Safeguarding Plant Health for Sustainable Rice

Our health and that of our environment depend on the health of our plants. Plants provide us with the oxygen we breathe and the food we eat. Yet they are regularly under threat by natural disasters, such as floods and droughts but also pest and disease infestations. The latter often leads to chemical exposition. These problems pose health risks that take place at the bottom of our food chain.

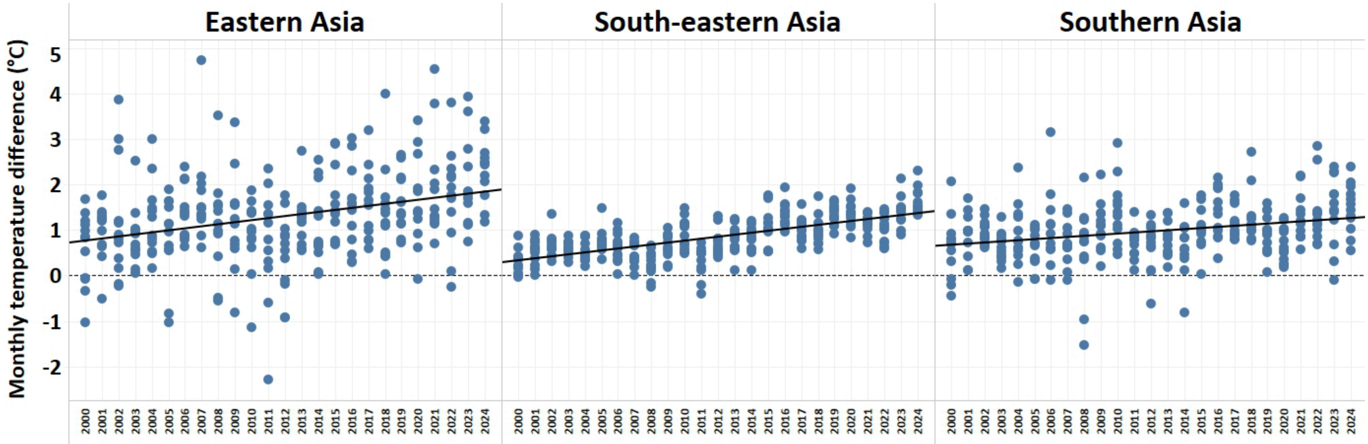
What threatens the health of rice?

When we think about 'being healthy', we tend to think of being able to perform in our daily lives without any restrictions imposed by factors of disease, disability, or anything limiting our body from functioning. But what about the health of rice plants?

Whether we look at plants from an ecosystem-centric or human-centric point of view, different perceptions of plant health emerge that make an understanding of a healthy plant subjective.[1] Plant health can be captured by an overall sense of growing without withering, blooming until fruition, and maintaining the ability to reproduce. The wellbeing of plants depends on factors of biological, environmental, and human-induced challenges.

[1] Perspectives on plant health: (i) the role of values in defining plant health in a naturalist versus a normativist approach; (ii) negative and positive definitions of plant health; (iii) reductionist versus holistic perspectives; (iv) the focus on functionality versus resilience, i.e. the ability of the plant to perform under stress with or without human interference; (v) materialist versus vitalist approaches; and (vi) biocentric versus anthropocentric view. Döring et al. 2012. Concepts of plant health - reviewing and challenging the foundations of plant protection. In: Plant Pathology 61(1) April 2012. DOI:10.1111/j.1365-3059.2011.02501.x

Figure 1: Temperature change between 2000 to 2024, compared to the average temperature from 1951 to 1980



Note: A blue dot represents one month from January to December in each respective year.
Source: FAOSTAT, accessed April 2025.

Weather Extremes

Healthy plants better resist weather induced environmental stressors of floods, droughts, and temperature extremes. They better resist or recover from insect or rodent pests and disease inducing pathogens. A major challenge that exacerbates those stressors on rice plant health is climate change.

