation during the whole growth period was independent of the applied N treatment levels. Therefore, band ratio was recommended for the N monitoring in rice plants [205]. Lee et al. [206] also tested a simpler spectral index (SI), containing the first derivative of rice canopy reflectance at 735 nm, for the measurement of N concentration in rice plants and reported a significant linear relationship of N with panicle initiation stage.

A study by Huang et al., [207] evaluated the "FORMOSAT-2 satellite images" for measurements of N status in rice crop for evaluating N application rate for top dressings at the stem elongation phase of rice crop. This study was conducted in Northeast China based at Five farmers' fields and six agronomic variables; (i) aboveground biomass, (ii) leaf area index, (iii) plant N concentration, (iv) plant N uptake (PNU), (v) CM readings and (vi) N nutrition index (NNI) were included. The NNI was demonstrated as the ratio of actual PNC to critical PNC. Collectively, 50 VIs were calculated and correlated with the value collected from field-based variables. The ArcGIS (ESRI, Redlands, CA, USA) and ENVI were deployed to read the pixels data from images collected through "FORMOSAT-2 satellite images," and VIs were computed for corresponding sites. The 6 variables were treated separately during the regression analysis. Results declared that 45% of NNI variability was explained through Ratio Vegetation Index 3 (RVI3). The computed differences between the estimated PNU and critical PNU based on the indirect methods can be used to draw guidelines for evaluation of fertilizer requirements for N-topdressing [207]. A study by Mosleh et al. [208] also focused on the development of RS based methodology to forecast yield of rice through rice canopy greenness during initial and peak color stages. A compound of normalized difference vegetation index images collected at 250 m spatial resolution demonstrated a significant relation between the MODIS-based model and ground-based calculation during the 2010-2012 period showing (R^2= 0.93). Authors also found a strong agreement between forecasted (MODIS-based) yields and yields obtained from ground-based data 2010-2012 period showing R^2 value 0.76.

6.2.0. Nano-Technology for nutrient management in rice

Nanotechnology (NT) is being visualized as a rapidly evolving field that has the potential to counter the present-day challenge of food security [209,210]. The word "Nanotechnology" has initiated from a Greek word "Nanos" which means "Dwarf". The term "Nanotechnology" was first used by Norio Taniguchi in 1947 [211]. Just like in human history, the Stone Age, Bronze Age and Iron Age, currently "Nano Age" is reckoned in the same regard. Now a day, nanotechnology has commenced in agriculture to revolutionize it with new concepts, tools, and ideas for maximizing the productivity [212]. Nanotechnology has many potentialities to agriculture (**Figure 2**), and the ambition of the nanotech in agriculture is to diminish the number of hazard chemicals, minimize nutrient losses in fertilization and increased yield through nutrient management [213].

Figure 2: Schematic description of applications of nanotechnology in agriculture [214]



6.2.1. Nanotechnology and nutrient management in rice:

Pitiable usage efficacy of present fertilizers is a major topic. World's largest consumer of nitrogen fertilizer is China, which can be lost up to 50% by volatilization and another 5–10% by leaching [215]. Fertilizers loss can cause serious environmental issues, i.e., eutrophication [1]. The aim of involving nanotechnology in the field of plant nutrition is to increase the fertilizer use efficiency either by increasing the bioavailable fraction of nutrients (for example, phosphorus, zinc) and/ or by controlling losses of mobile nutrients to the neighboring environment, e.g. nitrate [216]. Food production has been increased substantially with the use of excessive use of fertilizers in the form of nitrate or phosphate compounds, ammonium salts, and urea, but on the other hand, they also have many detrimental consequences on the beneficial soil microflora. Nano-coated particles have strong tenacity to hold materials due to strong surface tension, this property has strong contribution in fertilizer slow release compared to other particles having conventional surfaces. Moreover, larger particles are being surface protected by nano-coatings [214]. The strength of the nano-coating decreases the fertilizer dissolution rate and allows the fertilizers to release slowly into the soil to be efficiently absorbed by plants. Slow release fertilizers usage has become an advanced approach to overcome the gigantic problems of environmental pollution and excessive fertilizer consumption [217]. To meet the crop demands, many polymers have been used to release fertilizers slowly and sustainably. For example, polymeric chitosan nanoparticles depicted positive result for NPK slow release Corradini et al. [218]. Fernando et al. [219] concluded that the nutrient transfer rate increases with increased nano calcium carbonate in wax cation layer.

6.2.2.0. Nano fertilizers

Nanofertilizer can be defined as the provision of essential and beneficial nutrient to plant at the nano scale, which can improve plant growth and yield [216,220,221]. Nanofertilizer has three categories 1) macro-nano fertilizers, 2) micro-nanofertilizer 3) nano-particulate fertilizer based on nutrient requirements of the plants [221]. The overall use of nano-based fertilizer use and mechanism have been summarized in figure (3). Nano fertilizers increase the Nutrient use efficiency (NUE) by 3 times, and it also provides stress tolerating ability. Since thesenano-fertilizers contain nutrients, growth promoters encapsulated in nanoscale polymers; they will also have a slow andtargeted, efficient release [222]. When comparing to chemical fertilizers requirement and cost, nano fertilizers are economically cheaper and are required in lesser amount. For years farmers have found that nitrogen uptake is the main reason for improper yield. Nanofertilizers can improve the uptake of nutrients by plants [223]. Nanoparticles of silicon dioxide enhanced both the root development and seedling growth [224]. Synthetic or biopolymers have been used to develop many controlled-release fertilizers (CRFs) and slow-release fertilizers (SRFs) to avoid the potential leaching and denitrification of nitrogen fertilizers [225,226]. Benzon et al. [227] performed a greenhouse experiment to find the effects of nanofertilizer application. Results showed that application of nanofertilizer significantly enhances total antioxidant activity and phenolic content in rice and improved plant nutrition and crop productivity. The significance of nanoparticles is studied widely by many researchers. Such as, nano-K fertilizer application has provided higher grain yield in rice Sirisena et al [228]. Likewise, Liu and co-workers [229] documented that 20-40% of crop yield has been increased by the application of nanofertilizer. Some common methods of nonfertilizer application and some commercially available nano-products available for farmer usage are summarized in table (8) and (9) respectively.

Figure 3: Some types of nanotechnology-based products used in agriculture

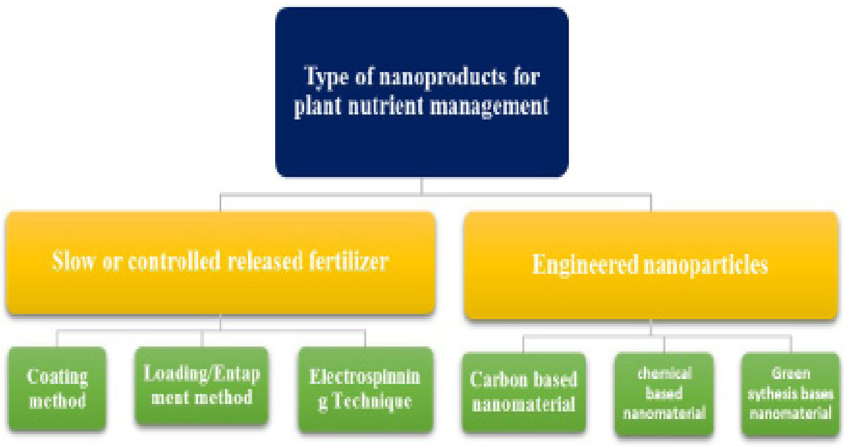


Table 8: Method of nanofertilizer application

Method	References
Spray or foliar application	[214]
Soaking method	[234]
Soil application	[235]

Table 9: Nanotechnology based commercial products and their application in agriculture

Nanoproducts	Suggested Role	References
Nano-sized nutrient (ZnO and TiO_2 nanoparticles)	Boost in growth and antioxidants	243
Hydrolyzed collagen/Nano-Na alginate composite	Preservation	244
Macronutrient fertilizers coated with nano-metal oxide	Enhancement of nutrients absorption by plants and the delivery to specific sites	245
Nano-emulsion	Nano-emulsion as larvicidal agent	246
Acetamprid loaded alginate-chitosan nano-capsules	Improved delivery of agrochemicals in the field, better efficacy,	247

6.2.2.1. Advantages of nano-fertilizer:

a. Nano fertilizer is using no ethylene compounds in its structure. Ethylene enhances growth process and prevents appearing indications caused by chlorosis in leaves [230].

b. Nano-fertilizer increases the nutrient use efficiency of the crop and minimizing the cost of environmental protection.

c. Nano-fertilizer causes improvement in the taste and nutritional content of the crops

6.2.2.2. Nano-fertilizer formulations and their smart delivery system

Nanofertilizer formulate keeping in view the following criteria:

- High solubility
- Stability
- Effectiveness
- Controlled or slow release
- Targeted activity
- Eco friendly in terms of safe delivery and disposal [231,232].

6.2.2.3. Mechanism of loading

In living systems target specific delivery of nutrients can be easily done with nanotechnology applications. The loading of nutrients on the nanoparticles is usually accomplished by

- absorption
- ligands mediated the attachment
- encapsulation
- entrapment of polymeric nanoparticles
- Synthesis nutrient-based nanoparticle [231,233].

6.2.3.0. Smart fertilizer

Smart fertilizer i.e. timely release fertilizers can be prepare by means of clay minerals, polymers, nano-composites such as clay minerals and hybrid polymer and metal oxides via different techniques i.e., nano-encapsulation, core shell preparations, spray drying and electro spinning. The nanoparticles are obtaining much attention in soil management and nutrient studies especially carbon and metal oxide based engineered nanoparticles. The “green synthesis” of nanoparticles makes use of eco-friendly, nontoxic, and safe chemicals. Nanoparticles manufactured with biological techniques or green technologies are diverse, with great stability and large dimensions. Synthesis of nanoparticles can be done by chemical, physical and biological techniques [236]. For nanonutrients synthesis, microorganisms are provided with necessary growth conditions and grown over selected nutrients. After desire growth, the biomass was detached, and the filtrate was used for isolation of extracellular specific proteins, and these were used for nanoparticle synthesis [235]. Similarly, Okorie et al. [237] and Chhipa [221] reported that some nanoparticles could be used in nano-fertilization, which produced through the biosynthesis process.

6.2.4.0. Nanotechnology in micronutrient supply:

Intensive farming and green revolution showed a significant rise in crop yields but in consequence make soil deficient in soil micro-nutrients like Zn, Mo, and Fe [238]. The practice of Nanotechnology can be practiced making micro-nutrients available to plants. Thus, different nano-formulations of micronutrients has been used to apply on soil or spayed on plants to augment soil health [239]. The formulation was found to have the potential for the slow release of agrochemicals such as “hormones” [240]. For plant micronutrients, many nanoparticles have been certified. The prevailing problem of Fe-deficiency in high pH calcareous soils can be resolved by nanotechnology practice [241]. Similarly, Alidoust and his coworker [242] reported the effect of foliar application of iron nanoparticles. Foliar spray of iron nanoparticle improved plant growth in rice enhances nutrient absorption by enhancing microbial enzyme activity in rhizosphere.

6.3.0. Biofertilizer

The beneficial-living microorganism like Rhizobium, *Azospirillum, Azotobacter,* blue-green algae, fungal mycorrhizae, *Pseudomonas,* etc. are termed as Biofertilizers. These microorganisms play an important role in increasing essential nutrient availability to plants and thereby enhanced crop yield and soil fertility by breaking OM into simpler compounds [248]. Silver and gold nanoparticles could be proved effective as growth promoting materials [249]. Under in vitro conditions, nanoparticles with biofertilizers (*Pseudomonas fluorescens, Bacillus subtilis* and *Paenibacillus elgii*) showed augmented growth promotion. Plant growth promoting rhizobacteria (PGPR) showed maximum growth promoting activities in comparison to several soil microorganisms of the rhizosphere. Gold nanoparticles effect was checked on PGPR in *B. subtilis P. elgii P. fluorescens,* and *P. putida* and its effect can be exploited in nano-biofertilizers as *B. subtilis, P. elgii* and *P. fluorescens* a showed significant increase [250]. Biofertilizers may augment plant growth by several mechanisms such as the production of siderophores, fixation of atmospheric nitrogen (by chelating the element to make it available to plant), mineral solubilization (e.g., P) and synthesis of phytohormones [235]. Organic acid production played an important role in some minerals solubiliztion, for instance, in the mineralization of organic S organic phosphorous played a major role [251]. Likewise, Wong et al. [252] documented that phytohormones in biofertilizers played an important role in plant growth by regulating cell division. For example, cytokinins (Phytohormones in biofertilizers) helped plants in improving growth with the production of more cells.

Table 10: Commercial products of biofertilizer and nanofertilizer:

Name	Interaction	Role	Formula
I. Biofertilizer			
Okadin	Symbiotic	N_2- fixation	Powder
SWERI	Non-Symbiotic	N_2- fixation	Powder
SWERI (NPK)	Non-Symbiotic	N_2- fixation P and K solubilizers	Powder
Cyanobacteria	Non-Symbiotic	N_2- fixation	Powder
Mycorrhizal	Symbiotic	P- solubilizers	Powder
Compost tea	Non-Symbiotic	Plant nutrition	Liquid
II. Nanofertilizer			
Name	**Method production**	**Role**	**Formula**
Nano-Se	Biological	Mitigation of the different stress i.e. salinity, drought, and heat.etc.	Liquid
Nano-Si	Biological	Plant nutrition and control from insects.	Liquid
Nano-cu	Biological	Plant nutrition and control from plant diseases.	Liquid

6.4.0. Summary

More than half the population of the globe is dependent on rice cultivation. Rice production will continue to share its role in achieving global food security but needs to achieve these goals looks very high. The fundamental question here is whether the traditional methods of rice cultivation and management practice adopted can guarantee the sustainability of rice production. Hence the nutrient management is one of a prime issue for the traditional methods of rice cultivation. Under the fluctuating climatic perils, continuous land degradation and expanding rate of urbanization will need more intensive practices for rice cultivation. The paddy soils due to their unique characteristics need special attention in term of management. The current fertilization practices will unlikely to work in the future for sustainable rice production. The paddy cultivation is not a local industry, yet it is spread on the globe comprising various ecosystems for rice climatization and hence the most diversified. Moreover, the cropping system and cultivation methods also differ but in low land plains where most of the rice is cultivated as rice-rice cropping or rice-wheat cropping, Normally, alternate-wetting drying cycles of irrigation are adopted which have substantial impacts on soil quality. Under existing cultivation practices, not only macronutrients have low use efficiencies, but soil deficiencies for micronutrients are also being reported worldwide. Despite the fact, the more than 50% of globally produced fertilizers are applied in the rice yet the crop yields are being stagnant and non-profitable. Rice cultivation has become a major source of groundwater pollution, greenhouse gases, algal blooms, and loss of soil productivity. Therefore, it is dire need to sustain the rice cultivation through managing the applied fertilizer. The 4-R stewardship for rice is widely recommended, which results in enhancing the nutrient use efficiency but reduce the losses of NPK. The practice integrated nutrient management ensures the sustainability of paddy soil to act as a source of all nutrient for longer periods. The key to profitable and maximum rice yield is balance fertilization, and there are no further doubts over this concept. Moreover, the rice yields can be more sustainable through precision agriculture with the help of site-specific nutrient management, optical sensing, or remote sensing. The nanotechnology is still a new concept for fertilizers, but it has significant potential to boost rice productivity at continentals' scales. Adoption of such modern practices which are key component precision crop management can ensure the enhancement in nutrient efficiencies and thus can ensure the food security.

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Austin Publishing Group

Insect, Pest and Disease Management in Rice

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Published Date: January 18, 2020

Abbreviations: D: days; DT: Days After Transplanting; Wk: Week; H: Hrs; %: Percent; Sp: Specie; @: At The Rate Of; Ha: Hectare; Kg: Kilo; Gram; Ml: Milli Liter; Ipm: Integrated Pest Management; Sq.M: Square Meter; E.G: For Example; 2.4.D: 2,4-Dichlorophenoxyacetic acid; Bt: Bacillus thuringiensis

1. Introduction

Insect, pest and disease management is vital in attaining sustainable rice production. Rice serves as a staple diet for about half of the world's population and it is cultivated in 110 countries of the world, covering about one-fifth of world's cropland under cereals. But its production is affected largely by insects, pests and disease attacks. Reduction in rice yield due to insects, pests, and diseases is recorded to be about 21 % in North and Central America and about 31.5% in Asia (excluding mainland China). Yield loss varies within production conditions. In utter terms, yield losses of about 1.2 to 2.2 tons/ha have been recorded due to weed, insect, pest and disease injuries in Asia. More than 800 rice insect's species have been reported in the worldwide ecosystems. From these, about 700 species did not cause damage to rice and are considered friendly insects while about 100 species attack rice. Almost 20 insects act as rice pests that include defoliators, stem borers, gall midge and vectors like planthoppers and leafhoppers that cause direct damages and also transmit several diseases at different growth stages (**Table 7-1**). Management practices are needed to control the loss carried out by different diseases and insects and pests. Most common practices include agronomic practices, biological and chemical control.

Agronomic practices include; growing of resistant and early maturing varieties, early sowing of seeds, proper/close plant spacing, avoiding rice hotspot areas of viruses especially of grassy stunt virus and tungro virus, crop and field sanitation/hygiene, ploughing after harvesting that helps to bring eggs to soil surface and abolish them, judicious use of fertilizers, flooding of fields in order to save irrigated crops and after forecasting etc. For biological control of insects and pests, numerous natural enemies (predators, parasites, pathogens, and microbial insecticides) of insects and pests are used. These living entities attack insects and pests and destroy them. A wide variety of insecticide and pesticides are used as chemical control, according to the extent of attack and crop growth stages.

Several viral, bacterial and fungal diseases have been noticed. Disease damage can greatly affect growth and yield of rice crops and can sometimes completely destroy the crop. It is observed that destructive viral diseases are not present in any of the rice-growing regions of the world, but fungal and bacterial diseases are widely spread and are very destructive. Some effects of diseases as direct losses include the spotted kernels, low number of grains, lodging, reduction in plant stands and a general plant efficiency reduction while indirect losses include the application costs of fungicides used to control the disease, yield reduction along with special agronomic practices that not only decrease the disease effect but may not be conducive to higher yield production. Diseases and their causal agents are listed in **Table 7-1**. The physiological disorders such as zinc deficiency, straight ahead, salt damage, cold injury and nutrient deficiencies are sometimes misunderstood as disease symptoms. Management is necessary in order to avoid damage caused by the diseases. Toward disease management, the first step is the identification of disease followed by field scouting so that extent of disease can be determined. Determination of varietal resistance to diseases can be helpful in determining the chances of having problems warranting preventive management measures.

Table. 7-1: Growth stages of rice attacked by insect pests

Growth stages	Insect pests
Vegetative Stage	Seedling maggots
	Rice seed midge
	Rice caseworms
	Rice leaf beetles
	Rice gall midge
	Grasshoppers, katydids, and field crickets
	Rice stem borers
	Black bugs
	Rice mealybugs
	Rice thrips
	Rice leaffolders
	Mealy bugs
	Rice hispa
	Armyworms and cutworms
	Stalked-eyed flies
	Colaspis
Reproductive Stage	Rice Skippers
	Leafhoppers
	Greenhorned caterpillars
	Planthoppers
	Lady bird beetle
Ripening stage	Stink bugs
	Ripening seed bugs
	Rice Chinch bug
	Panicle rice mite
Soil Inhabiting pests	Ants
	White grubs
	Mole crickets
	Root aphids
	Root-feeding mealybugs
	Termites
	Field cricket
	Root weevil
	Wire worm

Table. 7-2: Rice diseases and their pathogen

Plant growth Stage	Common name	Pathogen name	Cause
Seed and Seedling:	Seedling Blight	*Sclerotium rolfsii, Cochliobolus miyabeanus, Fusarium* sp., *Curvularia sp., Athelia rolfsii, Rhizoctonia solani, Athelia rolfsii*, and other pathogenic fungi.	Fungi
	Water Mold	*Achlya*sp. *Pythium* sp.	Fungi
Roots and Crown	Crown Rot	Erwinia chrysanthemi	Bacteria
	Root Rot	*P. dissotocum, Fusarium* sp., *P. spinosum,* and *Pythium* sp.	Fungi
	Root Knot	Meloidogyne sp.	Nematode
Leaf Blades:	Rice Blast	*Pyricularia oryzae*	Fungi
	Brown spot	*Bipolaris oryzae*	Fungi
	Narrow brown leaf spot	*Cercospora oryzae*	Fungi
	Leaf smut	*Entyloma oryzae*	
	Leaf scald	*Sarocladium oryzae*	Fungi
	Bacterial leaf blight	*Xanthomonas campestris* pv. *oryzae*	Bacteria
	Stackburn	Alternaria *padwickii*	Fungi
	White leaf streak	*Mycovellosiella oryzae*	Fungi
	White tip	*Aphelenchoides besseyi*	Nematode
Stem and leaf sheath:	Sheath spot	*Rhizoctonia oryzae*	Fungi
	Sheath blight	*Rhizoctonia solani*	Fungi
	Sheath blotch	*Pyrenochaeta oryzae*	Fungi
	Sheath rot	*Sarocladium oryzae*	Fungi
	Crown sheath rot	*Gaeumannomyces graminis*	Fungi
	Stem Rot	*Magnaporthe salvinii*	Fungi
	Flag leaf collar blast	*Pyricularia oryzae*	Fungi
	Node blast	*Pyricularia oryzae*	Fungi
	Tungro	Rice tungro bacilliform virus (RTBV)	Virus
	Grassy stunt	Rice Grassy stunt virus (RGSV)	Virus
Panicle, Florets, and Grain:	Rotten neck blast	*Pyricularia oryzae*	Fungi
	Head blight	Various fungi	Fungi
	Panicle blast	*Pyricularia oryzae*	Fungi
	Bacterial panicle blight	*Burkholderia glumae*	Bacteria
	Downy Mildew	*Sclerophthora macrospora*	Fungi
	Grain spotting or Pecky rice	*Fusarium* sp., *Cochliobolus miyabeanus, Microdochium oryzae, Sarocladium oryzae, Curvularia* sp. and bacteria	Fungi and Bacteria
	Kernel smut	*Tilletia barclayana*	Fungi
	False smut	*Ustilaginoidea virens*	Fungi
	Bakanae	*Fusarium moniliforme*	Fungi
	Black kernel	*Curvularia lunata*	Fungi

2. Insect, Pest of Rice and their Management

Stem Borers

Description: Stem borers are the most severe rice pests in the world. Three families; Noctuidae, Diopsidae, and Pyralidae, have been documented as rice stem borers. The pyralid borers possess high host specificity. They are most common and destructive. In Asia, the most destructive and widely distributed are *Scirpophaga incertulas*, *Chilo suppressalis*, *Sesamia inferens, Scirpophaga innotata*, and *Chilo polychrysus*. In Asia, *Chilo suppressalis* and *Scirpophaga incertulas* cause a damage of 5-10% of the total rice crop. *Scirpophaga incertulas is* distributed in the temperate and tropics areas. It is the dominant species in Pakistan, Malaysia, In the Republic of Korea, Bangladesh, Sri Lanka, India, Philippines, Vietnam, Thailand, and some parts of Indonesia.