With increasing temperatures, the global and regional ecological systems are disrupted. Rainfall becomes more unpredictable and extreme. Droughts become more frequent and prolonged. And floods become more frequent and devastating. This poses significant challenges to rice production. For example, in 2021 the Siem Reap province of Cambodia suffered a rice crop loss of 14,000 ha due to extensive droughts.[2] In terms of sports enthusiast, that area equates to 19,185 football fields.

In Asia from 2000 to 2024, increasing temperatures have been recorded for nearly every month, year by year (**figure 1**). In South-eastern Asia, since 2012 every month has been warmer on average compared to the baseline average temperature between 1951 to 1980. In Southern Asia, higher temperatures are noticeable in several month since at least 2006 being approx. 3°C higher. In Eastern Asia, temperature fluctuations are most pronounced: although negative temperatures are also prominent for individual years up until 2012, many months reached highs of 4°C to 5°C. Overall, every region recorded an increase of its average monthly temperatures until 2024.

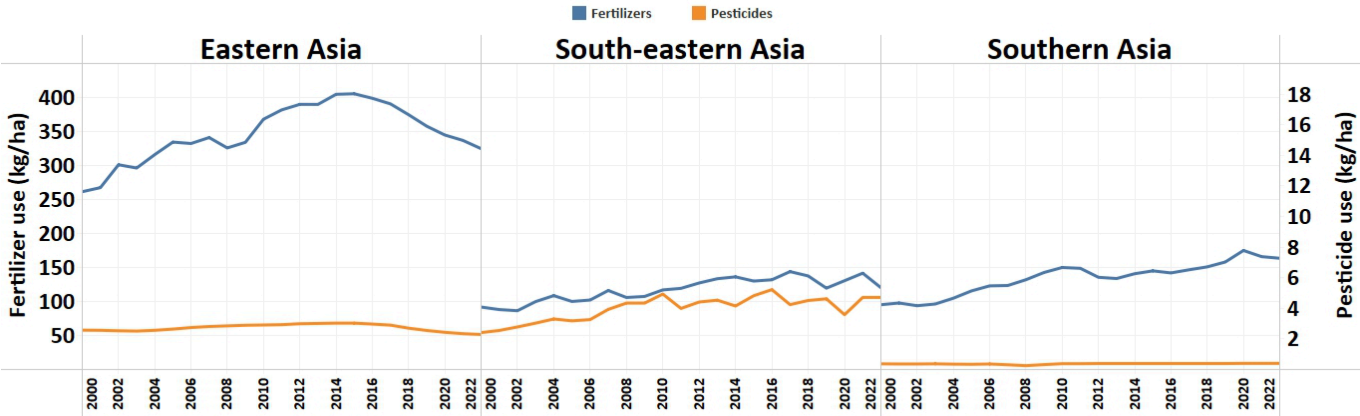
[2] Chakrya, Khouth Sophak. 2021. Drought destroys rice crops in Siem Reap. *The Phnom Penh Post, 26 August 2021. Access:* https://www.phnompenhpost.com/national/drought-destroys-rice-crops-siem-reap

The climate in Asia is changing and these changes disrupt healthy plant growing cycles. Prolonged droughts limit water availability, stunting rice growth and reducing grain quality. Extreme rainfall, on the other hand, leads to the prolonged submergence of too much of the rice plant, leading to waterlogging if not drowning it in the process. And severe storms result in flash floods upturning entire crop fields. As most plants, without sufficient or too much water, rice plants struggle to develop properly, leading to lower yields and economic losses for farmers.

But the challenges for healthy rice plants do not stop at weather events. Increasing average temperatures often create more conducive environmental conditions which both promote the reproduction of pests and diseases as well as enabling their propagation beyond their climatic and geographic origin.