Damage: The underlying feeding and boring by hatchlings in the leaf sheath cause vast, longitudinal, whitish, stained zones at bolstering destinations, however just infrequently do they bring about shriveling and drying of the leaf-cutting edges. At the point in the middle of the vegetative period of the plant, the focal leaf whorl does not unfurl, but rather turns tanish and gets dry, in spite of the fact that the lower leaves stay green. This situation is recognized as the dead heart, and the infected tillers dry off without panicles.

Management

Agronomic Methods: Crop agronomic practices show an intense effect on the population of stem borer. High rates of nitrogen fertilizer will provide more plant nutrition and result in higher yield. However, it also increases the incidence of bacterial and fungal diseases by increasing tiller density and tissue susceptibility and boosts the stem borer's multiplication. Insects generally grow larger and faster, produce more offspring by completing more generations per crop and cause more damage when high nitrogen is applied. Stem borer moth's oviposition occurs favorably under high nitrogen fertilizers. For its management, nitrogen is applied as a split application at optimal rates. Splitting the nitrogen application, and use of slow nitrogen release forms of fertilizers(e.g. sulfur-coated urea, urea super-granules) helps to attain higher crop yields and lower chances of pest attack. Silica application helps to increase crop resistance against stem borer. Slag application increases the silica content and makes it resistant to stem borer attack.

Clipping the seedlings tip before transplantation is done to eradicate the egg masses. This method is used only for mature seedlings. Crop harvest at ground level reduces the number of larvae. Harvested crop height is an important factor that determines the larvae percentage, left in stubble. Removal and destruction of stubbles from rice field, which will help in the destruction of egg masses. To destroy those remaining eggs, flooding and plowing of fields, and burning and decomposition of rice stubble are suggested. For decomposition, calcium cyanide is used in low amount. Plowing and flooding are most effective apparently. Uniform burning of stubble is also difficult in a field. Burning of stubbles is effective only when larvae migrate to subsurface soils.

In many countries, postponing of sowing and transplanting time is considered a good practice in escaping moth's first-generation and it can also decrease the density as well as damage of stem borers both in directly seeded and transplanted rice fields. Changing planting time is not always effective because of other agronomic attention. In Pakistan, planting date is scheduled by canal water release only after the emergence of *Scirpophaga incertulas* moths. This late-planted crop is less affected by moths than early field plantation receiving tubewell irrigation.

Delayed planting is an effective practice against *Scirpophaga incertulas* since emergence is also delayed with planting date. The number of generations of stem borer is dependent on the crop growth period. Thus, change in planting time has a slight effect in areas where rice cropping is practiced continuously.

Light traps are used for collection and destruction of moths. Catching of moths by Light-traps shows a variation from a uni-modal to a bi-modal pattern in first and second broods. The frequency-vibration-based pest lamps used to kill the stem borers. They are installed at 200 m distance from each other in a checkerboard pattern and 1.3–1.5 m above the ground. These lamps are switched on during the light period when immigration of stem borers occur. However, a disadvantage of these lamps is that it will also cause damage to beneficial insect pests. High insecticidal activities of Bt rice are observed against stem borers.

Chemical Methods: Stem borers are difficult to control with insecticides because larvae are exposed only for a few hours before they enter the tiller or plant. So when an economic threshold of the dead heart reaches at about 10% in the nursery and in the vegetative stage and 1 moth /sq.m. has reached, implementation of the chemical control method is suggested. Chemicals that are recommended at these stages are chlorpyriphos, fenitrothion, monocrotophos, cartap hydrochloride, etofenprox, phosalone, endosulfan, fenthion, phenthoate, and fipronil. Seedlings root dipping in chlorpyriphos (0.02%) for 12-14 h before transplanting gives safety against stem borer for up to 30 d.

Successful control involves repeated foliar applications. Granular insecticides, particularly diazinon and gamma BHC, are most effective than foliar sprays, specifically in high rainfall environments. Gamma BHC is a fumigant that kills inactive moths. In the dead hearts of young crops, granules fertigation is effective in preventing stem borer. The insecticide is dissolved partially in the water and is transported between the stem and leaf sheath by capillary action, to make contact with young larvae. The limitation in the use of this method is cost and water supply. Granules are costly to transport. Stable and deep water levels are required for control. A combination of chemo-sterilant and sex attractant (pheromones) also shows the potential of pest control. Sex pheromone application can decrease the insecticide use by 1–2 sprays, and the input costs can be decreased than insecticides.

Biological Methods: Biological control of stem borers in Africa and tropical Asia mostly comes from native parasites, predators, and entomo-pathogens. Over 100 species of these parasitoids have been recognized. The management and protection of these parasitoids are essential in the development of successful and stable integrated pest management (IPM) systems against stem borer. The essential genera include; *Trichogramma, Telenomus,* and *Tetrastichus, Telenomus* wasps parasitize stem borer eggs before the eggs are covered by the hair while the moth is in the oviposition stage. The wasp detects the female moth, gets attached near ovipositor. Many predators, crickets; *Anaxipha longipennis,* and *Metioche vittaticollis*, and mirid; *Cyrtorhinus lividipennis* feed on *Chilo suppressalis.* The long-horned grasshopper preys rapaciously on yellow stem borer eggs. Some important predators are carabid beetles such as *Ophionea* sp., coccinellid beetles; *Micraspis crocea* and *Harmonia octomaculata* that attack small larvae of stem borers. *Mesovelia vittigera* and *Microvelia douglasi atrolineata* prey on young larvae when they fall on the water. Ants and many other predators prey on larvae of stem borer.

Several fungal species can attack the larvae and ingest them at the stem base — the *Cordyceps sp.* Fungus feeds on the body of stem borers. Spiders attack adult moths when resting on foliage. Bats are effective at dusk while birds and dragonflies are active predators at daytime. Spinetoram, Spinosad, *Empedobacter brevis* and *Beauveria bassiana* possess greater insecticidal effects on stem borers. Another popular biological insecticide, Bt agent, is recommended in China to control rice stem borers.

Armyworms and cutworms

Description: The hatchlings of a few types of field noctuids are called armyworms and cutworms. They feed extrovertly on rice plants. They are comparable in propensities, however, can be comprehensively recognized by the attacking habits. The armyworm hatchlings grow on the over-the-ground plant's parts, frequently leaving just midribs. The cutworm hatchlings grow on the underground parts. The common armyworm, *Mythimna* (*Pseudaletia*) *unipuncta*, periodically cause crop losses. *M. unipuncta;* being polyphagous is also a severe pest of wheat, rice, barley, oats, and non-graminaceous crops, cereals, and grasses. The species is native to North America, but it is diverse in the allocation and documented throughout Asia, Europe, and Australia.

Armyworms and cutworms that are described in this chapter are; rice warming caterpillar, fall armyworm, and common cutworm.

Rice swarming caterpillar

Description: The rice swarming caterpillar (*Spodoptera mauritia acronyctoides*) infrequently makes substantial losses to rice crops. A preferred host of this polyphagous insect is upland rice, but it also infects weeds and graminaceous crops. It is standout amongst the most genuine creepy crawly bugs in South India and widely distributed in Southeast and East Asia. It is the most damaging pest of the armyworms in rice regions of Asia.

Damage: The swarming caterpillars appear unexpectedly in multitudes and move from field to field. They generally affect the nursery of rice, and the transplanted crop is not sternly affected by their attack. Newly hatched larvae give the plant a sickly look with cut leaves and withered tips while older larvae attack and feed wholly and ravenously defoliate the plant.

Fall armyworm

Description: The fall armyworm (*Spodoptera frugiperda*) causes economic losses to rice crops though it comes about only periodically. It is also known as southern armyworm grass worm and overflow worm. It also attacks cereals, grasses, tobacco, cotton, legumes, and cabbage. It has been noticed in Central and North America but is common in Central and, southern USA, and in neotropical areas.

Damage: The hatchlings feed on leaves, leaving the epidermis undamaged. At first, they eat just delicate parts of leaves, as they develop they eat up all foliage, leaving just the hard plant parts. Harm becomes obvious around 3-4 d after the invasion, and overwhelming defoliation ends up after the hatchlings assemble on the plants.

Common cutworm

Description: The common cutworm, *Spodoptera litura*, is also known as tobacco caterpillar or tobacco cutworm, grass cutworm, and vegetable cutworm. It is a common polyphagous insect of various agricultural crops. It is found sporadically and causes economic losses to rice, cabbage, maize, castor, smaller millets, jute, tobacco, sweet potato, and in many other crops. It is found generally in Pakistan, India, Australia, East Asia, Turkey, China, and several African countries.

Damage: The common cutworm needs dry land for pupation, and for causing damage, so it is a problem only on upland rice. Larvae migrating from grassy areas adjacent to low land rice usually cause massive damage. Young caterpillars feed on soft leaves, but fully-grown can consume the whole plant. Their effect is serious on seedlings where they cause damage at the base. Fully grown caterpillar severely defoliates the rice crop during late crop growth.

Management:

Control measures for all cutworms and armyworms are similar.

Agronomic Methods: Seedbeds should be made away from grasses and weeds areas to avoid cutworms and armyworms migration to alternate hosts. Plowing fallow land and weed removal from areas outside the fields helps to control cutworms and armyworms. Use of resistant rice varieties is recommended. Several wild kinds of rice have moderate resistance to *Mythimna separate* and *Spodoptera mauritia acronyctoides.*

Chemical Methods: Insecticides; Sevin (@ 0.15 to 0.25%) and Furadan (@ 10 kg/ha) are used to control armyworm and cutworms. These insecticides are suggested to be applied as sprays because of their effectiveness over granular form.

Since insecticides rapidly break down in high temperature and sunlight. Insecticide spray should be done in the late afternoon to make sure that larvae are in their resting places because after that larvae climb up the plants. To destroy large cutworm and armyworm larvae, higher doses are required, because of direct positive linkages between insecticide toxicity and insect body weight.

Biological Methods: Cutworms have several natural enemies. They colonize the crop in the rainy season immediately after land preparation. At this stage, populations of the natural enemy are low. Armyworms controlled at the egg and larval stage by parasites. Because of drought, these parasites fail then armyworms become epidemic. Larvae are parasitized by Tachinid flies, eulophid wasps (*Euplectrus chapadae*), chalcid wasps (*Brachymeria lasus*) and braconid wasps (*Cotesia* sp. and *Ropalidia fasciata*). Ants (*Odontoponera transversa* and *Chelonus formosanus*) are reported as larval and egg parasites. Moths are parasitized by spiders, *Oxyopes javanus* and *Pardosa pseudoannulat*.

Soil-inhabiting insect pests

Soil-inhabiting insect pests do not create the problem in irrigated rice fields because these pests attack and feed on underground plant parts. Non-puddled, Well-drained, upland rice soils are suitable sites for these pests.Soil-inhabiting pests described in this chapter are; Ants, Termites, Crickets, White grubs, Rice root weevil, and Rice root Apids.

Ants

Description: The ant is a social insect and is distributed widely but commonly found in dry-seeded rice fields in rain-fed wetlands and in upland rice. The most common species of soil-inhabiting ants that cause significant damage in Asia are *Pheidologeton diversus*, *Pheidole* sp., *Solenopsis geminata* and *Munomorium pharaonis.*

Damage: These harvester and fire ants feed on un-germinated rice seeds, and cause rice plant's destruction. Their nests are built on levees or below the soil surface in upland fields. If un-germinated seeds are not available, they attack germinated seeds. Damage by ants results in a patchy, reduced, plant stand. Ants help aphids in penetrating the soil by making the tunnels along with the root systems.

Management:

Agronomic Methods: Ants usually attack at seeds after sowing so in order to reduce loss, an increased rate of seeds is used.

Chemical Methods: Seed coating with powdered insecticides helps to control ants in rice fields.

Termites

Description: Termites belonging to family Termitidae, are subterranean and are commonly known as white ants as they also possess workers caste system, king, queen, soldiers, body shape, and wings. They cannot digest cellulose because of the lack of protozoans. Termites culture fungi in special underground cells that break down cellulose. Termites are a problem in upland rice areas, but can also occur in light textured soils in rainfed wetland areas. In Africa, *Macrotermes* and *Microtermes* termites have been recorded as rainfed upland rice pests. Termites are a serious problem in Africa and Latin America.

Damage: Soil texture and moisture content are important factors that affect the rate of infiltration. Light textured soils having low moisture receive more infiltrations. They preferably attack older plants with greater cellulose content but also attack a drought-stressed crop. They make a burrow all the way through plant stems and then eat roots.

Management:

Agronomic Methods: Provide another host at planting time for termites like crop residues that diverts termites from growing crops. Pulling out of damaged plants from the fields will reduce the dissemination of termites.

Chemical Methods: Insecticides are used to control termites in rice fields. Granular insecticide applications in seed hills and furrows and seed treatment with insecticides at planting time are the two most commonly used methods for termite control.

Crickets

Description: Four species of mole crickets are reported to attack rice; *Gyllotalpa africana* in Africa, *Gryllotalpa orientalis* in Asia, and *Scapteriscus didactylus* and *Neocurtilla hexadactyla* in Latin America. Several field cricket species are identified as rice pests; *Plebeiogryllus plebejus*, *Teleogryllus occipitalis*, *Gryllus assimilis*, *Brachytrupes portentosus*, *Teleogryllus testaceous*, *Loxoblemmus haani*, *Velarifictorus aspersus membranaceus* and *Gryllus bimaculatus*.

Damage: They live in branched burrows that are 8-10 cm below the soil surface. Under lowland fields, burrow making is common in non-submerged areas and near the levees while in upland fields, burrows are more in moist patches. These burrows lie near the soil surface and crickets feed on plant roots. That results in the complete separating of roots from the aerial parts. Some field cricket species remove the central portion of leaves and defoliate rice plants.

Management:

Agronomic Methods: Only agronomic practice for controlling crickets is the maintenance of standing water in the field. Standing water will prevent crickets to form tunnels in soil and ultimately cannot damage the plant roots.

Chemical Methods: The main control measure in deep water areas is the chemical treatment of soil as well as seeds at planting. Another measure that is recommended is poisoned bait made from powdered or liquid insecticide and from moistened rice bran can be placed on rice bunds or in a rice field to kill night-foraging field and mole crickets.

Biological Methods: Sphecid species; *Motes manila*, *Liris aurulenta*, *Motes loboriosus* and *Motes subtessellatus*, parasitize the field crickets. Mole crickets are cannibalistic and regulate their own numbers. Eggs of *Gryllotalpa africana* are preyed by *Pheropsophus jessoensis* larvae. Other parasites are Sphecid wasps (*Larva luzonensis*, *Larva carbonaria,* and *Larva sanguinea*) that parasitize nymphs and adults. Nymph and adults of mole crickets are parasitized by the nematode, *Mermis igrescens,* and the fungus *Beauveria bassiana.*

White Grubs

Description: The term white grubs are actually the large larvae of a scarab beetle. White grub larvae feed on the roots and they are also known as the chafers. White grubs are a serious damage causing pests of rice and they are distributed widely. They infiltrate the roots of sugarcane, cereals, vegetables, millets, and many other crops.

Management

Agronomic Methods: Delaying land preparation escapes the egg-laying phase of adults or they may die. Weeding also helps to reduce the chances of attack by reducing egg laying by females.

Chemical Methods: The only practical and effective insecticidal control measure is the application of granular insecticides against white grubs. Insecticides should be applied in crop hills or furrows at sowing.

Biological Methods: Mermithid nematodes and *Psammomermis* sp. parasitize the grub larvae. Several scoliid wasps, e.g. *Campsomeris marginella modest,* parasitize the white grubs.

Rice root aphids

Description: The rice root aphid, *Tetraneura nigriabdominalis,* is a major upland rice pest. It is reported in Pakistan, Bangladesh, India, Sri Lanka, Indonesia, Fiji, Republic of Korea, Japan, Malaysia, Nepal, Tonga, Philippines, Central America, Africa, New Zealand, the Caribbean, and Australia.

Damage: The rice root aphids affect rice crops at different stages. Aphid causes heavy damage at the tillering while light damage at the seedling stage. Rice root aphid causes deformed plant growth. Yellowing also occurs. These aphids reside in plant roots The main damage is caused by the nymphs and adults feeding, they suck the plant roots sap.

Management

Agronomic Methods: Increased plant density reduces the chances of Aphid attack so increasing plant density will help reduce the Aphid attack.

Chemical Methods: The usual prophylactic seed or soil treatment with appropriate chemicals or spraying formothion or oxydemeton methyl or phosphamidon (@ 250 ml/ha) will prevent the buildup of rice root aphids. Acephate and Carbofuran are also used as a chemical treatment.

Biological Methods: Several natural enemies are documented. Lady beetles (*Harmonia octomaculata*, *Coccinella repanda,* and *Menochilus sexmaculatus*), a mermithid nematode (*Mermis* sp.) and a braconid wasp (*Aphidius* sp.) are recorded parasites of nymphs and adults.

Rice root weevils

Description: Rice root weevil is the most damaging rice pest in Asia. They are widely distributed in Asia specifically in the Republic of Korea, Japan, and China, and in India.

Damage: Adults attack transplanted rice but rarely cause economic loss. Larvae cause real damage by attacking the roots and rootlets of young rice plants. They attack the redeveloping roots and restrict their development. The leaves give rusty appearance with yellow color and then plants die. The heavy attack in fields leaves large patches of dry plants. Tillering stage affected severely compared to other stages.

Management

Agronomic Methods: Late planting of the crop is recommended. This helps to escape the time of the highest larval attack. In flooded rice, growing of another crop along with rice can kill larvae. Dense planting decreases populations of rice root weevil.

Chemical Methods: Insecticides as a foliar spray and granular insecticides helps to control larvae, but granular insecticides show promising effects in controlling adults compared to foliar spray and dipping of rice seeds for 6 h before transplanting is an effective method for controlling larvae in highly infested areas. Leaf extract of the mahogany tree is used in research, and it affected the progeny production of rice weevil.

Rice mealybugs

Description: Mealybugs are immobile, plant-sucking insects. They are distributed widely all over the world and are economically important pests for rice, sorghum, potato, cassava, yam, coffee, citrus, and cacao. To cover themselves, they secrete white filaments of wax. Mealybugs are root, stem, or leaf feeders. *B. rehi* occasionally causes rice crop losses in Thailand, India, and Bangladesh.

Damage: They suck sap from a stem. This results in yellowing, abnormal tillering, and stunted plant growth. Because the young nymphs have restricted movement, damage occurs in patches. Under heavy infestation, panicle does not fully exert from the boot. Mealybug numbers vary between hills that cause several spots of depressed growth in the field which are identified as Sooraj and Chakdhora disease. Drought provides favorable conditions for the attack, and rice plants can least tolerate sap loss in this situation.

Management

Agronomic Methods: Agronomic control measures includes early or late planting to skip the timing of peak infestation. Flooding of the field throughout the crop growth period at 5-cm depth helps to reduce the damage because drought condition favors the epidemic. Removal and destruction of infected plants are done. No resistant varieties to *B. rehi* are commercially available.

Chemical Methods: Granular insecticides are operative in standing water. If there is no standing water in damaged fields, broadcasting the granules is an impractical practice. The waxy discharge covering the mealy bugs protects them from insecticidal effect. In that case, foliar sprays are effective.

Biological Methods: Main natural enemies of the mealybug are lady beetle species (such as *Harmonia octomaculata*, *Coccinella repanda* and *Menochilus sexmaculatus*). Dipterous predators of *B. rehi* are two chloropids (*Mepachymerus ensifer* and *Anatrichus pygrnaeus*) and one drosophilid (*Gitona perspicax*). Hymenopterous parasites of *B. rehi* recorded include; Encyrtidae *(Specie of Cheiloneurus, Gyranusa, Doliphocerus, Parasyrphophagus, Adelencyrtus, Xanthoencyrtus,* and *Mayeridia*), Eulophidae *(Species of Tetrastichus, Aprostocetus, Chrysocharis,* and *Desostenus*), Mymaridae (*Lymaemon sp.*), Ceraphronidae (*Cerapkron sp*.), Thysanidae (*Thysanus sp*.) and Pteromalidae *(Diparini* sp.and *Callitula sp*.).

Grain-sucking insects

Description: Several bugs feed on developing spikelets. They live on grasses or in the rice fields or in the surrounding areas where they reside and multiply in their vegetative stage. Then they move to flowering rice fields. In Asia, *Leptocorisa sp.* and in America, *Oebalus pugnax* are the important grain-sucking pests.

Rice bugs and Stink bugs

Damage: Rice bugs adults cause more damage because of a longer feeding period in spite of the fact that nymphs are more active feeders than adults. Rice bugs attack at the milk, dough making and even ripening stage of seed. Both nymphs and adult bugs feed on the endosperm of developing grains. In heavily infested fields, rice panicles contain unfilled grains. Rice bugs attacks on soft endosperm in a solid state and infuse enzymes to predigest it that results in kernel weakness and discoloration of mature grain. Damage during the milk and dough stage causes yield loss and poor grain quality, respectively.

Management

Agronomic Methods: Several agronomic and mechanical methods are being used to control grain-sucking rice bugs. Late planting is usually used as an agronomic practice especially for early maturing varieties. This is done in a synchronous pattern in order to make sure that all crops mature concurrently. During rice free periods, alternate hosts eradication from fields, from leaves and from surrounding areas is a good practice in controlling the bug multiplication.

Mechanical control measures include the use of sticky traps, hand picking of nymphs and adults, and smoking the field.

Chemical Methods: Granular insecticides are usually futile in controlling grain sucking bugs. Dust formulations or spraying the insecticides are sometimes suggested. Use of chemicals (e.g., Acephate) is recommended in some rice growing areas. Dusting carbaryl @ 10 %, for *Leptocorisa sp.* is sufficient and if there is the severity of the infestation, it is repeatedly used.

Biological Methods: As a biological control, several predators and parasites are recognized to outbreak the rice bug. A typical natural enemy of stink bug is *Nabis stenoferus*, called the assassin bug. A number of spider's species, e.g., *Tetragnatha* *javana*, *Neoscona thesis* and *Argiope catenulate,* target on nymphs and adults of rice bug. Eggs of *Leptocorisa sp.* are destroyed by small scelionid wasps (*Gryon Nixon*). Stink bugs are parasitized by several wasps species. The meadow grasshopper, *Conocephalus longipennis,* preys on rice bug eggs. A fungus, *Beauveria bassiana*, preys on both nymphs and adults.

Rice leafhoppers and planthoppers

Description: Leaf and planthoppers not only cause feeding damage, but they also cause viral diseases by acting as vectors. The more damaging species in Asia are the zigzag leafhopper *Recilia dorsalis*, green leafhoppers *Nephotettix sp.,* the white-backed planthopper *Sogatella furcifera*, the small brown planthopper *Laodelphax striatellus*, and the brown planthopper *Nilaparvata lugens* and *Tagosodes orizicolus*. The rice delphacid *Tagosodes orizicolus* is found in the north-central region of South America and the southern USA. Three *Nephotettix* species; *Nephotettix nigropictus* and *Nephotettix virescens* are found in tropical and temperate Asia.

Damage: Leaf and planthoppers damage plants by plugging phloem and xylem through sucking the sap. Similar effects appeared due to excessive oviposition. The ovipositional and feeding marks incline plants to be a bacterial and fungal infection. Honeydew boosts sooty molds due to a toxin injected during feeding on plants infested with *Cicadulina bipunctella.* Leaf and planthoppers are also vectors of rice viral diseases. *Nephotettix virescens* is a vector of tungro viruses, *Nilaparvata lugens* spreads grassy and ragged stunt virus in South Asia and Southeast Asia, *Laodelphax striatellus* act as a vector of a most dangerous disease, rice stripe in East Asian countries and *Tagosodes orizicolus* causes the spreading of 'Hoja Blanca' virus.

Management

Agronomic Methods: Nitrogen application in three split doses is effective in minimizing the population rate of *Sogatella furcifera and Nilaparvata lugens.* Silicon application is positively connected to reduce the planthopper population in rice fields. Water favors the growth of planthoppers and leafhoppers so 3 or 4 d fields draining during invasion have been endorsed for reducing *Sogatella furcifera* and *Nilaparvata lugens* populations. For *Nilaparvata lugens,* closer plant spacing is considered as an important factor favoring hopper build-up. Lower plant portion is slightly cooler due to low sunshine, humidity and provides a favorable microclimate for pest population build-up.

Field sanitation for control of leaf and planthoppers is used in many rice growing areas. Volunteer rice and ratoons may act as a source for the spread of a virus.

Rice crop rotation is an economical control measure. For this purpose, legumes are usually grown in most areas of Asia for reducing leaf and planthopper infestations.

Use of trap crop to control *Nephotettix virescens* and *Nilaparvata* lugens is suggested in a study conducted at IRRI. Trap crop transplanted 20 d before crop transplanting and it reduced the attack of *Nilaparvata lugens* on the main crop. Similarly, The banker plant system is also used in some countries, and it can boost the population of *A. nilaparvatae that* helps to control rice planthoppers. In the Jiaxing City of China, the incidence of planthopper transmitted viral diseases is considerably decreased by delayed sowing and non-significant variation in the grain yield is observed.

The frequency-vibration-based pest lamps used to kill the planthoppers. They are installed at 200 m distance from each other in a checkerboard pattern and 1.3–1.5 m above the ground. These lamps are switched on during the light period when immigration of planthoppers occurs. However, a disadvantage of these lamps is that it will also cause damage to beneficial insect pests.

Host-plant resistance is helpful in decreasing the damages. In a study in China, about 29 dominant resistance genes for planthoppers have been recognized from wild rice species and indica rice varieties. The transgenic rice plants with snowdrop Lectin (*Galanthus nivalisagglutinin*) have reduced the fecundity and survival rate by postponing the development of planthoppers because of there by an antifeedant activity.

Chemical Methods: For the control of leaf and planthopper vectors, insecticides application is used that not only reduces the effect of leaf and planthopper but also reduces the spread of the virus. The strategies used in chemical control of leaf and planthopper vector successfully are linked to vector behavior and virus transmission characteristics. With *Nephotettix virescens,* direct feeding is more damaging than the tungro virus transmitted by the vector. Tungro is a non-persistent virus and spread during a short feeding period, whereas grassy stunt and ragged stunt viruses are persistent and require more time. Therefore, rapid knockdown and prevention of feeding of the leafhopper are important. In tungro epidemic areas, prophylactic procedures are used for protection against this virus.

For *Nilaparvata lugens,* insecticide application at young nymph stage is inefficient because young nymphs do not cause damage to the crop. The insecticide should be applied only at an economic threshold level of population.

Leafhoppers are more responsive to insecticides than planthoppers. Most commonly recommended insecticides are chlorinated hydrocarbons, organophosphates, and carbamates in the Republic of Korea and Japan, but organophosphates have the highest selectivity against *Laodelphax striatellus, Nilaparvata lugens,* and *Sogatella furcifera.* Organophosphates have a lower level of ovicidal activity than carbamates.

Buprofezin is extremely discerning molting-inhibitor for *Nephotettix cincticeps, Nilaparvata lugens, Nephotettix virescens, Laodelphax striatellus,* and *Sogatella furcifera,* Buprofezin is found nontoxic to fish, or mammals.

For tungro virus control, systemic granules of insecticides are suggested for soil incorporation before seedbed sowing. Soil incorporated granules are advantageous than sprays or broadcast granules in the seedbed.

Broadcasting or soil incorporation of systemic granules provides protection to crop for 40 d whereas, seed soaking in insecticide solution before transplanting for 6-12 h gives protection for 20 d.

Insecticide sprays are more effective than a granular application for control of *Nilaparvata lugens.* However, in many countries, leafhoppers and planthoppers developed resistance against organophosphates carbamates and carbofuran.

Biological Methods: Several pathogens, parasites, and predators attack at all stages of leaf and planthopper. Inappropriate insecticides application may destroy the population of natural enemies that results in a striking outbreak of pest. Most effective parasites of *Nilaparvata lugens* eggs are; trichogrammatid (*Paracentrobia andoi*), mymarid (*Anagrus optabilis*), and eulophid wasps (*Tetrastichus formosanus*). Parasites of *Nilaparvata lugens* nymphs and adults are; dryinid wasp (*Echthrodelphax bicolour*), elenchid strepsipteran (*Elenchus yasumatsui*), fungal pathogens (*Hirsutella citriformis* and *Beauveria bassiana*), and nematode parasite (*Hexamermis sp.*). Underwater aquatic predators (e.g., *Cybister sp.*) and surface predators (e.g. *Ranatra dimidiate*, *atrolineata*, *Mesovelia vittigera* and *Microvelia douglasi)* prey on hoppers in water bodies.

The beetle, *Ophionea,* actively explore foliage for *Nilaparvata lugens* nymphs and adults. Damselfly and dragonfly prey on adults and nymphs. In laboratory tests, a single *Pardosa pseudoannulata* used up about 45 planthoppers/d. A white fungus, *Beauveria bassiana*, grows and covers the body of dead leafhoppers and grows inside it.

Common predators of eggs are *Cyrtorhinus lividipennis.* Parasites of nymphs and adults are dryinid wasp (*Echthrodelphax fairchildii*), pipunculid flies (*Tomosvaryella oryzaetora, Pipunculus mutillatus*), and strepsipteran. Greater than 50% parasitization of green leafhoppers by pipunculids is reported. Biological insecticide, 9% 12 α-hydroxy rotenone EW, shows greater insecticidal effects on planthoppers.

Rice gall midge

Description: The rice gall midge *Orseolia oryzae* (Wood-Mason) is one of the most damaging pests of rice in South and Southeast Asia. It also occurred in several parts of Pakistan, India, Sri Lanka, Cambodia, Laos, Nepal, Myanmar, Indonesia, Vietnam, and northern Thailand. It also occurs in Ghana, Ivory Coast, Cameroon, Liberia, Mali, Nigeria, Niger, Sudan, and Senegal.

Damage: The gall formed by the activity this fly is popularly known as 'anaikomban' 'onion shoot' or 'silver shoot'. Hollow pink or purple, pale green or dirty white tubes at the tip of the leaf, a reduced green leaf blade with auricles and ligules are formed. It also invades the rice nursery but tillers are ideal for their attack. It may cause up to 50% rice yield loss in a heavily infested crop.

Management

Agronomic Methods: The use of suitable amounts of nitrogen fertilizer in split doses on different growth stages is suggested. Field sanitation helps a lot to control the spread of gall midge. Removal of alternate hosts from fields is recommended controlling the pest population. Keeping land fallow free of off-season host plant and field plowing after harvest is recommended. Planting should not be done in neighboring fields within 3 wk to avoid staggered ages crops. Delaying planting of photoperiod-sensitive varieties helps decrease rice gall midge infestation because the vegetative stage is more prone to gall midge attack.

Chemical Methods: Insecticides are not recommended for gall midge control because larvae reside and protect inside the gall and plant. However, granular insecticides are applied sometimes. Granular insecticide applications at any rate in standing water in the field are usually effective than foliar sprays. Seed treatment with chlorpyriphos (0.2%) emulsion for 3 h is suggested in some rice-growing areas of the world. Seed mixing with either imidacloprid (0.5 kg /100 kg seeds) or chlorpyriphos (0.75 kg/100 kg seeds) provides protection for 30 d in the nursery. Seedling root dipping for 12 -14 h in 0.02% chlorpyriphos emulsion before transplanting provides 30 d protection.

Biological Methods: Numerous predators and parasites attack at gall midges. The natural enemies, controlling the African and Asian rice gall midge are diverse. Several platygasterid wasps are parasitoids of larvae and they start laying eggs on silver shoot walls when they first sting the larva from inside. The new hatchlings attack on the gall midges. A phytoseiid mite, *Amblyseius imbricatus, and Bracon sp.*, *aff. annulicornis*, *Platygaster pachydiplosisae*, *Anisopteromalus camerunus, and Neanastatus tenuis platygasteri,* attacks on eggs of Asian and African rice gall midges. Several pupal parasitoids e.g., *Neanastatus cinctiventris* and *Neanastatus* oryzae, and solitary larval parasitoids, e.g., *Obtusiclava oryzae* are also known. Adult midge is preyed by many spiders species, e.g., *Neoscona theisi*, *Argiope catenulata* and *Tetragnatha mandibulata*.

Rice leaf folder

Description: Larvae of eight pyralid moths' species roll or fold the leaves of graminaceous plants. They are *Marasmia exigua*, *Cnaphalocrocis medinalis*, *Marasmia bilinealis* Hampson, *Marasmia patnalis*, *Marasmia suspicalis*, *Marasmia ruralis*, *Marasmia venilialis,* and *Marasmia trapezalis*. They are found in the rice-growing tracts of 29 temperate and humid tropical countries of Asia, Australia, and Africa.

Damage: Several epidemics of leaf folders have been reported in the Republic of Korea, Fiji, Bangladesh, Philippines, China, India, Sri Lanka, Japan, Nepal, Vietnam, and Malaysia.

Under favorable conditions, several generations of leaf folders are produced. Only 1 larva/leaf is found. After feeding for about 2-3 d, larvae move to another leaf. Thus, each larva destroys more than one leaves during its growth period. The high insect population causes rice plants to dry up and appear scorched. The larvae longitudinally fold the leaves before feeding and fasten the leaf margins with threadlike silk stitches. Feeding affects the photosynthetic ability and vigor of the infected rice plant. The damaged leaves are the entry points for bacterial and fungal infections. Feeding on flag leaf by leaf folders caused maximum yield loss.

Management

Agronomic Methods: Nitrogen fertilizer management is highly recommended. N fertilizer plays an important role in improving the yield, in increasing the nutrition of the rice plant but it also helps to greater insect feeding rates, survival, and reproduction which in turn leads to greater damage. Nitrogenous fertilizer application in split doses is helping to reduce the growth, reproduction and surviving ability. Other fertilizers such as phosphorus, potassium and necessary elements should be applied in balanced amounts. They can enhance the rice plant vigor and improve the resistance of rice plants to leaf folders.

Removal of the alternate host plant is recommended e.g. grassy weeds removal from rice fields and surrounding borders that prevent the rice leaf folders build-up on alternate hosts. Varietal resistance can be used to reduce the damage caused by leaf folders. Bt rice posses first-rate insecticidal activities against leaf folders. Sex pheromone application can decrease the insecticide use by 1–2 sprays and the input costs can be decreased than insecticides.

Chemical Methods: In order to control severe leaf folder influx, chemical control is done. A most effective method of applying an insecticide is foliar sprays. Foliar sprays are needed to be repetitive because of washing off insecticides by frequent rains. Granular insecticides application by the broadcast method is ineffective. However, insecticide created resurgence of *ilaparvata lugens* acts as hindrances to successful chemical control. Fields should be monitored weekly because leaf folders can attack the crop at any growth stage.

Biological Methods: Several natural enemies of rice leaf folders normally push them underneath economic threshold levels. Several species of nematode (*Agamermis sp.*), Diptera (e.g., *Argyrophylax sp.* and *Megaselia sp.*), Coleoptera (*Coccinella sp.* and *Chlaenius sp.*), Orthoptera *(Metioche sp.* and *Anaxipha sp.*), Hymenoptera *(Apanteles sp., Trichogramma sp., Goniozus sp.,* and *Bracon sp.*) and Araneae *(Tetragnatha sp., Argiope sp.* and *Pardosa sp.*) have been reported as parasites and predators of leaf folders in Asia. Spinetoram, Spinosad, *Empedobacter brevis* and *Beauveria bassiana* possess grater insecticidal effects on stem borers. A few viral, fungal and bacterial pathogens and toads and frogs also parasitize the larvae, when the pest population is high. The biological insecticide 9% 12 α-hydroxy rotenone EW show greater insecticidal effects on leaf folders. Microbial insecticides, e.g. *Bacillus thuringiensis*, are effective against larvae.

Rice water weevil

Description: The rice water weevil (*Lissorhoptrus oryzophilus*) was originally found in the Mississippi River basin., but it is now one of the most destructive rice pests in all rice growing areas.

Damage: Adults feed on young rice plants and cause damage to leaves. Longitudinal strips are formed on the leaf surface. Maggots cause the main injury. They feed on the roots, severely pruning them in heavy infestations and causing vigor loss, reduced yields and plant lodging.

Management

Agronomic Methods: Early planting of rice can skip the time of pest attack and reduce the yield loss. In Japan, early transplanting of rice seedlings early reduces yield loss. Losses can also be decreased by transplanting middle-aged or mature seedlings. Intermittent rice fields flooding and draining at 15 d intervals reduces the damage. However, this practice has a limitation in areas where water availability is low and the loss of fertilizers also occur due to drainage. Removal of alternate hosts plants e.g. aquatic grasses, reduce the pest population. Areas receiving higher doses of fertilizers are more sternly infested. Rice resistance varieties to rice root weevil are recommended. Several rice varieties with low or moderate levels of resistance are recognized.

Chemical Methods: Granular insecticides are suggested and applied at the appropriate time.

Biological Methods: The fungus, *Beauveria bassiana,* attack on rice water weevil. A mermithid parasitized the female weevils in the USA. Several frogs and bird species are recognized to feed on the rice weevils. Tettigoniid grasshoppers such as *Orchelimum agile*, *Conocephalus fasciatus* and *eoconocephalus triops* prey on adult weevils.

Rice thrips

Description: The two most common species associated with rice are *Haplothrips aculeatus* and *Stenchaetothrips biformis*. *S. biformis* is a major rice pest in India, Sri Lanka, Japan, Bangladesh, Indonesia, and China. *S. biformis* is also known as rice paddy thrips, oriental rice thrips, and rice leaf thrips. The first specimen collected from watercourses.

Damage: Larvae, as well as adults, possess scratchy mouthparts. Thrips species with leaf-feeding habit possess a punch and suck feeding technique. Symptoms of damage include; leaves rolling inward along the margins, stunting and wilting. Fine, silvery or yellowish streaks appear. In a severe epidemic, plant death occurs, resulting in a low plants number/unit area. The damage is severe in dry land rice fields.

Management

Agronomic Methods: For rice thrips control, flooding the field for 2 d to submerge plants is an effective practice. Use of resistant varieties can reduce the chances of thrips attack. Many rice varieties resistance to thrips have been identified. Wild rice with resistance to thrips includes; *Oryza glaberrima. Oryza eichingeri, Oryza minute, Oryza officinalis, Oryza nivara, Oryza perennis, Oryza sativa f. spontanea* and *Oryza rufipogon.*

Chemical Methods: Insecticides as sprays, as systemic granules or dust controls pest build-up. In china seed treatment with methoxam reduces the trips infestation more effectively compared to the foliar application. Imidacloprid, carbosulfan, thiamethoxam, and thiacloprid are the insecticides most commonly used as seed treatments against rice thrips.

Rice caseworm

Description: The rice caseworm, *Nymphula depunctalis,* is an important insect pest of rice. It occurs in Africa, in Australia, South America, and many tropical countries. Among related species are; *Paraponyx fluctuosalis*, which occurs in Australia, Japan, India, Philippines, Sri Lanka, China, Malaysia, Thailand and in some African countries, *Nymphula fengwhanalis* and *Nymphula vittalis*, which occur in China and *P. diminutalis*, which occurs in India, Japan, China, Indonesia, Philippines, Thailand and Sri Lanka.

Damage: The freshly hatched larvae attack and feed on the tender leaf surfaces, but larvae at later stages, feed on the surfaces of the older leaves. Larvae caused the damage by feeding and cutting off the leaf tips forming a case. Removed leaf tissue gave the ladder-like appearance, while upper epidermis gave the papery appearance. They gave smaller panicles and less number of tillers and delayed maturity. If other pests such as stem borer or whorl maggot infest the crop within first 30 d of transplanting, yield loss occurs and plants' ability to recover is decreased.

Management

Agronomic Methods: Agronomic methods involving older seedlings transplant helps in limiting the period of larvae attack. Water management is also effective in controlling larvae of rice caseworm. Field draining for about 3 ds will exterminate most of the larvae because of low supply of oxygen. A non-flooded seedbed is protected from caseworm attack. However, this practice favors weed growth.

Chemical Methods: Larvae of rice caseworm are sensitive to insecticides. So, the foliar spray is recommended. They have controlled readily with granules application in floodwater or with foliar sprays. Within one week of transplanting, the insecticidal foliar spray is recommended.

Biological Methods: A tabanid fly; *Tabanus sp.* and a braconid wasp; *Dacnusa sp.* parasitize the caseworm larvae. The hydrophilids (e.g. *Berosus sp.*), *Cybister tripunctatus orientalis Gschwendther* and *dystiscids Laccophilus difficilis* are reported predators of caseworm larvae. Algae and snails foraging such as *Radix* sp. and *Pila sp.* may remove caseworm eggs from rice leaves. Red ants attack the larvae in infested dry field rice. Several spiders of Araneidae; *Araneus inustus,* and *Neoscona theisi,* one species of Clubionidae; *Clubiona japonicola*; one species of Tetragnathidae; *Tetragnatha nitens*; one species of Lycosidae; *Pardosa pseudoannulata* prey on the moth.

Whorl maggots

Description: Whorl maggots consist of a composite of several species of genus *Hydrellia.* All members of the genus are a leaf or stem miners. They prefer living in damp areas or near water. In the field, rice whorl maggots resemble with other flies. Because of this resemblance, rice whorl maggots are difficult to identify.

Rice whorl maggot/South American Rice Miner

Description: The rice whorl maggot, *Hydrellia philippina,* was first documented in the Philippines in 1962, as a serious pest of rice. The insect attacks only rice plants usually at the vegetative stage, in the irrigated fields. It feeds on the central whorl of the leaf. It is a semi-aquatic pest.

Damage: The fly maggots attack unfurled leaves. The hatchlings move to the center and feed on the mesophyll tissue. Chewed-up and discolored areas appear. These areas ultimately dry up and leave often droop.

Management

Agronomic Methods: Crop establishment methods result in insignificant damage because plants cover the water surface. Water surface covering with Azolla helps to restrict invasion. Recommended agronomic control is rice fields draining because adults are attracted to standing water. It is good to use mature seedlings to curtail the crop vegetative stage. Draining should be done during the first 30 DT at intervals of 3-4 d. Drained fields allow more growth of weeds. Direct-seeded seedbeds or fields are not striking to adults so direct seeding is recommended. Use of resistant varieties is recommended however only a few resistant varieties are available against whorl maggots.

Chemical Methods: Soil application of systemic granules before transplanting or broadcasting of non-systemic granules in standing water are usually more effective methods for whorl maggots' control. However, foliar sprays can be done 1 or 2 wks after transplanting.

Biological Methods: Wasps *Trichogramma sp.* parasitized the exposed eggs of whorl maggots on leaves and braconids parasitized the whorl maggot larvae. Another parasite of whorl maggots includes; araneid (*Neoscona theisi*), lycosid (*Pardosa pseudoannulata, Oxyopes javanus*) and a fungus of the genus *Entomophthora.* Adult whorl maggots are preyed upon by ephydrid flies (*Ochthera brevitibialis*).

Ladybird beetle

Description: The ladybird beetles are oval, convex, small, insects. A large number of these species act as predators. They grow on planthoppers, leafhoppers, aphids, and mealy bugs and on the eggs of many other insects. The most common and widely distributed are *Micraspis crocea* and *Micraspis discolor*.

Damage: Ladybird beetle has variable feeding habits. Adults and nymphs of ladybird beetles usually feed on planthopper, aphid and leafhopper nymphs, and adults, eggs of mealy bugs, thrips, and stem borer. In the absence of prey, they attack pollen and leaf blades (leaving small chewed areas) and recurrently damage grains.

Management

Organophosphate insecticides spray helps to control rice beetles. These beetles are predators of several harmful insects. Controlling or reducing prey population helps to control beetles.