Warmer temperatures and increased humidity create ideal breeding conditions for pests and diseases as, in short, more favorable conditions accelerate metabolisms and reproductive cycles among animals, insects, fungi, bacteria and viruses. As temperatures rise, the geographical distribution of many pests and diseases also expands towards previously cooler regions. This exposes plants not only to more pests and diseases in any one growing cycle but also to those which they had not encountered before, leaving plants without a natural resistance to them. The combination of extreme weather events with pest and disease spread threatens healthy rice cultivation.

Figure 2: Pesticide and fertilizer use from 2000 to 20022



Note: Pesticides include: Insecticides, Mineral Oils, Herbicides, Fungicides and Bactericides, Plant Growth Regulators, Rodenticides, other pesticides not elsewhere specified; Fertilizers include: Nitrogen, Phosphate, Potash.
Source: FAOSTAT, accessed April 2025

Crop Management

Such altered dynamics lead to more intensive infestation management strategies, whereby pesticides tend to be a primary tool for controlling outbreaks and protecting crops. Studies have shown a correlation between increased temperatures and pest outbreaks in rice, with farmers responding by increasing pesticide use to mitigate crop losses.[3] It goes without saying that other factors, such as industry marketing, also influence an increase in chemical use.[4]

Although no rice specific data is available for regional insights, comparing the application of pesticides in the agriculture sector between 2000 to 2022 (**figure 2**) indicates that in South-eastern Asia in particular, pesticide use from 2.4 kg/ha in 2000 to 4.7 kg/ha in 2022, being highest at 5.2 kg/ha in 2016. Eastern Asia saw slightly elevated applications, increasing from 2.6 kg/ha to 3.0 kg/ha in 2016, after which it declined until 2022 to 2.3 kg/ha. Southern Asia remains at low and even levels of about 0.4 kg/ha. Not only has pesticide use doubled and tripled in Eastern Asia and South-eastern Asia over decades, those regions far exceed worldwide averages.[5]

With its rapid increase in use, South-eastern Asia appears to face a dramatic need for combating pest and disease in agriculture. While this increase does not serve as evidence for increasing pests and diseases in consequence of climate change by itself, it nevertheless underscores the elevated stress placed on plant health in agriculture.

The excessive use of pesticides in agriculture can have severe consequences for plant health. While chemicals can protect rice crops and enhance yields, their overuse compromises short-term yields and cripples soil conditions long-term.[6] Not to forget, an overuse of pesticides can disrupt natural pest resistance of plants, making rice crops more vulnerable to infestation and disease over time. It can also harm beneficial insects, such as pollinators, as well as poison natural predators of pests, further affecting the natural balance of the ecosystem.

Adding to the effects of pesticides, excessive fertilizer application, especially nitrogen-based fertilizers, can further deteriorate healthy rice plants by weakening the overall plant stability, reduce nutrient uptake efficiency, and increase susceptibility to diseases.[7] While it is without question that

[3] For example: Arifah et al. 2022. Climate change impacts and the rice farmers' responses at irrigated upstream and downstream in Indonesia. In: *Heliyon, Volume 8, Issue 12, December 2022, e11923*. Access: https://www.sciencedirect.com/science/article/pii/S240584402203211X

[4] Compare: Peshin, Rajinder. 2023. Impact evaluation of rice integrated pest management dissemination programs on adoption and pesticide use in Punjab, India. In: *International Journal of Tropical Insect Science 43(1):1-12.* DOI:10.1007/s42690-023-00994-9. Access: https://www.researchgate.net/publication/369943442_Impact_evaluation_of_rice_integrated_pest_management_dissemination_programs_on_adoption_and_pesticide_use_in_Punjab_India

[5] Worldwide average use of pesticides stood at 1.2 kg/ha in 1990 and 1.5 kg/ha in 2000, and 2.4 kg/ha in 2022. (Soruce: FAOSTAT, accessed April 2025)