Rice black bugs

Description: The two most important and common species of black bugs are the Japanese rice black bug, *Scotinophara lurida* and Malasyan rice black bug, *Scotinophara coarctata* that attack rice plants. They are also known as rice pentatomid bugs. *Scotinophara lurida* occurs in Japan, Taiwan, China, Sri Lanka, and India while *Scotinophara coarctata* occurs in Taiwan, China, Indonesia, India, Malaysia, Thailand, Vietnam, Philippines, and Cambodia.

Damage: Both nymph and adults of rice black bug cause damage to plant by feeding the sap. They usually reside at the plant base. At the start of the day, they feed on upper parts of plants. But when sunlight intensity is high, they invade to undersides of stem and leaves and continue feeding there. At night, they become active and incessantly feed throughout the night.

Management

Agronomic Methods: Destroying the host plants usually b plowing the field is an important agronomic practice to control black bugs. Black bugs persist in the rice stubbles even after harvest, plowing is done to control the pests. Sunlight plays an important role in destroying black bugs. Weed removal allows more sunlight to arrive at the rice plants bases and kills the bugs.

Chemical Methods: Spraying the insecticides at the plant base is a most effective way to control black bugs. This practice is done because black bugs stay at the base of plants.

Biological Methods: Several natural enemies of the rice black bug are reported. These include; gryllid (*Metioche vittaticollis*), coccinellid (*Micraspis crocea*), carabid (*Agonum daimio),* nabid bug (*Stenonabis tagalicus*) and spiders (*Pardosa pseudoannulata*, *Oxyopes javanus*, *Tetragnatha virescens*, and *amaricus formosus).* Some fungi also act as a predator of black bugs e.g. *Paecilomyces lilacinus*, *Beauveria bassiana,* and *Metarhizium anisopliae*.

Colaspis

Description: Two species of colaspis; *Colaspis louisianae,* and *Colaspis brunnea,* are found throughout rice-growing areas. This pest usually causes damage to dry- seeded rice fields in a soybean-rice rotation.

Damage: Colaspis larvae start feeding on the plant roots when rice or any other crop is sown into a field. Fine root hair feeding by larvae may result in the death of the plant. The larvae will then pupate and develop into adults. Adults will not lay eggs on rice crop but will migrate to a nearby soybean field. Clumped larval distribution in the soil and patches of reduced plant stand loss are commonly found.

Management

Application of permanent flooding is the only agronomic practice that helps to minimize the pest attack. These pests do not live in water and they cannot survive continuous flooding. This is why they are not a serious problem in water-seeded rice.

Panicle Rice Mite

Description: The panicle rice mite (PRM), *Steneotarsonemus spinki*, is a pest of commercially produced rice in Asia, the Caribbean and Central America. This pest causes significant damage to rice crop, especially in the presence of bacterial panicle blight and sheath rot.

Damage: The panicle rice mite attack and damages the plants both directly by feeding on rice leaves, kernels, and stems and indirectly by acting as a vector of viral, fungal, and bacterial pathogens. Feeding destruction can cause the sterile grain syndrome, which is designated as a brownish, loose flag leaf sheath, damaged grain development with un-filled grains and brown spots, a twisted panicle neck, and erect panicles standing.

Management

All the control methods used for sheath rot and bacterial panicle blight will help to reduce the effect of this pest.

Chinch Bug

Description: Chinch bugs (*Blissus leucopterus leucopterus*) hibernate as adults in leaf litter, grass clumps, and other protected areas. They emerge in early to mid-spring for feeding and mating on grass hosts and on rye, wheat, barley, and oats grains.

Damage: Chinch bugs are sporadic and create more damage in drill-seeded rice because of the delayed application of permanent flood. Economic damage to rice usually occurs when different production practices and favorable weather conditions sanction chinch bugs to reside on wheat, corn and sorghum fields. When these crops are harvested at maturity, chinch bugs may migrate to young rice plants in nearby fields. Crop stand is reduced.

Management

Agronomic and chemical control methods are available. Agronomic control consists of flooding the fields, force the chinch bugs to migrate to rice foliage where they can be controlled with an insecticide. This practice necessitates that rice plants be large and levees be in place to resist a flood. Agronomic control is usually more costly than chemical control.

Rice Leaf Miner

Description: The rice leaf miner (*Hydrellia griseola*) is a sporadic problem in rice growing areas. Leaf miner attacks on the crop in the early spring and epidemic occur usually in the deep water, on the upper side of levees. Rice leaf miner is usually not a problem in 4 to 6 inches deep water.

Damage: The attack is more severe in continuously flooded rice fields with more than 6 inches deep water. Larvae make a tunnel between leaf layers. Leaf miner usually attacks and kills the leaves that are close to the water. Under heavy infestations, the entire plant may die and severely reduce the plant stand.

Management

Rice leafminer management involves agronomic control or insecticide application, perhaps both. Important agronomic practice is maintaining the water depth at 4-6 inches. Lowering of water level in rice fields helps to prevent injury.

Rice Seed Midge

Description: Adult rice seed midges (*Chironomus sp.*) always occur in flocks on levees, rice fields, and roadside ditches and in other water bodies.

Damage: Midge usually attacks water-seeded rice. Larvae injure rice by feeding on the seeds of very young seedlings, on germinating seed embryo and on the developing roots. In flooded fields, the potential of infestation increases. Midge infestation can be from insignificant (not economically important) to very severe.

Management

Most important agronomic method to control rice seed midge is field draining as this pest grows better in flooded fields. Draining the field will reduce the midge number. Sometimes, reseeding in highly infested fields is required. Methods that encourage rapid seedling growth and seed germination, such as avoiding cool weather planting and using pre-sprouted seed will help to escape vulnerable midge attack stage and reduce serious damage.

3. Rice diseases and their management

Seedling Blight

Description: Seedling blight, or damping off, is caused by several soil-borne and seed-borne fungi, including species of *Curvularia*, *Cochiobolus*, *Fusarium, Sarocladium*, *Sclerotium,* and *Rhizoctonia*. Brown thin and irregular spot on growing point or coleoptiles of rice appear. Fungi penetrate the undeveloped seedlings and injure them. Blighted seedlings that come out of the soil, dies out suddenly after surfacing.

Management

Suitable agronomic practices, such as sowing of early maturing varieties will decrease the effect of fungi. Draining the field and seed planting under optimum temperature, are the best control measures for this disease. Treating seed with seed-protectant fungicides (e.g. mefenoxam, metalaxyl, thiram, and mancozeb) effectively decreases the seedling blight and gives satisfactory stand.

Water Mold

Description: It is a fungal (*Achlya* sp. and *Pythium sp.*) disease. Water mold is noticed as a fungal ball strand around seeds on the surface of the soil. Seeds are rotted after draining seeding flood. This result in a greenish-brown or copper-brown spots on soil surfaces or above, about a dime size with central rotted seed. The color is due to green algae and bacteria, mixed with fungal hyphae.

Management

Draining and flushing the seeding helps prevent water mold. Pin-point flooding helps in reducing damage caused by water-mold. Sowing should not start till the mean daily temperature reaches 65 ^{o}C. Seed treatment with suggested fungicides helps to reduce the damage.

Crown Rot

Description: It is a minor disease of rice caused by *Erwinia sp*. This disease is observed rarely. During tillering, symptom first appears. The crown area is rotten and becomes soft that extends into lower internodes with a fetid odor. Tiller starts dying, one at a time. Roots die and turned black, with discolored streaks. A similar crown discoloration is caused by misapplication of a hormonal herbicide (e.g. 2, 4 –D.).

Management

No specific control practices are generally recommended.

Root rot

Description: Root rot is a fungal disease also called as feeder root necrosis, caused by *Phytium dissotocum*, *Pythium spinosum,* and other *Pythium sp.* This disease causes black discoloration of roots. As the root deterioration occurs, absorption of nutrient is reduced. The leaves become yellow and plants lack vigor.

Management

Proper fertilization reduces the disease symptoms however nutrient use is reduced. Control of rice root weevil can help to reduce root rots. Field draining enhances root growth but can create problems with nutrient use efficiency, blast, and weeds.

Root knot

Description: Root-knot is caused by nematode *Meloidogyne* sp., found only under dry-land conditions. Symptoms include swollen areas of the roots and formation of knots or galls. Plants are a yellow color, dwarf, and lack vigor.

Management

The disease is rare and yield losses are low. Prolonged flooding of field is recommended as nematode becomes inactive.

Rice blast

Description: A most important disease of rice worldwide and occupies the first position in terms of causing damage in intense rice cultivation areas. The causative agent of this disease is *Pyricularia oryzae*. This disease is also named as rotten-neck blast, node blast, leaf blast, collar blast and panicle blast depending on the portion of the plant affected. The disease disseminates through seeds, wild grasses and diseased plant debris lying in the field. Small spots appear on grains, leaves, nodes, and panicles and sometimes on leaf sheaths. The spots start as small, greyish, bluish or whitish, water-soaked dots. These spots rapidly multiply and their center turns grey. Black and brown spots also grow on glumes and inflorescence. In later stages, diseased heads blasted, and color becomes white. Grain development is affected and the panicles droop.

Management

If the disease is not widespread in an area, the blast can be controlled by burning and destroying the diseased plant debris and stubble, avoid over nitrogen fertilization as this increases the plant's receptiveness to the disease. Early planting, use of healthy seed, dusting the seed with the seed dressing organic mercurial fungicides, spray the crop with organo-mercurial, cultivation of resistant varieties, avoid excessive application of irrigation water and utilize good water management to ensure that plants do not experience water stress. Also avoid and control the excessive population of plants, grasses, and weeds. The disease might be successfully controlled by systemic fungicides when they are available. In a study in Nepal, Tricyclazole 22% + Hexaconazole 3% fungicide proved effective in controlling rice blast when applied at weekly intervals starting from the booting stage. Silicon application to rice crops showed a positive effect in combating rice blast disease.

Brown spot

Description: Brown spot is caused by the fungus, *Cochiobolus miyabeanus* and it is one of the most prevailing rice diseases around the world. It is also known as Helmintho-sporium leaf spot. This is another leaf spot disease that frequently occurs. The main cause of this disease is poor soil conditions. Round, brown lesions having a yellow halo appeared on leaves. Size of lesions fluctuates from the size of a pin-head to rice grain. As lesion grows, they remained round with necrotic grey center and reddish-brown to dark brown margin. These brown spots cause severe damage and ultimately leaf dies.

Management

Sowing of good quality seed and good land preparation helps to reduce the disease incidence. Destruction of stubble, sanitation and crop rotation are mostly used agronomic practices. Chemical seed treatments like appropriate fungicides are effective in reducing the prevalence of the disease. Copper fungicides spray in the right amount and at right time will reduce the damage. Disease resistant varieties are also grown to reduce chances of disease occurrence. Plants must be provided with correct nutrients, at the proper time and in the proper dose. Avoiding water stress in field reduces the propagation of disease.

Narrow brown leaf spot

Description: The causative agent of this disease is called *Cercospora janseana*. This disease differs in rigorousness from year to year and becomes more rigorous as rice plants mature. The disease occurs in major rice-growing regions in Africa, North, Central and South America, tropical Asia and Australia. Long narrow reddish-brown or brown lesions appear that are parallel with leaf veins. These lesions usually constrained between veins. The lesion may expand across veins that can kill leaves. The lesion can also appear on the leaf sheath.

Management

Treating seeds with appropriate fungicides or sometimes with hot water, before planting, can diminish the prevalence of the disease. However, chemical application is not currently suggested for this disease. Use of resistant varieties is also recommended.

Leaf smut

Description: Leaf smut is a distributed widely and is caused by a fungus, *Entyloma oryzae*. Lesions appeared on leaf blade that is small, black, and linear and may have a light brown or dark gold halo. Leaf tip dries up and becomes gray as plants reach maturity. Lesions are usually present on the upper sheath.

Management

Foliar fungicides (e.g. trifloxystrobin and propiconazole) are usually applied. Leaf smut attacks in the late rice growing season and causes minor losses.

Leaf Scald

Description: This disease is caused by a pathogen, *Gerlachia oryzae* and it is severe in West Africa and Latin America.

Damage may vary depending on growth stage, plant density, and cultivar. Leaves gave the scalded appearance. The lesion is consisting of a different zone of alternating wide bands of grey color with light tan and dark brown narrow bands from leaf tips or edges. Lesions often are tan marks with golden or yellow borders at leaf edges. Light brown halos appear as the lesions mature. Leaf tips and margins are translucent.

Management

Application of only recommended amount of nitrogen fertilizer in split dose helps to reduce the disease susceptibility. Growing of resistant rice varieties is an important preventive measure. Foliar fungicides (trifloxystrobin and propiconazole) application is recommended. But these fungicides are not applied after the rice seedhead emergence. Treat the seeds with suitable fungicide (e.g. iprodine and propiconazole).

Bacterial leaf blight

Description: Bacterial leaf blight is caused by a bacterium called *Xanthomonas campestris*. This is a serious rice disease during the rainy season. Elongated lesions appear near the tips of leaves or edges that are several inches long and water soaked in appearance. Leaf tips or edges turn firstly into white, then yellow and finally gave grey color due to fungi (Saprophytic fungi). Leaf edges become wavy. Death of leaf and plant occur, and grains remain empty.

Management

Bacterial blight can be managed effectively by plowing the straw and stubble into the soil after crop harvest. The burning of diseased stubble helps to reduce the chances of disease transfer. Appropriate land preparation and sowing good quality seed reduce the chances of disease manifestation. Resistance varieties are also used to avoid this disease. Excessive nitrogen application in the field increases the chances of disease manifestation. To avoid this situation, nitrogen application is done in split doses.

Stack burn

Description: It is also called Alternaria leaf spot, caused by a fungus, *Alternaria padwickii*. It is common in rice growing areas of the world. White or pale tan, round or oval spot appear with marrow reddish-brown margin. Two adjacent spots merge and form a double oval spot. In the center of the spot, a small black fruiting structure appears.

Management

Seed treatment with fungicides will decrease the seedling blight and in turn, will reduce the chances of leaf infections by reducing the number of available spores.

White leaf streak

Description: White leaf streak is caused by a fungal pathogen, *Mycovellosiella oryzae*. It is very similar to narrow brown leaf spot except that the spots are a little broad and have white centers. White leaf streak is widespread in West Africa and tropical Asia. Lesions are long, narrow with brown border and white center appears on leaves. Pathogen lives on infected straw and seed. The pathogen may go through the plant from cuts and bacterial exudates can blow out in irrigation water. High temperatures and humidity are favorable conditions for disease emergence.

Management

Planting of treated seed with fungicides can reduce the disease outburst. Use of resistant rice varieties may suppress the attack. Control of field moisture content also is used as a remedy.

White Tip

Description: A nematode; *Aphelenchoides besseyi* caused this disease. Leaf tips become white with yellow strips between diseased and healthy tissue and leaf edges become white sometimes.

Management

Use of resistant varieties is recommended but resistant varieties are not proved effective and still, a loss in yield occurs. Storage seed fumigation can reduce the population of the nematode.

Sheath spot

Description: This is a fungal disease caused by *Rhizoctonia oryzae*. The disease looks like sheath blight but is less severe.

The lesions appear on leaf blades or on sheaths midway up the tiller. Lesions are oval, cream color or white in the center and broad dark reddish-brown margin. The pathogen attacks and deteriorates the culm below the sheath lesion on susceptible varieties. The weakened culm breaks over where it was infected.

Management

Fungicides used to control sheath blight are also effective in reducing the sheath spot. Foliar application of recommended fungicides is done to control sheath spot (e.g. azoxystrobin, propiconazole)

Sheath blight

Description: The disease is caused by a fungus, *Rhizoctonia solani*, a pathogen of both soybeans and rice. This disease occurs in all rice growing areas of the world and it occupies the second place after rice blast in term of causing damage. It causes severe damage in areas where rice is intensively cultivated with excessive nitrogen fertilizer application and rapidly spread through irrigation. Alternating narrow bands of reddish-brown or brown with wide bands of greenish grey, white to tan, appears at the base of leaf blade. Under moist conditions, spreading of lesions from infection points of leaf sheath may occur. Fungal survival structure formed on the leaf surface is called sclerotia. Bird nest area of dead tissue may form under favorable conditions.

Management

Foliar application of appropriate fungicides (e.g. azoxystrobin, propiconazole, trifloxystrobin and propiconazole, iprodine) is carried out to control sheath blight. Higher rates of these fungicides are recommended when the attack is severe. Normally two applications, one at the time of early internodes elongation and second at 10-14 days after panicle emergence, are required to control this disease. Excessive nitrogen application increases the susceptibility to disease, avoiding the excessive application of nitrogen fertilizer to plants decrease the susceptibility to disease. Seed treatment with trifloxystrobin or azoxystrobin or carboxin + thiram is also used to control sheath blight.

Sheath blotch

Description: This fungal *(Pyrenochaeta oryzae*) disease distresses the leaf sheaths, especially the flag leaf sheath near the collar. The lesion starts usually at the sheath edge and expands to form a rhombus blotch that increases in size and it eventually covers the whole sheath. The lesion is generally restricted and turns out to be in a zonate form. This discriminates it from sheath rot.

Management

This disease is normally not severe or widespread enough to warrant control measures.

Sheath rot

Description: *Sarocladium oryzae* is the causative agent of this disease. Symptoms appear during the booting stage on the leaf sheath in which young panicles are enclosed. Irregular oval-shaped spots with brown centers and a diffuse reddish-brown margin appear. This disease causes partial emergence of panicle, grain discoloration and white powdery growth inside of the sheath.

Management

Usually, the fungicidal spray is recommended but fungicides showed little effect on these pathogens. Fungicidal sprays help to lessen the damage in a disease management process, but it was observed that many bacteria also sow similar symptoms on rice plant.

Crown sheath rot

Description: A fungus, *Gaeumannomyces graminis* var. *graminis*, is the causative agent of crown sheath rot. It is also called Arkansas foot rot, brown sheath rot, and black sheath rot. Mycelial mats of reddish-brown color are formed in the inner side of infested sheaths. Dark perithecia are formed on the sheath. This disease can be easily muddled with stem rot. Under severe conditions, lodging occurs.

Management

As this fungus survives on plant residues and is wind-borne in moist conditions, management practices do not work for this disease. However, foliar application of appropriate fungicides (e.g. azoxystrobin) is somewhat effective in controlling this epidemic.

Stem Rot

Description: Fungus (*Sclerotium oryzae*) subsists even after harvest in crop residues and fruiting bodies and then they are brought to the soil surface due to flooding and they infect leaf sheaths. Infested soil helps the organism for its survival. Symptoms generally start to appear at tillering or initial stage jointing growth. Black angular lesions appear on leaf sheath. These lesions expand and start to blight leaf sheaths from inside and then culm starts to rot. Culms have black or dark brown streaks. At maturity, culms may collapse and black round sclerotia form in dead tissues. This infection can cause unfilled panicles, plants lodging and death of tillers.

Management

Avoid excessive nitrogen fertilizer application. Try to apply nitrogen in split doses. In potassium deficient soils, potassium application will decrease the disease severity. An important agronomic practice is burying of crop residues in the soil after harvest. Growing resistant rice varieties is also helpful to reduce disease susceptibility. Stem rot does not cause damage to early maturing varieties. Fungicides (trifloxystrobin and propiconazole) are applied as a foliar spray. Higher rates of fungicides are applied in case of disease severity. These fungicides are not applied after seedhead emergence. Destroy the sclerotia by tillage, by burning the stubbles and by crop rotation. Use of antagonistic organisms also helps to reduce the damage.

Tungro disease

Description: A virus, Rice tungro bacilliform virus (RTBV), is the causative agent of tungro disease. It is the severely destructive rice virus in South Asia and Southeast Asia. Leafhoppers spread this virus. Plants are stunted and change color from green to yellow then orange. Numbers of tillers are reduced, and brown colored lesions appear on the leaf. Leaves are striped, mottled or show inter-venial necrosis.

Management

To control the tungro virus, many rice resistant varieties have been used and controlled the disease effectively. But intensive farming has collapsed the impact in some potent leafhopper strain. In Indonesia, this virus is controlled effectively by obtaining synchronous plant development through scheduling the planting time and practicing crop rotation with resistant varieties. To reduce the chances of virus infection, rice seedlings should be cultured far away from areas where rice virus diseases occur every year.

Grassy stunt

Description: It is a viral disease (Rice grassy stunt virus (RGSV)) and transmitted by leafhoppers. It is pervasive in rice cultivated areas of South Asia, Southeast Asia, Japan, China, and Taiwan.

This virus causes narrow yellow or pale green leaves. Dark brown irregular blotches appeared on leaves. On newly unfolded leaves, the striped or mottled pattern appears. Plant growth is stunted and few or no panicles produced.

Management

Suitable insecticides spray can reduce infestation by decreasing the vector populations. A spray of fenthinon or phosphamidon or monocrotophos helps to control the damage. Many rice resistant varieties to the leafhopper vectors have developed but leafhoppers have overcome the resistance in some countries due to a favorable environment for virus vectors. To reduce the chances of virus infection, rice seedlings should be cultured far away from areas where rice virus diseases occur every year.

Bacterial panicle blight

Description: It is caused by bacteria, *Burkholderia gladioli,* and *Burkholderia glumae.* Lesions are formed on flag leaf sheath that extends to leaf collar. The lesion is discretely having a necrotic and gray color in the center with reddish-brown border. The lesion length may reach several inches. The panicle may have unfilled or aborted florets.

Management

Avoiding excessive nitrogen application helps to reduce the damage caused by this disease. Early planting can reduce disease by escaping the favorable period of disease attack. Some rice varieties are partially resistant while most are susceptible to disease. An important control measure is to not plant infected seed from previous year seriously affected rice fields. To test seed lots, the procedure has been developed but they are not widely available. No pesticides are currently recommended to control this disease.

Downy mildew

Description: Causative agent of downy mildew is a fungus called *Sclerophthora macrospora*. Due to mildew, panicles do not come out of the leaf sheath and become irregular and twisted. Their size remains small with no seeds.

Management

This disease is extremely rare. No control measures are recommended.

Grain Spotting or Pecky Rice

Description: The fungus infects the developing grain and causes discoloration of the kernels or hulls. Rice stink bug also cause kernel discoloration. Kernel discoloration caused by fungal infections or insect damage is called pecky rice. Single or several florets/panicles appear with reddish-brown spots. Grain discolored due to fungal growth and stink bugs feedings. Similar symptoms also appeared by high winds at early heading stage.

Management

Management practices used to control stink bugs reduces the extent of this disease

Kernel smut

Description: It is a fungal disease, caused by *Neovossia barclayana.* It is distributed in all rice growing areas. Symptoms appeared shortly before maturity. A black smut spores mass replaces a part or all of the grain endosperm. In an ear, few grains are affected partially or wholly. If severe infestation not occurs, seeds germinate but seedling growth is stunted.

Management

Use of healthy seed, sowing of resistant and early maturing varieties, collection and burning of diseased ear heads and avoid threshing and winnowing of the diseased crop in the field are useful agronomic practices. Nitrogen application in split doses is recommended. At booting stage, fungicide applications can be effective for controlling this disease. Seed treatment with suitable chemicals is used in many rice growing areas.

False smut

Description: The causative agent of this disease is *Ustilaginoidea Virens*. It is usually a minor disease but it causes an epidemic sometimes in many rice cultivating areas. Large orange fungal fruiting structure appears on rice grains panicle. The orange membrane of this orange fruiting structure bursts and a mass of spores is exposed. These spores turn dark green to black with time and grain is then replaced by fungal structure sclerotia.

Management

Seed treatment is recommended. Seeds are treated with hot water at 52 ^{o}C for 10 min. Field sanitation helps a lot in reducing the chances of disease occurrence. Keep the rice field and its surrounding clean. Roughing of infected plants from the field is suggested in some rice growing areas. Use of resistant varieties is helpful in some areas. Maintain moisture content in the field by alternate wetting and drying process. As increased nitrogen application increases the incidence of the disease, balanced amount of fertilizer should be applied. Recommended fungicides application at booting can hinder the disease.

Black Kernel

Description: The fungus, *Curvularia lunata,* causes black kernel disease. Severe discoloration of grains occur, and kernels appear black after milling. In case of severe infection, the fungus can cause weakened seedlings or seedling blights.

Management

Use of the right amount of fertilizer, maintaining good soil drainage, hatch layer management, and soil compaction reduction are effective agronomic practices for the reduction of black kernel disease. Proper insect (stink bug), nematode and fungus control practices help to reduce the damage. Seed treating for managing other diseases will diminish the seedling damage. No other management measures are necessary.

Bakanae Disease

Description: The causative agent of Bakanae disease is *Fusarium moniliforme*, also called white stalk disease and distributed in all rice growing areas. Contaminated seedlings are chlorotic, thin and sometimes die when they are transplanted. In the field, leaves of affected plants die out in short time and plants have only a few tillers. Live plants have unfilled panicles. Many affected plants sometimes become elongated. Abnormal elongation of these infested plants in the field and in seedbed is a common disease symptom.

Management

Cultivation of resistant varieties and seed treatment with effective chemicals helps to reduce the damage caused by this disease. Do not plant the infected seed that comes from an infected field. Stubble destruction of the previous crop either by plowing or uprooting of infected plants before sowing. Biological control is also available for the control of *Gibberella sp.* Biological product namely Tri-Cure (*Trichoderma harzianum* isolate MIT04), is used mainly in Africa.

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Weed Management in Rice

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Published Date: January 18, 2020

1. Introduction

Rice *(Oryza sativa)* is being used as a staple food by more than 50% of worlds' population which makes it highly significant in terms of plant production or food security [1]. The major producer and consumer of rice in Asia, contributing more than 90% to the global rice production and consumption. On global scale, the requirement of rice is projected to rise up by 25% to fulfil the demand of growing population up to 2025 [2]. In Pakistan, rice is considered as second most vital crop for earning foreign exchange after cotton [3]. Rice provides 27% of dietary energy and 20% of the protein diet in developing countries [4].

However, weeds are known as one of the significant issues in rice, which results in yield losses of 50-60% in direct-seeded while 70-80% in transplanted lowland rice. Therefore, weed management in rice fields is highly complicated and challenging. This chapter highlights the significance and implementation of different weed management approaches including mulching, tillage, manual weeding, herbicides, allelopathy, crop rotation, intercropping and other preventive measures, and also describes that how the judicious use of these weed control methods at optimum level could benefit the farmers along with environmental sustainability.

Weeds, a Dilemma in Rice

Several essential factors limiting rice production include weeds, insect pests, and diseases. A serious reduction in paddy yield is usually accredited to severe weed infestation in the fields [5]. Weeds are included among the big hurdles for restricting yield and productivity of rice [6-8]. "One year's seeding means seven years' weeding" is a well-known quote to describe the danger of letting weeds to produce seeds [9]. It was revealed that the weeds which are not controlled reduce about 80% production in direct seeded rice, which is much higher than transplanted rice seeded system [10,11]. Recently, the yield losses of 14-100% and 7-80% have been reported in the case of direct-seeded and transplanted rice, respectively [12]. Meanwhile, the reduction in crop yield due to weeds infestation may depend on location, the predominance of weed flora, or duration of weed attack [13]. The deleterious effects of such harmful plants on crop productivity may also be accompanied by their negative impacts on native beneficial microbial species [14].

Rice Cultivation Systems and Weed Infestation

It is essential to mention the adopted rice production systems in different countries for describing the occurrence and infestation level of weeds [15]. Several rice cultivation systems have been described, including transplanted and direct seeded rice being the main rice plant management methods [10]. Transplanting rice cultivation is the most conventional in Asian countries [16]. In the case of transplanted rice, the nursery is grown in seedbeds and then transplanted in the puddled or flooded fields manually or mechanically. The puddling is performed to suppress weeds and to support beneficial living organisms in the water. However, this approach is expensive and laborious as a huge amount of water is required. The direct seeded rice is further subdivided into wet-seeded rice, flooded rice, and dry direct-seeded rice. These different approaches are being used in different countries [15]. The fields facing the problems of weedy rice can be benefited by line sowing method as it is challenging to assess weedy rice and cultivated rice during early stages if the broadcast method is adopted [16]. The line sowing facilitates the identification and eradication of weedy rice plants between lines or rows during initial growth stages. Additionally, the mechanical and manual weeding is also easy to perform in case of row or line seeded rice as compared to broadcasting [17].

Weed Flora in Rice Crop

In paddy fields, above1800 plant species have been found during the last century [18]. However, fifty species have been known to be the most dominant in diverse environments. The rice weed flora varies with the method of rice cultivation, cultural practices, location of the field, and associated environment [15]. A classical weed atlas, "*C. rotundus*" is known as "The world's worst weeds" [19]. The ranking of weeds is done on the basis of frequency where *Echinochloa* species and weedy rice species dominate worldwide. After that, *Cyperus* species and other representatives of the Cyperaceae family are most frequent. During the end of the 20th century, *Leptochloa* species became major issue in rice fields. In some Asian countries including Vietnam or Malaysia, *L. chinensis* is known to be among the most common grass species found in rice [20] which was first discovered in Italy during the 21st century [21]. In South Asia, major rice weeds include: *Cyperus iria, Cyperus rotundus, Cyperus difformis, Cynodon dactylon, Dactyloctenium aegytium, Echinochloa crus-galli, Echinochloa colona, Eleusine indica, Fimbristylis miliacea, Ischaemum rugosum, Leptochloa chinensis* and red rice *(Oryza sativa)* [12].

Rice-Weed Competition

The losses in crop production due to weeds mostly vary depending on the intensity and types of weed species. A linear correlation has been observed between the level of weed attack and yield reduction. However, above a specific weed population yield losses become stable due to the competition of weed plants with each other. The most severe rice competitors include grassy weeds, followed by broad-leaved weeds and sedges [22,23]. The maximum yield loss by weeds occurs due to their competition with rice crop for nutrients, space, soil moisture, and light [24,25]. The cultivation of direct seeded rice along with jungle rice or *Ludwigia* species resulted in the significant reduction of growth, development, and productivity of rice plant due to shoot competition as compared to the root competition [26]. The productivity of wet seeded rice was highly affected because of severe weed competition with rice plant until 45 days after sowing [27,28]. It was therefore found essential to maintain weed-free period till 45 days after sowing for improving the production of rice crop. The critical time duration for the rice-weed competition was usually observed till 40 days after transplanting[29] however; the rainfed lowland rice showed critical period between 30-60 days after sowing to limit the reduction in yield [30].

Weed Control Strategies

Weed Prevention

Weed prevention is the most common method of weed control, which inhibits the initiation and extent of weeds in the crop area [31]. It generally involves all the practices to assess the access of weed seeds and their development in a specific field. One of the most critical tactic to prevent annual production of already present weed seeds, rhizomes, or tubers is farm hygiene, which includes all measures preventing the weeds infestation. For example, all the physical, chemical, or mechanical practices restricting weeds development are a part of farm hygiene. It also involves quarantine laws preventing weeds from getting access to a new habitat. Meanwhile, the non-cropped areas associated with fields such as irrigation/drainage channels, fence lines, ditches, and bunds should not be neglected [32]. On the other hand, contamination of crop seeds with weed seeds must be prevented either by growing a weed-free rice crop or by cleaning the rice seeds before storage or at least at sowing time. If a clean field free of weed infestation is being planted with rice seeds which are contaminated with weedy rice at 2 seeds kg^{-1}, could cause an infestation of weed rice seeds at 10 kg ha^{-1} after three years of the plantation [33]. The weeds mimicking rice plants need special care for their eradication. Therefore, the rice nursery must be free from weed seedlings. It is suggested to use clean and certified seeds from a reliable source to minimize the spread of weeds to new fields [16]. In addition, maintenance of clean fields, irrigation channels, border, and farm equipment are included in weed prevention [34].

a) Physical/Mechanical Methods

Mechanical or physical control includes any practice that suppresses or kills weeds through physical disturbances. These methods include digging, pulling, plowing, mowing, and disking. Various hand tools were used to destroy and kill weeds. Jethro Tull created the first animal-drawn weeding tool, the horse hoe, in the 18th century. The rotary rice weeder and conoweeder can be used to control weeds in rice. Bushening and halod are used to control weeds in some regions of India [35]. A rotary weeder can be employed four times after 15 days of transplantation at an interval of 10 days to manage weeds in the field. In this way, labor can be saved by minimizing hand weeding. It also aerates the root zones and soil and improves root activity, which ultimately results in high yields [36]. In dry-seeded rice, inter-cultivation repeated twice or thrice by-passing small blade or hoe harrow between 20 and 45 days after sowing can efficiently control weeds. Two weedings are recommended in rain-fed rice where first weeding is carried out between 15-21 days after germination and second weeding may be done after first weeding between 30-45 days. It was reported that the conoweeder alone contributes to 17.4% increase in grain yield [37].

Manual Weed Eradication

Hand weeding is a conventional method for controlling weeds which is preferably used by smallholders [38,39]. In past, the agriculture as a major occupation and high availability along with cheap cost of labors had made the hand weeding as comparable to the management of weeds. Hand weeding is tricky and time consuming as one weeding takes almost 25-35 days ha^{-1} depending on the method of plant cultivation and type of land. Weed plants which can easily be pulled by hands are pushed out of the soil and wasted [40] however, smaller weeds can also be removed by hands with difficulty. Harrowing is effective in direct-seeded rice if plants are longer than weeds [41]. Any delay in weeding will enable the weeds to absorb nutrients thus early hand weeding is suggested. Hand hoeing is practiced as a faster and reliable method particularly where line/row seeded rice is grown. For resolving long-lasting issues associated with weeds, amalgamation of weed control approaches is very essential therefore, hoeing and hand weeding are also being used in modern agriculture. After the application of herbicides, the leftover weed plants should be uprooted before seed setting. Such weed plants could survive due to resistance or improper spraying technology. The escaped weeds must not be allowed to produce seeds. In order to limit their competition, the germinated weeds should be pulled two or three times during the crop growth period [42]. It was revealed that the hand weeding, if repeated twice results in reduced weed population as compared to chemical application like herbicides or untreated plants [43]. Continuous hand weeding for two times also showed reduction in weed dry biomass and improvement in mean straw or grain yield of crop [42]. In direct-seeded rice, manual weeding should be repeated three to five times for the complete eradication of weeds in a field [17].

Tillage Practices

The phenomenon of least soil disturbance is called tillage. The soil disturbance process significantly influences the profile, size and number of weed seed bank species [44]. Precision land levelling or using a laser leveller to create regular, sloping fields enables appropriate water management which has a profound impact on weed proliferation and the bio-efficacy of herbicides. A well-levelled field is important for best weed control: fields with low and high areas contain changing water depths, which are too deep for the rice in the low spots and too shallow for weed control in the high spots. The development of levelled fields by using precision land levelling or a laser leveller enables proper water management, along with a profound influence on the growth of weeds and herbicides efficiency. A well-levelled field is imperative for substantial weed control. The unlevelled fields contain variations in distances of water, too deep for the rice in low spots while too shallow for weed control at high spots [16].

Changing tillage practices alters the depth of weed seed in soil [45] which could influence the excess of weedy species [46] and efficiency of control methods in the field [47]. The exploitation of tillage system has a major influence on perennial weeds as compared to annual weeds. The conservation agriculture may be responsible to increase the growth and development of seeds of newly-shed weed which can be seen on or near the surface of soil. The utilization of zero tillage is arising as a significant method in the procedure of integrated weed control. The phenomenon of zero tillage helps to reduce weed density by eliminating the tillage [48]. It also offers efficient weed management in combination with the application of herbicides at reduced levels [49]. Under zero tillage, it is hard to manage perennial weeds due to the production of vegetative or reproductive parts such as tubers, stolons and rhizomes. If it is essential to employ minimum or zero-tillage practices, the other appropriate weed control methods should be used for successful eradication of weeds.

b) Cultural Practices

Cultural practices have a significant effect in analysing the competition of plant and weeds for above and below ground resources and thus effects weed control [50].

Rice Production Methods

The rice production methods affect the composition of species and the severity of weed infestation in the crop. Different rice production methods have been described, including transplanted or direct seeded rice being the main rice cultivation methods [10]. The uncontrolled weeds result in the reduction of grain production by 63, 71, and 76% under transplanted, wet-seeded, and dry-seeded rice, respectively [51]. The mean reduction in production due to weed-rice competition varies from 40 to 60%, which could rise up to 94-96% if uncontrolled [28]. For good weed control, transplanting method is primarily employed as puddling results in anaerobic conditions for destroying weed plants. In recent years, many South-East Asian countries have shown a shift from transplanted to direct-seeded rice, which is being preferred due to a shortage of water and deteriorated soil structure caused by puddling. Since the 1950s, the direct-seeding was practiced as the principal method of rice production. Farmers follow different direct-seeding methods depending on the resource levels such as land development, weather conditions, and infrastructure [52]. Direct-seeded rice gain several benefits over transplanting system such as minimized labor requirements, early crop maturity, efficient water usage, less drudgery, increased tolerance of water deficit, and lesser release of methane. However, weed proliferation is the main issue faced by direct-seeded rice. Therefore, the integration of several rice management practices has more significance in the case of direct-seeding as compared to transplanting. This is due to diverse weed flora which could not be controlled by a single control method. In direct seeding system, the problem of weedy rice can be greatly avoided by shifting to the manual transplantation of seedlings or by the broadcast method in flooded fields. The drudgery involved in manual transplanting can be reduced by the use of mechanical transplanters, which are equally effective for transplanting in zero-tilled or puddled fields [53].

Puddling or Submerged Conditions

Puddling or submerged conditions are helpful in reducing weed germination. In lowland rice, puddling or flooding is considered as an excellent weed management method. The transplanting system showed minimum weed density (63.5 m^{-2}) and dry weight (24.1 gm^{-2}) which happened by the sowing of sprouted seeds under puddled conditions [54]. The ploughing in summer season and cultivation of rice crops during post rainy days are helpful for reducing weed infestation. In direct-seeded lowland rice, soil compaction is a very effective tool for minimizing weed pressure by decreasing bulk density up to 1.8 g cm^{-3}. For wet-seeded rice production, well-drained fields along with appropriate water management systems are essential requirements for reduction of herbicide phytotoxicity on non-target flora. The variations in tillage practices for the cultivation of rice have caused major shifts in weed-flora during summers. Several new weeds such as *Cyperusdifformis, Fimbristylistenera,* and *Ischaemumrugosum* have also become inhabitants of rice fields. Furthermore, long-term cultivation of rice under flooded conditions have transformed the soil environment in favor of aquatic and semi-aquatic weeds like *Caesuliaaxillaris, Sagittariaguyanensis, Ammanniabaccifera, Ipomoea aquatic, Leptochloachinensis, Sphenocleazeylanica,* and *Oxalis* species. The variation from paddies (anaerobic) to aerobic conditions have changed the rice ecology, causing an abrupt shift in weed flora [10,55].

Weeds cause 12-46% reduction in water use efficiency of rice [56]. Although, productivity of water as evapotranspiration is low, huge amount of water is used for the preparation of land (paddies) in transplanted/puddled rice systems. Most of the weeds flora is unable to germinate under flooded/puddled conditions thus making flooding an efficient tool for weeds control. In addition to preparing slurry for sowing of seedling and forming a hard pan, puddling destroys weeds in lower layers of puddled soils where they are decomposed by the anaerobic process by forming ammonium compounds, which are further utilized by the crop. However, the deep ponding of water should not be done during early growth stages as it could destroy developing seedlings of rice crop. After the establishment of transplanted seedlings (about a week after transplanting), the field is completely flooded to a depth of 7.5-10 cm to avoid the growth of weeds. The depth of water can be slowly increased up to 15 cm as the rice plants develop.

The increase in ponding period from 3-9 days after transplanting improves the efficiency of rice herbicides. The exploitation of clean and good quality seeds and water seeding can reduce the problem of red/weedy rice. The practice of flooding rice fields is commonly used as a basic cultural control method to destroy weeds in transplanted rice under puddled conditions. However, its impact is often species-specific [57]. Thus, the flooding can be efficiently used to suppress the emergence of weedy rice, however, some weed species like *Eleusine indica* and *Leptochloa chinensis* may be flourished due to alternate drying and wetting in puddled and direct-seeded rice. The emergence of weed seeds is usually dependent on moisture content in the plough layer (0-15 cm).

Differential competition has been observed under water stress. For example, grass weeds under stressed conditions show serious competition with rice crops. Because of canal irrigation systems, weeds like *Ageratum conyzoides* have become residents of rice fields, water channels, and bunds of the fields. The semi-aquatic conditions developed due to flooded conditions have encouraged the weeds belonging to marshy places, e.g., *Eleocharis acicularis, Hydrilla verticillata, Scirpus roylei,* and *Najas argute*. In direct-seeding systems, there is a direct need to grow rice cultivars which are capable of germinating in flooded or anaerobic conditions to avoid the attack of weedy/red rice. In regions where water is plentiful, the introduction of such varieties with suitable flooding time and depth can significantly help to diminish weedy rice. This weed control method was highly useful in decreasing chemical load [56].

Intercropping

Simultaneous cultivation of two or more crops on the same field is known as intercropping, which results in the production of high yield as compared to a monoculture of any participating crop [58]. The establishment of intercrops as compared to simple cropping is determined by a succession of agronomic practices including final plant density, date of the plantation, provision of resources and intercropping models as interaction among species could be influenced by them [59]. The suppression of weeds by competition varies significantly in case of intercropping as compared to monoculture. The pattern of availability of resources exceptionally light to weeds can be changed by enhancing the complexation of cropping system by interplanting plant species of varied growth forms, physiologies, and phenologies [60].

Cover Crops/Mulching

Cover crops or mulches can diminish weed problems by adopting preventing measures for the germination of weed seed or by suppressing the development of growing weed seedlings. If tillage practices are followed, the perennial weeds can be suppressed by growing cover crops. At harvesting, an efficient smother crop can leave the field free of weed plants. Mulches, either organic or inorganic in nature, are composed of living ground cover, loose soil particles laid on the ground or layers of natural/artificial materials. The selection of cover crop depends on the crop growth duration, nitrogen fixation, and its rooting behavior. Azolla, being a green manure crop like sannhemp and sesbania is being used in rice fields for this purpose. One of the most important considerations involved in the selection of cover crop is that the selected crop should not be a competitor with the rice crop for main resources [16]. It was observed that the use of sesbania as a cover crop with azimsulfuron (30 g ha^{-1}) and fb bispyribac Na (25 g ha^{-1}) should be grown for reducing weed growth and improve the yield of rice [61].

Crop Rotation

In traditional farming system, a significant part of weed control was the rotation of diverse crops having variable life cycles. The crop rotation is defined as a practice of growing different types of crops in succession on the same land. As specific weeds are linked to a specific crop, the weedy plants increase rapidly due to continuous cultivation of a favorable crop in the same field. These weed plants, if allowed to survive for a long duration, are tough to control [62]. In conservation agriculture, crop rotation is a successful method to overcome the weed growth. The rotation of crops is considered to be effective for controlling crop-specific weeds. The dynamics of long-lasting weed populations can be disturbed by the sequencing and selection of suitable crops. Different management practices are related to different crops, and rotation of such crops is found to disrupt the life cycle of several weeds, including weedy rice [17,57]. The cultivation of non-rice crop causes the exploitation of different cultural practices along with the use of variable and effective herbicides. In rice monoculture systems, one rice crop (dry season crop) is rotated with an upland crop. However, weed infestation can be overcome by "mixed cropping" of rice and Azolla or rice and some green manure. The growth and germination of weedy rice can also be controlled by the addition of some short duration crop such as green/black gram between two crops of rice. The inclusion of sesbania as a green manure or summer cowpea as a fodder crop after harvesting the wheat crop during rice-wheat rotation can provide proper weed management, and also reduces the use of herbicides [63]. In Italy, about 90% reduction in weedy rice was achieved by the rotation of soybean for one year. Few crops, including maize, pearl millet, and sorghum, also suppress the intensity of weeds through allelopathic interruptions. The residual effect of pearl millet is useful for the suppression of weeds in the following crop. Therefore, it can be used in rotation as a fodder crop. However, the adoption of this system depends on the yield stability and market prices of rotation crops. Thus, weeds demography and population density are severely affected by crop rotation [64].