[6] Chen, R. and Zhang, Q. 2024. Pesticide Usage in Rice Cultivation: Consequences for Soil and Water Health. *In: Molecular Soil Biology, 2024, Vol. 15, No. 3.* DOI: 10.5376/msb.2024.15.0013. Access: https://bioscipublisher.com/index.php/msb/article/html/3884/; Maneepitak, S. and Cochard, R. 2024. Uses, toxicity levels, and environmental impacts of synthetic and natural pesticides in rice fields – a survey in Central Thailand. *In: International Journal of Biodiversity Science, Ecosystem Services & Management, 10(2), 144–156.* DOI: 10.1080/21513732.2014.905493. Access: https://www.tandfonline.com/doi/full/10.1080/21513732.2014.905493

[7] Yu, Lula et al. 2025. Effects of nitrogen fertilizer application rate on lodging resistance for rice (Oryza sativa L.) stem. *In: Scientific Reports 15, 2149 (2025).* DOI: 10.1038/s41598-025-85641-8.

fertilizers can have a positive effect on rice crop growth and its quality, their continued application poses a detrimental effect on healthy growth.[8]

As also shown in **figure 2**, fertilization increased in South-eastern Asian by approx. 33 percent and Southern Asia by approx. 44 percent from 2000 to 2022. In Eastern Asia, the trend appears to have reversed from its peak in 2015 when fertilization increased by 55 percent, whereas in 2022 it stood at an increase of 20 percent compared to the year 2000. Despite the reversal, Eastern Asia applies the largest amount of fertilizer not only among the compared regions but worldwide. In any case, the higher application of fertilizers demonstrates a need for increased application. This may indicate changing environmental conditions as well as shifting to substances requiring higher amounts.

In any case, the fertilizers and pesticides are likely to extent to plants in adjacent areas through water runoff from the rice fields. An over-application also poses health risks to aquatic life and human health, leading to oxygen depletion in rivers and lakes as well as contaminating groundwater, besides airborne transmissions affecting respiratory tracts. Additionally, an accumulation of these substances within the fields degrades soil quality over time, ultimately backfiring on healthy crop growth.

What are common pests and diseases of rice?

With warmer environmental conditions, pests and diseases can be expected to spread more rapidly and more frequently. Currently, rice yield losses due to pests and diseases, excluding weather events, have been estimated to sit between 24.6 to 40.9 percent globally.[9]

Diseases

Rice is susceptible to numerous diseases that can impact yield and quality. Some of the most common include bacterial blight, which causes seedling wilting and leaf yellowing; bakanae, a seedborne fungal disease that infects plants through the roots or crowns; or rice blast, which can affect the leaf, collar, node, or neck, can lead to severe yield losses by reducing grain production. Tungro is particularly present in South and Southeast Asia, and is transmitted by leafhoppers.

Rice blast: This disease goes by many names, such as ryegrass blast, oval leaf spot, pitting disease, rice rotten neck, or Johnson spot and it is one of the most common and thus destructive diseases. As a fungal disease, is can be highly destructive to rice plantations. Rice blast caused by the fungus Magnaporthe oryzae. It occurs under moist conditions and frequent and prolonged periods of rain in combination with cool temperatures and affect all aboveground parts of a rice plant. In upland rice, large day-night temperature differences that cause dew formation on leaves provide ideal conditions for this fungus. Though a rice plant can be affected by the disease in all growth stages, its incidence rate tends to lessen as plants mature and develop higher resistance.

How to identify: Initial symptoms appear as white to grey-green lesions or spots, with dark green borders. Older lesions on the leaves are elliptical or spindle-shaped and whitish to grey centers with red to brownish or necrotic border. Some resemble diamond shape, wide in the center and pointed toward either ends.