Planting Density

Good quality seeds and seedlings along with plant protection measures should be adopted to maintain maximum population of the crop. A crop ensures more repressing influence on weeds by maintaining high seed rates and narrow row spacing in an agriculture ecosystem as lesser space is vacant for weeds to grow [65,66]. Weeds population can be reduced by keeping up the predominant position of the crop over weeds and changing the canopy structure with the help of increasing crop density for every unit region [67]. However, row management and plant population also affect weed population by cutting light availability at the ground level. Crops become more competitive against weeds as they put pressure on space availability for weeds growth by growing higher plant population [68.69]. Thus, the development of rapid canopy cover with narrow row spacing improves the competitiveness of crops with weeds. With cultural management strategies like decreased plant row space, the ability of rice crop to struggle against weeds for light could be increased [26,70]. Depending upon weeds biology and rice cultivars existing in the field, high seed rates could partly control weed. Thus competition can be diverted to promote plant growth [71]. It is noted that increasing the plant density from 33-44 plants m^{-2} can reduce dry matter accumulation by weeds in a transplanted rice crop. The growth of weed is higher in a thinly populated crop compared to a thickly populated crop. By smothering the weeds and compensating the damage caused by rats and birds or for poor crop establishment, high seed rates are used to manage weeds in direct seeded rice. In organic production and low-input systems or where herbicides resistant weeds have been developed, higher plant population is of great importance. High seed rate help to minimize the weed problem in affected areas of rice [17]. The density of sedges is also affected by seed rate; however, the density of *E. canola* is not influenced by the rate of seeds in direct seeded rice. Sedge density was decreased by 35% when the application of seed was improved from 15-240 kg ha^{-1} [72]. Although, weed density decreases linearly with increasing seed rates; however, beyond the optimum level, the high seed rate has no effect on weed biomass. An increase in seed rate from 15-125 kg ha^{-1} led to rapid canopy closure, thus reducing weed competition and significantly decreasing weed biomass [73]. Narrower row spacing allows less light penetration through the rice crop leaves, and thus smothering weeds and preventing them from competing effectively with the crop in early crop canopy cover [74]. Higher grain yield and productive tillers are attained by narrowing row spacing [75]. In transplanted rice, seedlings are transplanted randomly by the farmers/laborers. However, changing the plant geometry could help farmers to control weeds more efficiently. Thereby, enabling the rice plant to comparison with weeds more efficiently and to produce substantial yields by achieving a favorable condition for plant growth by narrow row spacing and increased plant density [68].

Fertilization

Weeds are affected by both soil fertility and fertilizer use. Fertilizers use has a significant effect on weed population, its growth, proliferation, dormancy, hardiness and persistence, weed dynamics, weed diversity, and crop-weed competition in rice crops. Some weeds favor low-fertile soils, whereas others predominate in well-fed soils. Balanced use of fertilizers, especially nitrogen is favourable agriculture management for minimizing weed severity [76]. However, under high weed pressure, crop fertilization with different nutrients helps weeds more than the crop because the absorption of nutrients is higher and faster in weeds than in crops. The yield of rice in weeds-controlled areas was significantly improved through increased rate of nitrogen application up to 150 kg ha^{-1} in direct seeded rice, however, in reduced weed control environment it resulted in a severe yield reduction [77]. Thus, crop fertilization alone is not helpful in achieving higher net returns. There should also be more emphasis on the application of fertilizers using band placement methods along crop rows, at the most effective times and in optimum quantities. To date, limited research has been done in this directio, particularly for the rice crops.

Selection of Cultivars

For reducing hand weeding and herbicide inputs, selection of weed-competitive rice cultivars (producing high yields) could be a significant method [78]. Weed-competitive ability cannot be related to a single feature but, is an outcome of the relationship amongst various suitable varieties [79-81], thereby making it tough for plant breeders to work for weed-competitive varieties of crops. More work is needed for weeding upland direct-seeded rice field than lowland transplanted rice field [82]. Thus, the farmers of South Asia are favoring practices other than hand weeding or limiting the use of hand weeding by the exploitation of other weed control methods to minimize the cultivation cost [83].

Allelopathic Control and Development of C4 Rice

Allelopathic rice cultivars can play a role in weed suppression. According to Duke et al.[84], the weed suppression by allelopathy utilization can be increased either by increasing the existing crops' allelopathic potential or by introducing the allelopathic capability via incorporation of foreign genes that encode for allelochemicals. International Rice Research Institute (IRRI) established an approach for screening allelopathic rice or complete plant-bioassay [85] to reduce the results of competitive interference for common resources among test plant and rice. The barnyard grass can be controlled by 111 cultivars of rice in the Philippines [86] which showed that allelopathy might give 34% reduction in dry weight of weed after 8 weeks of seeding. The momilactone B was released by rice seedlings and found to be the primary source to the allelopathic potential of rice, especially for barnyard grass [87]. Commonly presumed allelochemicals discovered in rice are phenolic acid composites which include p-hydrobenzoic acid, p-coumaric acid, vanillic acid and ferulic acid [88-90].

In addition to allelopathic control, rice scientists are struggling for developing C4 rice crops either through conventional breeding or using transgenic methods [91]. Since rice is a C3 plant and shows less resistant to competition against C4 weed plants like *C. rotundus* and *E. crusgalli.* The development of C4 rice is appreciated because C4 plants are more competitive and efficient than weeds, even under water-stressed conditions [92].

b) Biological Control

The use of an agent, combination of agents or biological ways to suppress weeds is known as biological control of weeds. In biological control agents, all types of a microbial organism can be considered. Use of living organisms, including insects, herbivorous fish, animals, disease-causing organisms, and competitive plants to limit weed infestation is defined as biological control. This method can reduce the weed population to a significant degree but cannot eradicate weeds. For example, a rice root nematode (*Hirschmanniella spinicaudata)* that controls most upland rice weeds in case of rice; a moth *(Bactra verutana*) that destroys *Cyperus rotundus* ; the steel blue beetle (*Altica cyanea*) which completely destroys *Ludwigia parviflora* and the rust fungus (*Puccinia canaliculata*) which controls *Cyperus esculentus*. Various fungi are being used as myco-herbicides for example, *Cocholiobolus lunatas* and *Exserohilum monocerus* are used to overcome the infestation of barnyard grass [93]. Integrated rice-duck farming (Aigamo Method), a 500 years old Japanese tradition, to increase rice productivity, decrease weeds and pests in rice fields and increase fertilizer availability to rice crop by making use of the mutually beneficial relationship between rice and duck crops [94].

In weed management systems, seed predation through granivore fauna, like ants and other insects, could be used as an important tool mostly under zero-till systems where newly produced seeds of weed plants stay at the surface of the soil [95]. By mixing seed predation with other weed control measures, herbicide use, and the risks associated with it can be reduced. Thus, seed predation can significantly decrease the intensity of weed seed bank as they serve as forage for the predators of weed seeds, which could be stimulated by leaving plant wastes in fields. Since, no reserve price is involved in applying such management techniques, these environment-friendly, safe, and economic approaches for weed control can be mixed with existing practices as a part of an integrated weed management package. Biocontrol agents' potential should be exploited. However, it must be considered that there may be less population of natural enemies of weeds at the required time to control weeds in specific agricultural situations.

c) Chemical Control

Significance of Herbicides

The exploitation of herbicides is significantly proportional to the availability and cost of the worker. One of the first labor-saving techniques to be adopted is herbicides, which have been proved to offer the best weed management. Herbicides are energy and labor efficient than other weed control methods like mechanical or manual methods of weed management. These chemical measures are also highly efficient in controlling weed plants that mimic crops or which propagate asexually [62,96]. The success of direct seeding of rice is dependent on the use of herbicides because manual means of weed control are often not feasible. The application of anilophos at 0.6 kg ha^{-1} after one day of sowing along with a hand weeding after 45 days of sowing has proven significantly better in destroying weeds and securing high grain yield [97]. Also, weeds grow extremely rapidly without the use of herbicides in the early stages before the fields can be flooded. In addition, the application of herbicides is common in transplanted rice systems. Angiras and Kumar [98] reported that pyrazosulfuron ethyl applied at 25 g ha^{-1} between 3-10 days after transplanting was found effective in reducing weed density or dry matter yield. Sulfonylurea is a well-known group of herbicides worldwide which shows high activity, tremendous selectivity, application feasibility and minimum toxicity to mammals with a diverse range of weed control even at extremely low application rate [99-101].

The major constraint to the widespread adoption of herbicides is the involvement of economics. However, increased labor wages have led to the adoption of chemical weed control alone or as a component of an integrated weed control system by many farmers in Asia during recent times. Therefore, the use of herbicides varies considerably between countries [16].

Types of Herbicides

Different types of herbicides include non-selective or selective, and pre-, early post- or post-emergence. In rice production systems, the majority of herbicides being used are selective, having broad or narrow spectrum, and having a limited effect on the crop. The selection of herbicides is dependent on the chemical used for its formation, its rate, duration, and ways of application. Thus, it is critical to comply with recommendations for effective and selective weed control. The application of nonselective herbicides like glyphosate is suggested before rice establishment or on weed invasions like weedy rice which are not easy to control with selective herbicides. Pre-emergence herbicides are applied on the soil to manage weed before emergence, while the herbicides that are applied to weeds after they emerge are known as post-emergence herbicides. The amide group includes herbicides such as propanil, pretilachlor, and butachlor. Butachlor may be implemented both as a pre-emergence or early post-emergence herbicide to control a wide range of narrow as well as broad-leaved weeds. Different pre-emergence herbicides like thiobencarb, butachlor, oxadiargyl, pendimethalin, anilofos, pretilachlor, oxadiazon, pyrazosulfuron ethyl, nitrofen and oxyfluorfen offer a fair range of weed control [62,80,102,103]. For the efficient use of pre-emergence herbicides, they must be applied with some limitations, for example, under appropriate soil moisture and short time duration, preferably in standing water conditions. Also, the use of chemicals during early growth stages of the crop is impossible due to several limitations at field level while the continuous application of a single herbicide develops resistance in undesirable plants. Therefore, the use of post-emergence herbicides becomes essential [104]. In conventional rice cultivars, the use of selective herbicides is not common to manage weedy rice. Some studies have reported that effective control of weedy rice may be provided by pre-plant herbicides (e.g., oxidation and metolachlor). However, such herbicides should be applied before rice plantation for preventing damage to the rice crop. It is also essential to use mixtures of several suitable herbicides in direct seeded rice system where diverse weeds exist, especially in dry direct-seeded systems [57]. Therefore, sprays of pre-emergence herbicides followed by post-emergence herbicides are recommended to ensure good weed control [55]. It was reported that the pretilachlor applied as pre-emergence herbicide at 0.75 kg ha^{-1} followed by 2,4-Dicholorphenoxyacetic acid as post-emergence herbicide at 0.5 kg ha^{-1} was considered most efficient in diminishing the weed quantity and dry biomass thus improving the uptake of nutrients, grain yield and net return [105].

Herbicide-Resistant Weed Flora, a Constraint

Several species of weeds are not controlled effectively even after utilizing the mixture of herbicides. Moreover, a few weed species continue emerging throughout the plant life cycle due to the high level of seed dormancy. Injudicious and non-stop use of similar herbicide or herbicides with same mechanism of action over a prolonged time period may additionally results in resistant biotypes' development, alterations in weed flora and adverse impacts on the following crop [96], which put loads of chemicals in the environment [106-108]. Weed population has shifted from *Echinochloa* sp. to *Ischaemum rugosum, Cyperusiria* and *Caesulia axillaris* by continuous use of butachlor herbicide for years, and continuous use of pretilachlor have also resulted in weed population shift from *Echinochloa* sp*., Cyperusiria* and *Caesulia axillaris* to *Ischaemum rugosum* [109]. Thus, to increase the efficacy of applied herbicides and to cut back the cost of weed control, extremely efficient and low-cost herbicide application techniques such as spray instrumentation and nozzles, herbicides adjuvants and carriers should be adopted along with ensuring the appropriate timing of herbicides use. Furthermore, advanced research on the use of herbicides mixture is required to postpone the development of resistance and to provide more efficient and cost effective ways of weed management.

Herbicide-Resistant Rice, a Boon in Disguise

Herbicide-resistant rice technology has the potential to overcome infestation of a wide variety of weeds such as grasses, broad-leaved weeds, and sedges, which result in serious yield reduction in lowland rice, including weedy rice and *Echinochloa* spp. [110] and can be considered a boon in disguise.

Also, the aptitude to effectively manage weeds makes the development of herbicide-resistant rice a smart technology which can easily be adopted by the farmers in several circumstances. In rice, three systems of herbicide-resistance have already been develope, including imidazolinone, glyphosate, and glufosinate-resistant cultivars [111]. Glufosinate and glyphosate are post-emergence herbicides and known as comparatively environmentally benign. The application rates of these fertilizers can be managed according to the severity of weeds. Additionally, the technology has a broad time frame for the application of herbicides as compared to traditional technologies.

In spite of the expected benefits of herbicide-resistant technology, there are limitations related to the possibility of gene flow from herbicide-resistant rice to weedy and wild rice species. For example, in different regions, weedy and wild relatives are present; therefore, gene flow could take place from herbicide-resistant rice to such species [97]. The dependence on this technology for efficient weed management in a rice crop will rely on carefully introducing genes and further management of cultivars.

d) Integrated Weed Management

A single approach for weed management may not be capable of controlling weeds below the threshold level and may also cause a rift in weed communities, development of resistance, and environmental harms. Therefore, the implementation of a diverse system is important for weed control as weed flora is very responsive to weed control methods [47]. An effective weed control method must intend to reduce weed population at a certain level where weeds infestation would not have any adverse effect on ecological interests and economics of farmers. The combination of various suitable weed control practices is helpful for farmers to use additional opportunities for weed management thereby minimizing the occurrence of escaped weeds. Thus, integrated weed management is a scientifically decision-making practice that synchronizes the use of weed ecology and biology, environmental evidences and all currently implemented technologies to manage weeds by using most feasible and economical means, and posing the least threat to human and environment [112].

Integration of different weed management methods is a traditional approach. For instance, the conventional method of "puddled soils" to destroy pre-existing weeds and assist in water retention, use of transplanting method to obtain optimum plant density, and leaving standing water in rice field to kill unwanted plants followed by one or more hand weeding is a well-known example of this system [113]. Since, provision of resources is important for weed occurrence [114], improving the utilization of resources by intercropping also becomes a part of an integrated system. However, the most significant feature of all weed management practices is "weed prevention" which includes all measures to foresee the onset of weeds infestation and avoid their spread in the field [115]. Thus, effective integrated weed management is an amalgamation of preventive, physical, cultural, mechanical, biological and chemical control techniques for destroying weeds in an efficient and economical manner, and further considering the environmental sustainability.

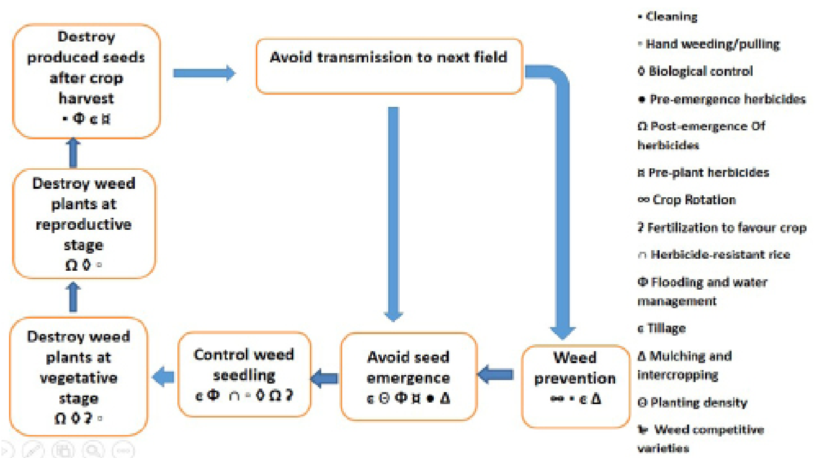

Figure 1: Weed Management Strategies During Different Growth Stages of Weeds

Conclusion

Rice is a vital food commodity being produced worldwide, especially in developing countries where it accounts for 33% of the total input of calories by these populations and has become an important employment source, especially in rural areas. Meanwhile, weeds play a significant role as a primary biological constraint in rice cultivation throughout the crop production systems. Under weedy conditions, yield losses in direct seeded and transplanted lowland rice were recorded around 50-60% and 70-80%, respectively. Thus, weed control in rice fields is quite complex and challenging. Among weed management strategies, the use of herbicides is a highly adapted practice nowadays. However, the large scale and consistent application of such chemical treatmentsare restricted due to the involvement of risks to the environment. The flooding of rice fields is another effective strategy which adversely effects the germination of weed seeds and results in the death of weed seedlings. Weed infestation could also be reduced by crop competitiveness during growth and reproductive stages. Hand weeding is widely practiced depending on the availability of labour however, mechanical weeding could reduce labour cost up to 72-74%. The judicious use of all weed control methods including mulching, tillage, hand weeding, herbicides, allelopathy, crop rotation, intercropping and other preventive measures as an integrated approach is preferred which could defeat the weed menace to an acceptable level.

Future Paths

Adequate knowledge of the agronomic, soil, genetic, biological, ecological, physiological, biochemical, environmental, toxicological and economic aspects of plant growth, behavior and production are required for the formulation of packages of complex strategies for different rice ecosystems. Moreover, complete coordination of different techniques and improved instrumentation is essential to ensure system productivity, prolonged weed management, food security, and environmental sustainability. The best management practice can be adopted by applying numerous herbicides, rotating crops, embracing best cultural weed management practices, use of weed-free seeds, scouting fields routinely, and cleaning the equipment, non-cropped areas and water channels to minimize weed transfer to other fields. A strategy that integrates different weed control systems allows us to manage weeds effectively and may help to delay the evolution of herbicide resistance. For different agro-ecological regions, it is important to develop and popularize integrated weed management techniques, which considers the geographic, ecological, agronomic, and climatic features of farming methods. To further attain sustainable, long-term, and effective weed management, an integrated approach that concentrates on prevention of weed attack, reproduction and recruitment must be developed. These complexes weed control packages could be environmentally sustainable and effective for continuing preservation of natural resources and improving agricultural productivity along with adequate economic returns and less adverse ecological influence on farmers.

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Water and Rice

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Published Date: January 08, 2020

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**.

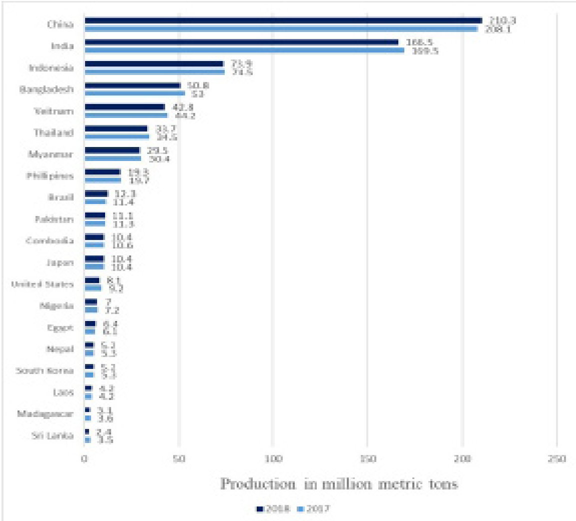

Figure 1: Rice production in million metric tons of rice producing countries
Source: Statista-2018 (https://www.statista.com/statistics/255937/leading-rice-producers-worldwide/)

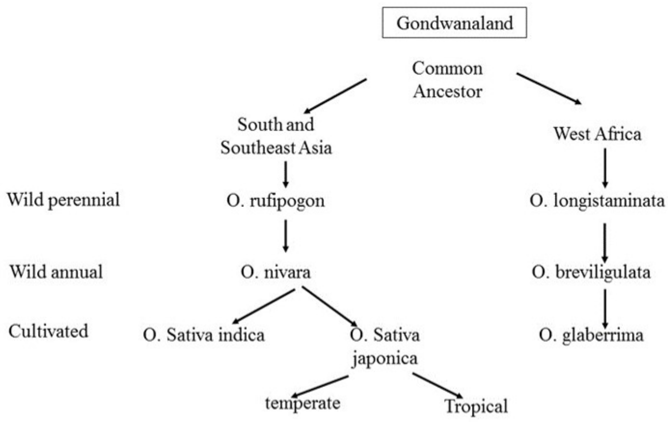

Figure 2: Evolution stages of Rice

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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Biofortification of Rice

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Published Date: January 18, 2020

Abstract

Rice is an important staple food crop for most of the population around the world. On a global basis, more than 2 billion of population are affected from micronutrients deficiencies and alarming health hazards that result from this type of malnutrition. Folate, Zn and Fe deficiencies are among the most commonly found deficiencies around the world especially in developing countries. Biofortification is the increment in the nutritional contents of food crops by biotechnology or plant breeding. The biofortification of the edible parts of staple foods offers an sustainable and inexpensive measure to combat the prevalent human disorders resulting from micronutrients malnutrition. Rice serve as a suitable target for biofortification as most of the people around world eat rice as a staple diet. The white rice or polished rice consists of insufficient amount of micronutrients which is unable to fulfil every day necessity of micronutrients in food. That's why, the biofortification of rice grains is the solution to this problem. By controlling and facilitating the transportation of micronutrients, including absorption from soil, their translocation and especially their loadings in the grains, it is possible to enhance their concentration in the seeds. This chapter will provide a comprehensive overview of the agents governing micronutrients transport in rice, the transporters and genes involved (uptake and transport) and used for micronutrients biofortification in rice and currently available technologies for micronutrients rice biofortification. Moreover, the progress and future prospects of existing biofortification techniques in rice will also be elucidated in this chapter.

Keywords: Micronutrients; Global malnutrition; Rice; Biofortification; biotechnology; Transgenic varieties; Gene

Abbreviations: Zn: Zinc; Fe: Iron; Mn: Manganese; GNP: Gross national product; SAM: S-adenosyl methionine; NA: Nicotinamide; DMA: 2-deoxymugineic acid; NAS: Nicotinamide synthase; QTL: Quantitative trait loci; CRISPR: Clustered regularly interspaced short palindromic repeats; TALENS Transcription activator like effector nucleases

1. Introduction

Biofortification can be defined as increasing the nutritional value of crops (usually minerals and vitamins) via agronomic practices, conventional breeding of plants or modern biotechnological techniques. It has proved as a best strategy to overcome extensive micronutrients malnutrition especially in developing world. More than half of the world's population relies on rice as a staple food. The aleuone layer of rice seed consists of minor amounts of pro vitamin A and Fe. This bran layer and husk is removed during milling process to get edible endosperm called white rice or polished rice. This is the main cause behind worldwide Fe and vitamin A malnutrition [1,2]. The micronutrients Fe, Zn, and Mn deficiencies are most commonly seen. Fe plays various roles as it acts as a cofactor for many enzymes in the human body. Stoltzfus [3] and Hentze et al [4]. reported that the Fe malnutrition might cause serious disorders in humans like anemia. While, cognitive impairment, immune dysfunction hypogonadism, and growth retardation are often observed in Zn deficient peoples [5]. According to the World Health Organization [6], the predominant micronutrient deficiencies in humans are Zn and Fe deficiencies, which are resulting in over 0.8 million deaths every year by affecting two billion peoples worldwide. Although, the deficiency of Mn is less dominant than Zn and Fe deficiencies among the peoples. However, the pathological issues like chronic birth defects and asthma are most commonly reported in the cases of Mn malnutrition. The combined effects of these micronutrient deficiencies pose a significant threat to human health.