Bacterial blight: Bacterial blight is caused by Xanthomonas oryzae. Bacterial blight is another serious disease among rice. The disease is most likely to develop in areas with weeds and stubbles in addition to tropical and temperate environments, particularly in irrigated and rainfed lowland areas with prolonged humidity above 70 percent. That makes rice the ideal target plant given its

Access: https://www.nature.com/articles/s41598-025-85641-8; Haque, M. M., Biwas. J. C. 2020. Long-Term Impact of Fertilizers on Soil and Rice Productivity. *In: Resources Use Efficiency in Agriculture (pp.259-282).* DOI:10.1007/978-981-15-6953-1_8. Access: https://www.researchgate.net/publication/344334120_Long-Term_Impact_of_Fertilizers_on_Soil_and_Rice_Productivity_8; Frontini, M. et al. 2022. Increased Rice Susceptibility to Rice Blast Is Related to Post-Flowering Nitrogen Assimilation Efficiency. *In: Jounral of Fungi, 8(11), 1217.* DOI: 10.3390/jof8111217. Access: https://www.mdpi.com/2309-608X/8/11/1217

[8] Irawan, S. and Antriyandarti, E. 2021. Fertilizer Application, Climate Change and Rice Production in Rural Java. *In: IOP Conference Series: Earth and Environmental Science. 755.* DOI: 10.1088/1755-1315/755/1/012086. Access: https://iopscience.iop.org/article/10.1088/1755-1315/755/1/012086/pdf

[9] Savary, S. 2019. The global burden of pathogens and pests on major food crops. In: Nature Ecology & Evolution volume 3, pages 430–439. DOI: 10.1038/s41559-018-0793-y. Access: https://www.nature.com/articles/s41559-018-0793-y

environmental requirements. It is commonly observed when strong winds and continuous heavy rains occur, allowing the disease-causing bacteria to easily spread through ooze droplets from infected plants. High nitrogen fertilization further the conditions for bacterial growth. As a rule of thumb: the earlier the disease occurs, the higher the yield loss can be expected.

How to identify: Notable wilting and yellowing occurs on leaves and wilting can take place at rice's seedling stage (also called kresek). On seedlings, infected leaves turn greyish-green and roll up. As the disease progresses, the leaves turn yellow to straw-colored until drying up and causing the plant's death.

Bakanae: Bakanae is a seedborne fungal disease caused by Fusarium fujikuroi. It grows systemically within the plant and spreads further through infected rice seeds. The infection can cause seedlings to die at the early tillering stage. If the plants survive to maturity stage, they tend to become abnormally tall with pale, thin leaves and fewer tillers, and they notable produce only partially filled or empty grain. The grain may also be sterile. The disease spread occurs when seeds covered in fungal spores are used at the planting stage, but also can when the pathogen is present on adjacent plants or in the soil. Present spores can be spread by wind and water from one plant to another, so can farm operations.

How to identify: Infected unhealthy seedlings have lesions on roots, which can die before transplanting or immediately after. Infected plants are several inches taller than normal plants. They are also thin, with yellowish green and pale green leaves. During their growth stage, a white powder substance at the base or on the lower portion of the infected plant can be found.

Tungro: Tungro is one of the most damaging and destructive diseases of rice in South and Southeast Asia. The tungro disease is a combination of two virus types, tungro baciliform and tungro spherical virus. The disease is typically transmitted by grasshoppers. The infection can occur during all growth stages of the rice plant, but is most frequently observed during the vegetative phase. Leafhoppers prefer to feed on young rice plants, when the plant is most susceptible to infection. Infections can also take place from infected stubble of previous crops, and infected plants carried over from nearby fields. Once it is present in the field, it increases rapidly in young rice plants and can cause total yield loss.

How to identify: A primary warning sign is the presence of leafhoppers. Once infection has taken place, yellow to orange discoloration is noticeable among plants. Discoloration begins from the leaf tip and extends down to the lower leaf portion. Infected leaves may also show mottled or striped appearance, rust-colored spots, and inter-veinal necrosis.

Other viral diseases like rice grassy stunt and rice stripe virus disease inhibit panicle production and can cause substantial yield losses. Fungal diseases, such as false smut leading to chalky grains and reduced seed germination, or brown spot causing large leaf spots, also pose threats. These are just a few examples of the many diseases affecting rice, with several others posing serious risks to production and food security.