Stein [7] stated that the deficiencies of micronutrients had deteriorated the economic productivity and social welfare by increasing the incidents of diseases worldwide. On a global scale, at present more than 3 billion people are suffering from severe disorders resulting from Fe and Zn malnutrition. The consumption of diets containing less nutrition is the main root cause behind the ever-increasing Fe and Zn deficiencies. Specifically, in developing countries, this kind of malnutrition is the major cause of the decreased GNP by reducing work productivity among individuals. According to a study conducted by Wessells et al. [8], around 18 % of the total world population is affected by Zn malnutrition. Shekari et al. [9] stated that On a global scale, among 20 micronutrients which are categorized as deficient in humans, the number of Zn is the 11th while, in less developed countries total 10 micronutrients are reported as deficient where the Zn is ranked at 5th number. The South Asian population is suffering from severe health problems owing to Zn malnutrition as 95 % of total individuals eat rice as a staple food. Figure 1 overviews the world population (%) suffering from deficiencies of micronutrients.

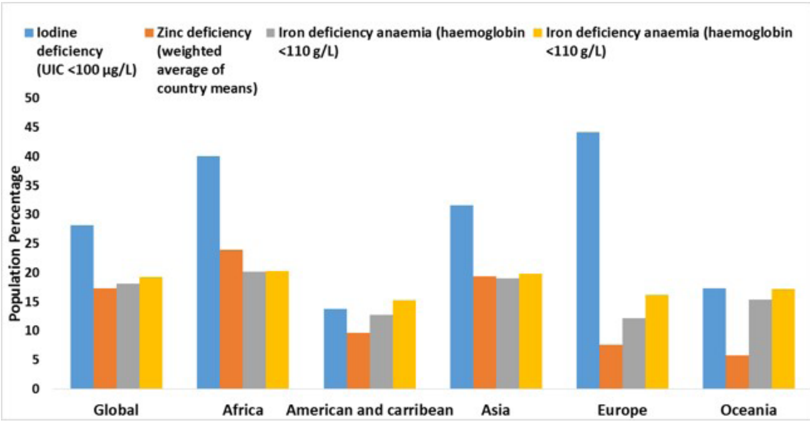

Figure1: Population in (%) with deficiencies of selected micronutrients (Source: Black et al [83]).

The Zn and Fe malnutrition arises in the circumstances when people consume a diet with less variation or consume one or two staple foods. Yang et al. [10] reported that in less developed countries, even the population's consumption is based on only rice as a staple food. Moreover, white rice or polished rice is unable to meet regular supplies in foods due to consisting of inadequate quantities of micronutrients [11]. The strategies to alleviate micronutrient's malnutrition include supplementation of micronutrients, nutrient fortification of food on an industrial scale, and grain biofortification. Minhas et al. [12] reported that supplementation of micronutrients and nutrient fortification of food had played well globally to mitigate problems associated with micronutrients malnutrition, but these methods have some shortcomings being expensive and framework requiring for the fortification of foods and the production of micronutrients supplements. Even this malnutrition-related problems may pose even more threat to the people which cannot pay for the non- staple diets rich in micronutrients [13]. Hence, rice biofortification with micronutrients can prove a less costly and defensible strategy to overcome micronutrients malnutrition [12]. In spite of all the above facts that biofortified rice can prove suitable diet, yet very little evidence are available for its usefulness.

2. Localization of micronutrients in the seed and rice biofortification

In rice seed, Fe is confined mainly to the scutellum of the embryo and its vascular bundle, endosperm, aleurone layer, and dorsal vascular bundle. As germination proceeds, this Fe is shifted wholly to an embryo, and after 2 days of sowing changes its place to the radicle, leaf primordium, epithelium, and coleoptile [14]. On the other hand, Zn has its maximum portion in the embryo and aleurone laye, and it is disproportionately dispersed to all seed parts [14]. Unlike Mn and Fe, the flow of Zn is very vigorous during the germination process. Mn is found mainly in the embryo and endosperm and as germination starts it started accumulating in the scutellum instead of the coleoptile. Beside these micronutrients, 2-deoxymugineic acid (DMA) and nicotianamine (NA) are also found in the rice seed which during germination are responsible for the chelation and mobilization of micronutrients [14,15,16]. Gregorio et al. [17] reported that different studies highlighted the Fe contents in rice seed with considerable variations. Although Fe is abundantly found in mineral soil but due to lack of solubility, it is not bioavailable, hence in order to increase seed Fe contents supplementation of soil with Fe as a fertilizer is not an effective measure. The fertilization of soil with Zn increase plant growth effectively, but different reports evaluated significantly different rice grain Zn concentration and Zn use efficiency with respect to different rice genotypes [18,19,20,21,22]. The leading factors controlling Fe concentration in the soil are, field conditions like dry and moist soil, carbonates contents and soil pH, while for Zn these are Zn concentration in soil is the Zn status of native soil. [20]. Depending on the Zn status of soil, the Zn concentration may vary from 8 to 47 mg kg−1 within a same variety [21,22] and On the basis of genotype, the Zn concentration in rice grain can be as high as 59 mg kg-1 and as low as 16 mg kg-1 [20].

3. Techniques for Biofortification of Rice

Agronomic (Non-genetic) practices

Various agronomic practices are there in use to for obtaining biofortification of crop grains and may prove more efficient for enhancingthe nutritional quality of crops as well as yield. The examples of such non-genetic approaches are management practice, fertilizer application, and adding O.M in the soil for improving the availability of nutrient elements [23]. The specific nutrient element may be applied as fertilizer either in soil or to the leaves via foliar application to increase its concentration in that plant and its edible portion. From these two methods, the foliar application of a specific element is more effective in this regard compared to soil application [24]. Moreover, the fertilization of specific element for biofortification may prove more fruitful by adopting integrated soil fertility management approach, which includes a combination of both organic and inorganic fertilizers. It has been proven that agronomic practices like foliar fertilization have enormous potential for increasing micronutrient contents in the rice and its edible part [25,26,27,28].

Conventional breeding

The most promising solution to combat micronutrients deficiencies is to develop genotypes after breeding having more vitamins and minerals. Earlier, the rice breeding programs were emerged with the purpose to produce high yield rice cultivars while the development of rice cultivars having high nutritional contents was ignored [29]. Later on, the qualitative enhancement gained importance along with the quantitative increment of rice grains. The breeding of rice cultivars having high micronutrient contents is sped up by germplasm screening of wild species, traditional varieties, and landraces to induce variations in alleles. For increasing Zn and Fe concentration of rice grains, the breeding programs are started with germplasm screening. Later many modern and more developed germplasms evolved. The preservation of these germplasms was done using gene banks containing a pool of genetic variation required for breeding [30]. Kumar et al. [31] reported Zn and Fe concentration in rice grains ranging from 10 – 39 and 10 – 44 mg kg-, Respectively using this approach. On the other hand, Anuradha et al. [31] screened out 126 brown rice cultivars and gave a range for Zn from 27 to 67 mg kg-1 and for Fe 6 to 72 mg kg-1. While, for Fe concentration, 52 rice genotypes were screened out by Jahan et al. [32] who reported a range for Fe from 1.3 to 100.5 mg kg-1. An inbred line of rice 185M was tested for bioavailability in comparison with its parent Swarna and reported three times and two times more bioavailability for Zn and Fe respectively with this line in the presence of ascorbic acid at National Institute of Nutrition, India in an in a vitro cell system. Beside it, the high Zn inbred lines IET 23814 and IET 24775 were also screened out in India which gave promising results. Although, the conventional breeding approach gained considerable success regarding Zn and Fe biofortification in rice, many of these evolved genotypes were failed in attaining consumers and farmers acceptance due to the reasons that in most cases in inbred lines Fe increment was in aleurone layer which is removed during the milling process. The Zn and Fe rich breeds often showed less yield. Beside it, lack of awareness among consumers regarding buying biofortified rice and lack of special prices for farmers in the market for biofortified rice [33].

Rice biofortification by increasing the number of metal chelators

Rice plants secrete small molecules called phytosiderophores belonging to family mugineic acid. These help to uptake and transport micronutrients from roots towards shoots and then to the grains. These phytosiderophores have the mechanism for the solubilization of Mn, Cu, Zn, and Fe [34]. The synthesis pathway of these mugineic acid family phytosiderophores has been illustrated in the Figure 2. Nicoitinamide can also bind metal ions through chelation. Nozoye et al. [35] stated that these mugineic acid family phytosiderophores are secreted into the rhizosphere via mugineic acid 1 transporter. It is an antiporter belonging to a superfamily, which is a major facilitator [35]. Inoue et al. [36] reported that the transporter, which is the member of a family yellow stripe like (YSL) is responsible for facilitating uptake of the metal-phytosiderophore complex by plants. According to Haydon and Cobbett, [37] in the vacuole, the transporter of NA 1 is found, which is known as one of the best Zn facilitators. It has been proven that in rice plants if DMA and NA concentration is increased, the grain metal contents were also increased. These results were later confirmed by Wirth et al. [38], (Lee et al. [39], and Johnson et al. [11], who reported the significant increment in the rice grain concentration of Zn and Fe through overexpressing the Pvferritin and AtNAS1, OsNAS2 and OsNAS3, and OsNAS1-3 transporters respectively.

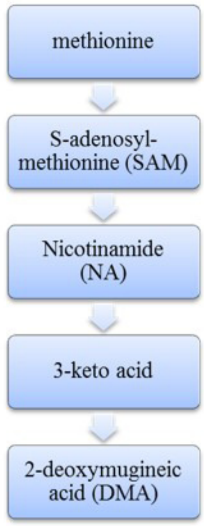

Figure 2: Synthesis pathway of mugineic acid family phytosiderophores (Source: Suzuki et al., 2012)

Rice biofortification by utilizing metal transporters

The uptake of metal ions in rice plants is positively correlated with the metal transporters belonging to various families [40]. The transporters often reported involving in Fe regulation are, OsNRAMP5, OsNRAMP1, OsIRT2, OsIRT1 [41,42, 43,44] respectively. In case of DMA and NA chelated metals, the Fe(III) – DMA is transported by OsYSL15, OsYSL16, and OsYSL18 while, Fe – NA or Mn – NA are transported by OsYSL2 [40]. The PEZ1 and PEZ2 are phenolics efflux transporters involved in apoplastic phenolics secretion in xylem and roots and help to facilitate the apoplasmic Fe transport after solubilizing it [45,46]. According to the findings of Kobayashi and Nishizawa, [47], the loadings of xylem is governed by TOM1, and the transportation from xylem to phloem is regulated by OsYSL2, OsYSL16, and OsYSL18 transporters. Moreover, the translocation of micronutrients towards seeds as well as their uptake from the soil is controlled by OsNRAMP5, OsYSL15, OsIRT, and OsIRT2. A significant increment in the Mn and Fe contents in rice grains was obtained by overexpressing phloem localized transporter OsYSL2 [48]. Lee et al. [49] and Lee and An, [50] reported the increased concentration of Zn and Fe in rice lines by the overexpression of OsYSL15 and OsIRT1 transporters, respectively. Hence, in rice grains, the flow of Fe can be considerably increased by controlling the temporal and special genes expression, specifically in the case of metal transporters. Metal biofortification in rice is positively affected by supplementary transporters.

Transgenic Practices for rice Biofortification

The biotechnological practices such as plant alteration play a significant role for increased metal contents in rice grains. The plant alteration is carried out by utilizing genes encoding phytase, nicotianamine synthase, ferritin (a Fe storage protein), metal transporters and metal chelators. The types of selected genes and the promoters utilized for the transformation of rice plants for increasing micronutrient concentration in rice grains have been reviewed in Table 1. The more promising results can be achieved by expressing multi genes, for example, the combination of NAS genes and ferritin genes (six fold increment) compared to single gene expression (two-fold increment). An experiment was conducted by using promoter OsGluB1 found in the endosperm of rice to produce transformed rice plant which express SoyferH1 gene (a soybean ferritin gene) [51]. The resulting transformed rice exhibited 2-fold increment in Fe concentration in endosperm and 3-fold increment in brown grains. These findings made the way that a further increment in rice endosperm Fe concentration can be achieved by facilitating absorption of Fe from the soil and then its transport within the plant. In order to increase Fe uptake, the rice endosperm was supplied with phytase (thermo tolerant) obtained from a fungus, and metallothionein-like proteins rich in cysteine were overexpressed. The results showed 130-fold increment in phytase contents in rice grains with high Fe and cysteine peptide contents. In another study, by utilizing nicotinamine aminotransferase (NAAT) gene (from barley), the transformed rice plants were developed, which showed high Fe uptake from soil [52].

Table 1: Some selected studies utilizing genes and their promoters for Zn and Fe biofortification of rice (Source: Bashir et al. [81], Kok et al. [82])

Promoter of gene	Gene	Rice cultivar	Zn/Fe Fold Increase	Reference
Glu-B1	SoyferH-1	Japonica cv. Kitaake	... /3.0	Goto et al. [51]
Glb-1	PvFerritin+ rgMT	Japonica cv. Taipei 309	... /2.03	Lucca et al. [70]
Glu-B1	SoyFer	Indica cv. IR68144	1.4/3.7	Vasconcelos et al. [71]
Glu-B1; Glb-1	SoyFer	Japonica cv. Kitaake	1.1/3.0	Qu et al. [72]
Genomic fragments	HvNAS1, HVNAS1+HvNAAT, IDS3	Japonica cv. Tsukinohikari	1.0/1.0, 1.1/1.1, 1.3/1.4	Masuda et al. [73]
CaMV 35S, Glb-1, Glb-1	AtNAS1+, Pvferritin+, Afphytase	Japonica cv. Taipei 309	1.6/6.3	Wirth et al. (74)
Actin	HvNAS1	Japonica cv. Tsukinohikari	2.3/3.4	Masuda et al. [16]
Activation tagging	OsNAS3	Japonica cv. Dongjin	.... /2.2	Lee et al. [49]
Ubi	OsIRT1	Japonica cv. Dongjin	1.1/1.1	Lee and An [50]
OsSUT1	OsYSL2	Japonica cv. Tsukinohikari	... /4.4	Ishimaru et al. [48]
GluB1	OsNAS1	Japonica cv. Xiushui 110	1.3/1.0	Zheng et al. [75]
CaMV 35S	TOM1	Japonica cv. Tsukinohikari	1.6/1.2	Nozoye et al. [35]
CaMV 35S	OsNAS1, OsNAS2, OsNAS3	Japonica cv. Nipponbare	1.4/2.2, 2.2/4.2, 1.4/2.2	Johnson et al. [11]
Activation tagging	OsNAS2	Japonica cv. Dongjin	2.7/3	Lee et al. (39,76)
OsSUT1, Glb-1, Glb-1. Glu-B1, Act	OsYSL2+, SoyFerH2+, HvNAS1	Japonica cv. Tsukinohikari	1.6 /6	Masuda et al. [77]
OsGluA2	OsFer2	Indica cv. Pusa-Sugandh II	1.4/2.1	Paul et al. [78]
OsVIT1 or OsVIT2 T-DNA	OsVITs	Japonica cv. Zhonghua11	... /1.4	Bashir et al. [79]
AtIRT1, Pvferritin	MsENOD12B, OsGlb1	Japonica cv. Taipei 309	.... /4.3	Boonyaves et al. [80]

Quantitative Trait Loci (QTL)

Quantitative Trait Loci (QTL) are genetic loci regulated by many genes and control quantitative characteristics. The transformed varieties can be can be produced utilizing marker-assisted selection, by the transformation of QTLs. This can be achieved by the Identifying and characterizing genomic regions responsible for increased concentration of rice Zn and Fe [53]. For the purpose of mapping, the consistent and strong methods are compulsory for analyzing Fe and Zn contents in rice grains. This QTL mapping technique has been applied for the identification of various genes involved in Zn and Fe uptake from the soil, their translocation within the rice plants and storage in the grains [54]. Various researchers have presented their work through interspecific and intraspecific crosses utilizing QTL mapping for increasing Zn and Fe contents in rice grain [55, 56,57,31,58]. The markers RM7488 and RM3322 are involved in Zn and Fe concentration in rice. In rice grains, the QTLs governing Zn and Fe contents are found on chromosome 12 and chromosome 7 [59]. Later findings suggested that by targeting the same regions on the chromosome, the cereal grains Zn and Fe contents can be aggravated [60]. For the identification of genes responsible for Zn and iron biofortification in rice, QTLs meta-analysis was carried out which discovered 22 meta-QTLs and genes associated GRMZM2G178190 and GRMZM2G366919 and marked as NRAMP i-e natural resistance-associated macrophage protein genes [61]. The techniques of functional validation and expression analysis can be implied for further characterization of gene sequence inside the QTL regions through knocking out or overexpression of gene responsible. The genes within the QTLs can be identified if the genome sequence is available. The rice seed Zn and Fe concentration are positively correlated with the expression pattern of genes within Zn and Fe QTLs [62]. Furthermore, the information coded on these genes can be utilized for the production of functional markers for breeding programs like marker-assisted selection (MAS), fine mapping of QTLs/saturation in order to enhance nutritional characteristics of rice grains.

Utilization of non-coding microRNAs

In order to enhance Zn and Fe concentration in rice grains, specific non-coding tiny RNAs can also play a role and are called microRNAs. Beside it, these also have a role in various metabolic and biological phenomena like plant stress responses, cell wall biosynthesis, and plant development [63]. According to Fischer et al. [64], these microRNAs are involved in the absorption and translocation of various mineral elements inside the plants. These microRNAs also have a role in the regulation of gene expression after transcription through controlling translational repression or degradation of mRNA [65]. These are tiny non-coding RNA molecules having subsets of 22 endogenous nucleotides [64]. Agarwal et al. [66] Explored the role of microRNAs in controlling Zn and Fe concentration in rice plants by reporting the microRNAs expression analysis with respect to nutrient homeostasis and biognenesis. The identification of four microRNAs have been made in response to Fe deficiency are miR156, miR171, miR169, and miR172 [66].

Gene editing

This technique involves engineering methods based on nucleases to create substitutions, mutations, and precise incisions. The engineering approaches include CRISPR (clustered regularly interspaced short palindromic repeats)/CRISPR-associated systems (Cas), and TALENS (transcription activator-like effector nucleases). Shan et al. [67] developed 2-acetyl-1-pyrroline containing fragrant rice by targeting OsBADH2 gene using the TALENs engineering technique. However, recently, the CRISPR/Cas techniques have been gained more importance due to high efficiency and ease of engineering compared to TALENS [33]. Recent studies have used CRISPR/Cas technique to develop herbicide and disease (blast lesion) resistant rice [68,69]. These studies revealed that CRISPR could be an effective tool for the replacement of genes which will be helpful for the nutrient enrichment of rice grains. The editing of genes involve in the absorption, translocation and loadings of Zn and Fe in rice and their promoter sequences has been made possible using this technique. OsYSL15 OsDMAS1, OsNAS2, OsIRT2, OsYSL2 and OsNAS2 genes have been identified involving in Zn and Fe homeostasis [31,62]. Due to high specificity and precision the gene editing techniques have more advantages than other methods with respect to Zn and Fe enhancement of rice grains The precise gene expression of responsible genes and the creation of desirable alleles by using genome editing techniques is extremely useful for the micronutrients biofortification of rice [1].

Conclusion and future prospects

Rice biofortification with micronutrients is an effective technique to combat micronutrients deficiencies among the population which relies on rice as a staple food. It has gained enormous attraction for researchers, industries, and especially in developing countries suffering from micronutrients malnutrition among individuals. The biofortified cultivars of rice are being developed by supplying nutrient elements by fertilizer, conventional rice breeding programs and advanced biotechnological strategies. The genetic techniques like genes and QTLs mapping for enriched Zn and Fe have made possible the discovery of target genes which can be utilized for the production of biofortified rice grains by means of conventional or transgenic practices. For the micronutrients enrichment of rice grain future, Research should be focused on the combination of agronomic and advanced genomic practices for increasing uptake, transport, and storage of micronutrients in rice grains. The advanced transgenic tools like QTLs, MicroRNAs, and genome editing practices like CRISPR and TALENS have led to considerable improvement in the biofortification of rice with Zn and Fe and the characterization, mapping and engineering of specific genes involved in Zn and Fe homeostasis.

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Improvement of Rice Production by the aid of Information Technology (IT)

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Published Date: January 18, 2020

Abstract

Information technology (IT) use in agriculture is becoming more and more visible. As with the passage of time, the use of IT getting popularity among people on a matter relevant to rice production as well as protection. Now a day's people are carrying a computer or a device to avail the use of information technology because promulgation of information alone cannot sustain growth in agriculture; agricultural industry must have the ability to manipulate that information to make informed decisions. Modern farming practices like satellite farming has already got popularity in different corners of the world. This precision farming uses IT to make a direct contribution to maximize the rice productivity. Satellite technology, geographic information systems (GIS), remote sensing, soil science, and agronomical technologies can be used to increase the agricultural production especially in large tracts of land where this approach is cost effective and useful. Along with this, modern management in sustainable agriculture requires the fast information about the condition of cultivated plants and the quick response to undesirable phenomena such as the appearance of pests and weeds in rice. The use of drones for spraying plants will allow for rapid application of plant protection agents on the growing areas. However, the potential use of farming sector seems unexploited. Lack of awareness about the technologies is a significant constraint. Currently, the farmers are hesitating to come out of the tangles of a traditional source of inputs. Using information is not only useful but a requirement these days. Studies show that the use of modern technologies is capable of making a remarkable hike in agricultural production.

Keywords: Information technology; Modern farming; Rice; Satellite technology; GIS; Remote sensing

1. Introduction

Background Information

In agriculture development, the information is a critical driver if it is relevant, right, and received on time. For empowerment of farmers, agricultural information plays a vital role because it improves their livelihood by providing vital information such as sowing time, ways improve soils, seeking the best price of their products and methods to combat pests and diseases [1]. Farmers suffer through hardships to answer to such issues even if they are very experienced in the specific cropping system. Variation in weather patterns, deterioration in soil conditions and infrequent climatic events such as floods, droughts, pest and disease outbreaks makes difficult for farmers to decide the proper ways to tackle these issues without the proper information. Therefore, Up-to-date information allows farmers to survive and even benefit from these changes by using advance measurements.