For more information, consult IRRI's Rice Knowledge Bank on diseases.

Pests

Insects pose major threats that are detrimental to rice plants. As there are countless insect species, rice plants are subjects to numerous insect predators. Many insects causing harm can be categorized by the type of damage they cause.

Grasshoppers and locusts can consume the entire aboveground rice plant, from the leaf to the stem, and in consequence destroy rice crop production, in particular when occurring in large numbers. While locusts tend to roam in drier environmental conditions, grasshoppers tend to thrive in tropical conditions. Many insects feed on parts of the rice plant and utilize the plant as shelter causing damage in the process. Leaf-feeding

Armyworm Spodoptera mauritia; Green semilooper Naranga aenescens (Moore); Rice leaffolder Cnaphalocrocis medinalis; Short-horned grasshopper Oxya hyla intricata (Stal).

insects, such as **rice leaffolders**, **semiloopers**, and **armyworms**[10], scrape leaf tissue, leading to defoliation, or cut into leaf blades. Loss of leaves leads to reduced photosynthetic capacity. At the vegetative phase, a plant can recover from non-extensive damage, but plant growth can also be stunted. When infestation and damage take place at the reproductive (grain forming) phase, the reduced photosynthetic capacity results in yield losses.

A number of insects have specialized in sucking plant fluids—its sap—instead of consuming the plant fiber. Extracting fluids from leaves or stems causes dehydration of the plant, resulting in withering and impaired plant vitality. As in the case of partially or fully consumed plant material, dried leaves lead to reduced photosynthetic capacities and stems become brittle and incapacitated to transport liquid to higher parts of the plant, causing further withering.

Brown planthopper Nilaparvata lugens (Stal); Green leafhopper Nephotettix malayanus; Zigzag leafhopper Recilia dorsalis (Motschulsky); Mealy bug Brevennia rehi (Lindinger).

Green leafhoppers are the most common leafhoppers in rice fields and are primarily critical because they spread the viral disease tungro. They are common in rainfed and irrigated wetland environments, but not in upland rice. They also prefer rice plants that have been fertilized with large amount of nitrogen.

The rice **zigzag leafhopper** is found in all rice environments. It is abundant during the early rainy season in the early growth stages of the rice plant. The adults usually stay in the upper parts of the rice plants.

[10] There are at least three species of armyworm which attack rice in Asia. These are the rice swarming caterpillar, common cutworm, and the rice ear-cutting caterpillar.

Brown planthoppers cause leaves to turn orange-yellow before becoming dry and killing the plant—a condition called hopperburn. Planthoppers can be a problem in rainfed and in irrigated wetlands but also under continuously submerged conditions. Closed canopy of the rice plants, densely seeded crops, excessive use of nitrogen, and early season insecticide spraying also provide a breeding ground.

The **mealybugs** thrive under dry periods, well-drained soils, and the presence of grassy weeds. They are typically found in upland and intermittent rainfed environments.

Rice bugs also damage rice by sucking out fluids but target the developing grains from pre-flowering spikelets, causing empty grains. Nearby woodlands, wild grasses, or weedy areas near rice fields provide favorable population conditions. Warm weather and frequent drizzles, such as at monsoon onset and end of rainy seasons favor its population buildup.

The **stemborer** larvae bore at the base of the rice plant during the vegetative stage. On older plants, they bore through the upper nodes and feed toward the base. They cause 'dead hearts'—drying of the central tiller. There are several species of stemborer, each thriving under different conditions.[11] For instance, the yellow stem borer is a pest of deepwater rice, found in aquatic environments with continuous flooding. Striped stem borer is most abundant in non-flooded areas of temperate countries. The pink stem borer is found in upland rice, which is grown near sugarcane or related grasses. Unlike other species of stem borers, the pink stem borer lay bare eggs between the leaf sheath and the stem.