According to RLDC [2], most of the rice farmers are lack of agricultural information in mostly in farming practices and market trends. Hence farmers end up using their traditional and old methods of farming practices. The ultimate result is a reduction in yield and profit. In the continent, Africa, farmers are unable to access day to day updates of agricultural information, which is needed to assist farmers in making decisions regards farming practices and market price [3]. In agriculture, each step towards high production of crop needs information according to seeds, pest, and diseases, weed management, agronomy practice and market price, quantity and quality needed to the market, agricultural credit/loan and storage method to help them in decision making [4].

In the past nearly in the early 19th century, farmers used middlemen, extension officers, farmer groups, market boards, family, and relatives [5]. At the start of 20th-century television and radio and the mobile phone begins as a significant source of information to the farmers but the way of communication is one way, but through mobile phone, information is transfer in two ways manners. With the use of information technology through mobile phone, radio and television increase communication among farmers, market and traders without involving middlemen and extension officers because it provides day to day information through message, calls, and broadcasting and easily accessed [6]. The IT role in the agriculture sector is getting importance day by day. Therefore, IT importance in agriculture wouldn't be denied as it helps farmers to meet the need of information that will help them to obtained high yield, better market price, and communication among farmers and other agriculture actors [7].

Rice: an important crop

All over the world, rice is a significant food in general, and in Asia, about 90% of the world rice (*Oryza sativa* L.) is produced and consumed. More than half of the world's population is feeding on rice; however,>400 million people suffering from chronic hunger in the rice-producing areas of Asia, Africa, and South America. But as the population of the world is increasing day by day the demand for rice as a food increases within the globe which is expected to rise by the further 38% within 30 years according to United Nations [8]. The rice production in the world stands at 454.6 million tons per annum, with an average yield of 4.25 ton/ha [9]. Average yield per hectare must, therefore, be increased through careful research and through policies formulation. After the green revolution, the decrease in yield occurs abruptly, because of Imbalance use of fertilizers and pesticides, overexploitation of the natural resources especially water, spoiling of soil physicochemical properties of soil and generation of new resistant bio-type pests and diseases.

On one hand is to increase the production of rice is through the application of new technologies such as system of rice intensification (SRI), laser land levelling, direct seeded rice (DSR), precision farming, use of leaf colour chart (LCC), brown manuring, crop residue management, crop diversification, water conservation technologies, integrated crop management (ICM) and site-specific nutrient management (SSNM) along with application of resource-conserving techniques (RCTs). On the other hand, the use of information technology also playing its role in the improvement of the production of rice. Information technology (IT) is a strategic tool for agricultural development and the welfare of rural areas. Therefore, the main aim to agrarians and researches is to innovate the appropriate the technologies to produce more food from diminished soil resources to full fill the food requirements of growing and mushrooming population of the world population and to improve and conserve the natural resources of the small and marginal farmers.

2. Issues Involved in Rice Sustainability and Production

Rice feeds almost half of the world population because it is the staple food for most people. Its cultivation caused the start of agriculture, most ten thousand years ago farmers have made tremendous efforts to increase the yield under tropical and subtropical areas. But there are still many factors involved in the reduction of growth and production of rice.

Residues management and organic matter reduction in soil

In the field of rice, the main issue is maintained by rice straw. Among rice and wheat residues, the significant portion of wheat residues are used by the animal husbandry sector, but rice straw has high silica contents in rice, which make it inappropriate for animal diet. It also has comprehensive C:N ratio, which immobilizes the nitrogen and therefore farmer prefers to burn the residues in the field to make sure the sowing of wheat. The plant friendly insects are killed during the burning of rice causing global warming, imbalance of nutrients and degradation of soil and also the reduction of soil organic matter which ultimately affect the both biological and physicochemical health of the soil [10].

Labour storage

As rice cultivation and transplanting is an energy, water, and labor-intensive system because harvesting and spraying of rice need labor. Reduction in labor is a growing issue in rice cultivation system due to a shortage of labor; the availability of labor is responsible for the increase in wages. To resolve the labor problem, transplanting, mechanical transplanting, and direct rice are the reliable because manual transplanting is lengthy and needs more time and need more or less 300 persons per hectors. While the delay of one month in transplanting will leads to a 25% reduction in yield while the delay of two months causes a delay of 70% in the yield [11]. Under zero tillage the germination of weeds increased and to uproot these weeds labor is required for water productivity and lower land, weed seeds stayed near the upper soil surface get more water, light, and nutrients [12]. Labour shortage is considered as the problem towards reliable agriculture [13,14].

Nutrient deficiencies and toxicity in a rice field

Early in the sixties, the use of macronutrients is supposed to be essential for the rice plant but with the passage of time when the health of soil start deterioration, and micronutrients started in wheat and rice cropping system. This deficiencies of micronutrients overcome with the addition of different micronutrient fertilizers like borax, sulfur application helped in yield production and yield enhancement [15,16]. But other than deficiencies rice plant also facing the problem of toxicity. The selenium toxicity in wheat after rice harvesting is the major issue in the coping rice system; it is worth noting where the cultivation of kharif rice is carried out from 8 to 10 years, however, under wheat and maize crop system, the toxicity of Se was not witnessed. The appearance of toxicity in all living organisms is not an exceptional case. The other problem is the deficiencies of micronutrients such as Fe and Zn in the rice field which is playing its own role in the sustainability of rice because farmers can neither identify them precisely nor improve them by putting on their balance dose by broadcasting, spraying, and fortification.

Reduction in groundwater table level

The use of groundwater is more than a quarter of the total global water use earth [17]. Although agriculture is the major consumer of water, still the water usage in agriculture is decreasing day by day [18]. Availability of per capita water is reducing day by day in the main rice cultivating countries of Asia (Table-1)[19]. Water is the elementary for the agriculture, but due to its unequal and un-judicious distribution, other sources of water are required for the agriculture [20]. Keeping in view of over mention situation of water depletion in this rice grown major area in the region it was suggested that there is terrible requirement to talk about the issues relating workable production of crop and average water use. In some countries, the provision of free electricity to the agriculture sector also creating complication and centrifugal pumps are failed to full fill the water requirements, so the installation of submersible pumps is needed because of deeper underground water. The reduction in groundwater table has multiple reasons, but 3 major causes are following 1) water pumping cost increase; 2) growing tube well arrangement costs (3) bad quality of water below ground. Due to the pumping of a large amount of water, the salts start upwelling from the deeper native groundwater and also due to the mixing of saline water into fresh water, the groundwater becomes un-useable.

Contamination of groundwater

Due to the excess use of fertilizers, insecticides, and pesticides in the rice field, the underground quality of water become polluted. Application of this polluted water causes numerous agricultural issues led toward the rise of many infections and reduced the quality of the grain, which at the end affect the living organisms health. Nitrate leaching is because of more use of nitrogen fertilizers leads to the groundwater contamination causes serious alarm [21]. In short, the contamination of groundwater is an evolving issue which must be attended by creating social awareness.

Weed diversity in the rice field

Unnecessary and different weed flora is an essential issue towards agricultural sustainability as these weeds compete with the rice plant, light, water, and nutrients and reduced the overall production of the land. In Asia, the major biotic constraint in agriculture sustainability is weed as it is causing grain yield losses ultimately. In direct-seeded rice, the water use efficiency is higher as compared to in puddled soil rice because early weeds growth is uncontrollable by flooding in dry direct-seeded rice [22,23]. Therefore alterations in technology, sowing methods, and weed management methods in dry direct-seeded rice result in various weed composition. Therefore, these are the primary source for the yield reduction in any ecology [24,25].

The occurrence of insect-pest and diseases

Rice crop is grown in the extreme environment; the green crop with a high dose of N-fertilizers and wet conditions because of repeated irrigation act as a heaven for the outbreak of insects-pests and diseases. It is generally accountable for lowering of land and water production and considered as a severe problem because it somehow decreased the productivity of the crop. New breeds of insect-pest causing a number of diseases appeared from previous months, the breeders have to developed around more resistant crop varieties to tackle this issue. Some significant diseases in rice are; blast and stem borer, sheath blight disease, false smut, and bacterial leaf blight in rice. From the above mention discussion, it is concluded that evolving disease and insects are a liable source of lowering productivity of land.

Degrading soil structure and health

To reduce percolation losses, easiness in tillage and suppress weeds, rice is generally grown under wet conditions through tillage. Rapid puddling of rice become major source sub-surface compaction apart from labor requirements, which have been unfavorable wheat [26]. Again and again, puddling of soil also affects the soil health to an alarming rate due to deficiencies of micro and macronutrients. Intensive tillage leads to a breakdown of large aggregates along with poor contact with seed and soil contact, which reduce the crop productivity [27]. Conventional practices like burning of crop residues also common in a rice field for management of residu, which is causing serious problems such as loss of nutrients, emission of greenhouse gases.

3. Use of Advanced Techniques and the Role of IT for Sustainable Production of Rice

Resource-conserving technologies (RCTs) are those practices that conserve resources and ensure their optimum utilization and boost up resource or input use-efficiency. It has also following aims

- Mountainous of soil cover, particularly through the retention of crop residues on the soil surface
- Profitable and sensible crop rotation

Direct seeded rice

There is two types of rice cultivation wet and dry-seeded rice. In the dry type of rice cultivation, the seeds of rice can be directly seeded by using a drill, the seeds of rice are seeded into fine seedbed at a depth of 2-3 cm. while in wet seeding the field for rice is leveled and after flooding field was left for 12-24hrs of puddling. The drum seeder is used for sowing of germinated seeds. In both seeded field, seeds can be broadcast, but weeding of the rice field is difficult in both cases. Therefore the timely application of herbicides or one or two hands provides effective control of weeds in a rice field.

Management of crop residue

Crop residues are the major source of organic matter into the soil. It is remaining parts of crops and plant left after harvesting and thrashing. It is not a field waste but an important part of the organic source, which plays an essential role in agriculture stability. Many researchers suggested that cultivation of rice on raised bed areas is good in areas where the groundwater table is dropping its level, and herbicide-resistant weeds are causing a problem for rice crop. Soil tillage and establishment of crop helps in crop modification.

Leaser land leveling (LLL)

Leaser land leveling is the very first conservation technology of land resources. It is the predecessor of all techniques and process of leveling land surface more or less 2 cm from its present average elevation using laser furnished dragging machines. For equal and uniform distribution of water and other resources, it is a very beneficial technique to increase the resource use efficiency. It is used to level the land having slop of 0 to 0.2%. It has the following advantages over non leveled land like: it saves water (10-15%) due to uniform distribution of water and land leveling of field, it increases the fertilizer and water use efficiency, 4% increase in cultivated area due to elimination of bunds and channels, and reduce the cost of production and increase crop productivity.

Brown over green manuring

As water resources are reduced nowadays as compared to past, green manuring is not picking up by the farmers. To resolve this issue, brown manuring is being recommended instead of green manuring. In brown manuring, sesbania is intercropped with direct seed rice. After 30 to 35 days the plants of Sabina is killed by spraying 2,4D (without affecting the rice plants). The plants of sesbania turn brown and fall down on the surface and act as mulch. It has following advantages: it helps to reduce the germination of the weed (40-50%), keep the soil moisture conserve, improved soil fertility, and there is no need of water for the growth of sesbania crop in summer before rice when evaporation demand is close to 10-13 mm/ days.

Use of advance technologies for rice

Precision farming system (PFS)

In developing countries for the promotion of agriculture, they should allow entry of IT which will move agriculture from its traditional pathway towards mechanized agriculture. In this way, they will improve the labor efficiency and productivity before getting high level in PFS. Site-specific or precision farming (PFS) is a manner of crop management by which areas of land within a field may be managed with different levels of input depending upon the yield potential of the crop in that particular area of land. There are following advantages of precision farming:

1) Production cost in the area can be reduced

2) Control of environmental pollution due to lower level use of agrochemicals

It is an integrated agriculture management system along with several other intercropping techniques. These technological tools mostly are the global positioning system (GPS), geographical information system (GIS), remote sensing, yield monitor, and variable rate technology.

Rice integrated crop management

All the innovations and technologies described in this chapter described works for the PFS. In most of the developing countries research wing of agriculture is familiar with PFS. In industrial countries, the tools and the technologies used in PFS are beyond the access of poor farmers. Both the continent Asia and Africa are making slow progress in mechanizing agriculture because they are less advanced in IT and it's everyday usage in PFS. Due to this reason, scientist and field workers in developing countries use integrated crop management to improve crop yield across the fields. The basic unit of PFS is spatial, and temporal variability is the basic unit of PFS. To determine the yield of rice production, the correct use of fertilizers is essential due to its effects on grain yield, crop establishment, and pest and weed occurrence. In Asia, for the correct use of N-fertilizers chlorophyll and leaf color charts are used by farmers to check the field-specific N management [28]. For farmers having small landholding in the continent, it's not an easy job to convince them for crop management.

There are several factors that determine the crop management practices like varieties of crop, factors of environment, market trends. PFS improves the skills of farmers by using the data collected and information because it is the major feature and due to its joining into the improvement and dissemination of rice integrated crop management (RICM) in a number of developing countries.

The rice growing farmers perfume number of traditional operations during rice sowing season, all these operations directly or indirectly affect the crop growth and development and automatically yield. RICM systems identify the problems of rice growing area by following framework [29,30]:

1) Identification of the area needs more management.

2) Computing the good management practices (GMP) of progressive grower and analysis of production technology and practices adopted by farmers. It is done to identify the problems and differences in management from area to area.

3) Study of previous literature: The study of outcomes of researchers, field workers, and farmers is important to improve current knowledge.

4) Development of temporary organize step by step GMPs with the collaboration of with researchers, extension workers, and farmers.

5) After the formation of evaluation of GMPs with the help of experienced farmers and trained extension worker in group discussions.

Therefore in developed areas of the world agricultural and research scientist use the IT, e.g. GPS, GIS and yield maps to articulate recommendations for site-specific management and implementation of pest, drought, floods, and diseases management plans.

Global positioning system (GPS)

GPS is a manged system of satellites that save and record the information about longitudes, latitudes, and elevation with almost 100 and 0.01 m accuracies [31]. It tells about the accurate location of field features like pests, weeds, water holes, soil, hurdles, and field boundaries; therefore, according to this information, farmers are able to use agrochemicals effectively. It also helps them to check the performance criteria and history of previous input usage [32]. There are following functions performed by using GPS: farms machines are guided along long tracks by making small scale deviations, able to avoid repeating the same row of crops when applying different chemicals on the crop rows,

Tools and apparatus can be operated in the same way from year to year, It makes conceivable to work at night or in the mud with precision because it is not affected by weather changes and a supplementary recorder can store field information to be used in making a map [33].

Geographic information system (GIS)

Its use starts from 1960, comprises software, hardware, and procedures designed to help the assembling, storage, recovery, and analysis of characteristics and data of a certain location to create maps. The linkage of information in one place so that it can be extrapolated when needed, is the main function of GIS. The GIS database of a farm provides information on topography, drainage from surface and subsurface, soils type and testing, irrigation, amount of chemical applied, and crop yield. After analysis of data, one can be able to understand the relationship among numerous components affecting the crop on a specific spot [34].

GPS and GIS is an important tool for PFS

As the rice field is more vulnerable for insects, pests, and diseases as the field conditions are more suitable for the growth of these insects and pests. To tackle these insects and pests at their specific location field portable GPS and GIS receivers are available for rapidly making insects invasions and data collected from this can be accurately communicated to the field manager who may apply some specific spry and chose some relevant specific chemicals for the specific site of infection. It's not only for time the application of these chemicals but also the spray operator can provide history or record to the field manager with GPS data where and when the treatment took place [35]. Identification and mapping of crops are needed nowadays to get more precise information of the field to conserve the resources. Crop mapping is done both at national and international levels agencies, and local agricultural boards to prepare a record about what was grown in certain areas and to identify the age of the crop. The most important activities include the identification of crop types and depict their extent (often measured in acres). The efficiency and accuracy of data are enhanced when remote sensing data products and GIS are used as shown in **Figure-1**.

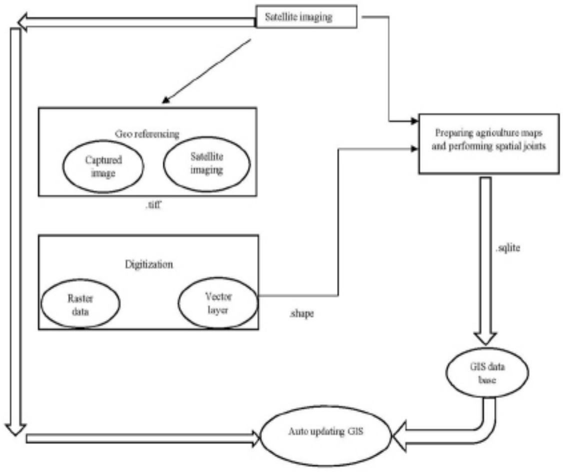

Figure 1: Flow of system in GIS and satellite imaging

Table 1: Per capita water availability in major rice-growing countries of Asia (2000–2050).

Country	2000 m^3	2005	2010	2015	2020	2050
China	2210	2134	2068	2006	1956	1927
India	2000	1844	1717	1611	1525	1292
Japan	4314	4292	4307	4348	4423	5381
Indonesia	12,325	11,541	10,881	10361	9952	8781
Nepal	6958	6245	5695	5230	4820	3467
Pakistan	3159	2822	2533	2277	2069	1396
Philippines	4158	3778	3450	3175	2945	2210
Sri Lanka	2302	2212	2117	2041	1990	1990
South Korea	1424	1390	1363	1345	1336	1500
Thailand	2871	2714	2627	2559	2505	2440

Along with this rice productivity is the major concern of farmers and also the sustainability of rice production. For this purpose the yield monitors will be connected to GPS receivers to map yield. The resultant yield maps will help identify areas of the field requiring different treatments [36].

Sensor technologies

There are various sensor technologies used in agriculture to measure used to measure temperature, vegetation, humidity in air and vapor etc. These include electromagnetic, conductivity, photo-electricity, ultrasound, etc. The important and commonly known as remote-sensing it is used to find out stress conditions, pests and weeds, differentiate crop species, soil, and plant conditions. Sensors enable the collection of a large amount of data without analysis in the laboratory. The use of sensor technology at farm operations are; to check physicochemical conditions of soil [37], sense colors to understand plant conditions relating, e.g. plant population, water scarcity, and plant nutrients, Monitor crop yield and humidity, Variable-rate system to monitor the movement of fertilizers and check weed attack.

Use of remote sensing in agriculture

In agriculture, most of the farming in a broad acre is carried out by using human-driven machines nowadays.

Intensive farming methods in mechanized agriculture, farmers lack applied experience for sensing the condition of the field. Remote sensing method has been suggested, which helped in precision farming to collect data and the analysis of data to check out the growth throughout the season. Satellite imaging data availability is increasing day by day during the season. Drusch et al., 2012 coated the examples such as satellite images from Sentinel-2 satellites are available and provided by the European Space Agency (ESA). Drones, or Unmanned Aerial Vehicles (UAV), or Remotely Piloted Aircraft System (RPAS) are another source for remote sensing. With drones, imaging is possible in cloudy conditions, whereas satellite-based imaging is limited in these situations [38].

Use of Unmanned aerial system (UAS) for monitoring rice field

UAS required because of its monitoring technologies of crop diagnostic information due to their advantage in manoeuvering tasks at high-spatial resolutions and low costs in a user-friendly manner. Jeong et al., [39] reported that UAS-based remote sensing techniques could represent an innovative way of projecting reliable spatiotemporal crop productivities for precision agriculture in the rice field. In drought assessment of rice field area, application of UAV (Unmanned Aerial Vehicle) remote sensing and geo-information system (GIS) based images in detection and measuring of rice field drought area in South Korea was carried out by research, and they concluded that Drought-damaged paddy rice reached is 47.1 %. For paddy rice by UAV investigation, the drought monitoring and crop productivity were effective in improving drought assessment method [40].

UAS also plays its important role in quick and accurate detection of plant disease at the field scale and improve the management of diseases effectively by on time and site-specific application of fungicides and pesticides. Most important rice disease in the world was detected accurately and quickly with the combined use of a UAV with high-spatial resolution camera is an innovation that has the high potential for quick and accurate detection of ShB, one of the most important diseases in rice in the world. This technology can aid in the scouting and monitoring process of this disease and reduce the costs in time and effort associated with this process. This UAV system in the current form can also assist crop breeders in breeding for rice cultivars with resistance to ShB [41].

Variable-rate technologies (VRT)

It is a reflexive technology used in the numeral operation of farm operations. According to map and set rate, the inputs are applied on the soil as its type is already noted. GIS Information can control processes, i.e., seeding, fertilizer, pesticide, herbicide selection, and application, at a moveable but appropriate rate, time and place [32,42].

Grain yield monitors for mapping

To measure the grain yield of wheat, rice, barley and oat crops a video display unit attached on the combine harvester which constantly measures and records the grains flow in the grain elevator. After linking of it with GPS, yield monitors can offered data for a yield based map that helps farmers to regulate the complete controlling of inputs such as fertilizer, pesticides, tillage, lime, seed, and water [43].

4. Conclusion

Rice is an important crop in many countries of the world on this blue planet. There are a number of issues in the sustainability of rice production to full fill the dietary requirements of the growing population. To solve this issue their number of adoptable technologies along with the use of modern IT technologies which helps to sort out the rice issues like insect pests, nutrient management, weed control, improvement of soil health and control of environmental pollution. From last few decades, latest technologies are included in the precision agriculture to improve the productivity of the crop. These technologies are useful where human interventions are not possible for spraying of chemicals on crops and scarcity of the labor. This could also be reduced the wasting of water and chemicals.

Future aspects

IT in precision agriculture and rice cultivation is still in its early stage and maybe scope for further development in both the technology and the agriculture applications. Conveniently, it is used that with the development of IT, improved image processing techniques, lower costs, new camera designs, low volume sprayers, and nozzle types. A significant number of experimental studies of IT-based remote sensing, use of GPA, GIS, and drones for agriculture application. It will be a more noticeable benefit of these systems in precision agriculture and environmental monitoring.

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