Mole cricket Gryllotalpa orientalis (Burmeister); Gold-fringed stemborer C. auricilius (Dudgeon); Rice bug Leptocorisa acuta (Thunberg).

Mole crickets feed on seeds, tillers in mature plants, and roots. They can cut rice plants at the base resulting in a total loss of the plant. Mole crickets occur in all types of rice environments. They are most common in non-flooded upland fields with moist soil. In

[11] In Asia, there are the yellow stemborer, white stemborer, striped stemborer, gold-fringed stemborer, dark-headed striped stemborer, and the pink stemborer.

flooded rice fields, mole crickets are usually seen swimming in the water.

Crickets are both leaf- and stem-feeding insects. They are active at night, and their nymphs are more destructive than the adults. They are common in the irrigated rice environment. In upland environment, the insects are found underneath heaps of weed piles.

For more information, consult IRRI's Rice Knowledge Bank on insect pests.

What can IRRI do to support the health of rice?

Efforts to modernize and intensify rice production by increasing fertilization, increasing pesticide treatments, increasing crop-per-season production, under increasing climate constraints is the equivalent to feeding the human body stimulants and painkillers for ever increasing workload demands while the house is on fire.

A key pattern to avoid is the initiation of cultivation cycles that are too demanding of natural resources and do not take into account the ecosystem surrounding agriculture.

To avert collapsing plant health and the food (production) chain, IRRI promotes ***integrated pest management (IPM)*** through more pest- and disease-resistant varieties, ecological engineering approaches, and integrated pest management strategies. The premise of IPM is that no single control method can be successful over a long period of time. For sustained success, integrating strategies to control multiple infestations into crop cultivation is essential. For example, the development and incorporation of new rice varieties with pest and disease resistance through breeding reduces the reliance on chemical interventions.

Site-specific nutrient management (SSNM) is important to satisfy healthy crop growth with needed nutrients while not poisoning the soil and adjacent waterbodies. SSNM reduces the overall quantity of fertilizer required, leading to a lower cost of farm management, higher profit, and a reduced environmental impact. It also reduces greenhouse gas emissions as a more efficient use of nitrogen reduces nitrous oxide emission from the field, as well as indirect emissions by reducing the need for producing nitrogen fertilizer.

IRRI has developed and continues to develop tools and methodological **protocols for monitoring rice diseases and pests**. For example, IRRI created markers to identify and track the distribution of bacterial blight.[12] IRRI also developed DNA-based diagnostic methods for diseases such as Tungro, Sheath rot, and Bacterial leaf streak. Currently, a forecasting model is under development to predict the severity of rice blast under specific climate conditions.

Through **genome identification and editing**, IRRI is exploring ways to accelerate the development of drought-tolerant and disease-resistant rice cultivars. Using this technology, processes that would traditionally take decades through crossbreeding methods can potentially be accomplished much faster.

IRRI is also searching for **natural solutions** to prevent or manage infestations. These include utilizing helpful insects or microbes (biocontrol agents) that help manage pests and diseases either by directly attacking pests or by helping the plant defend itself.

IRRI explores **integrating drones** to better manage pests and diseases by farmers, such as for nutrient monitoring through real-time assessments for mid-season fertilizer application, weed monitoring for zonal and hot spot herbicide application, and disease surveillance and early detection.

But holistic farm management is key. This involves integrating resistant cultivars, efficient agronomic practices, and conservation practices that support and enhance the natural ecosystem. To further promote healthy rice plants, farmers and policymakers must collaborate on sustainable practices, explore organic alternatives, and adopt precision agriculture techniques that do not contribute to climate change any further.

Declared by the United Nations, the International Day of Plant Health is celebrated on 12 May to raise to encourage communities to tackle plant and crop health issues as a way to help end hunger, reduce poverty, protect biodiversity, and boost economic development.

[12] See PathoTracer: http://3.0.204.70/pathotracer2/