RSIS S. RAJARATNAM SCHOOL OF INTERNATIONAL STUDIES
Nanyang Technological University, Singapore

NTS INSIGHT

NTS Insight, no. IN23-03, October 2023

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Is Rice Production Becoming a Wicked Problem?

By **Paul Teng** and **Jose Ma. Luis Montesclaros**

There has been a recent chorus of concerns about global warming's impacts. While the UN Food and Agriculture Organization (FAO) has projected the need to increase rice production by 5 million tonnes per year to meet growing demand up to 2050, it is hampered by climate-related disruptions, from short-term droughts and floods to longer-term yield and production declines. Adding to these, growing more rice will inevitably lead to more methane and nitrous oxide emissions, which contribute significantly to greenhouse gase (GHGs) emissions to which climate change has been attributed. This presents a "wicked problem" of meeting both food security requirements as well as reducing greenhouse gas emissions. What is the scientific evidence that supports the concerns about insufficient growth in rice production to feed the demand from a growing population of rice eaters, and how can the apparently contrasting goals of producing more rice and reducing GHGs be reconciled?

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Recommended citation: Paul S. Teng and Jose Ma. Luis Montesclaros, 'Rice Production as a Wicked Problem,' NTS Insight, No. IN23-03 (Singapore: RSIS Centre for Non-Traditional Security Studies (NTS Centre), Nanyang Technological University Singapore. 2023).

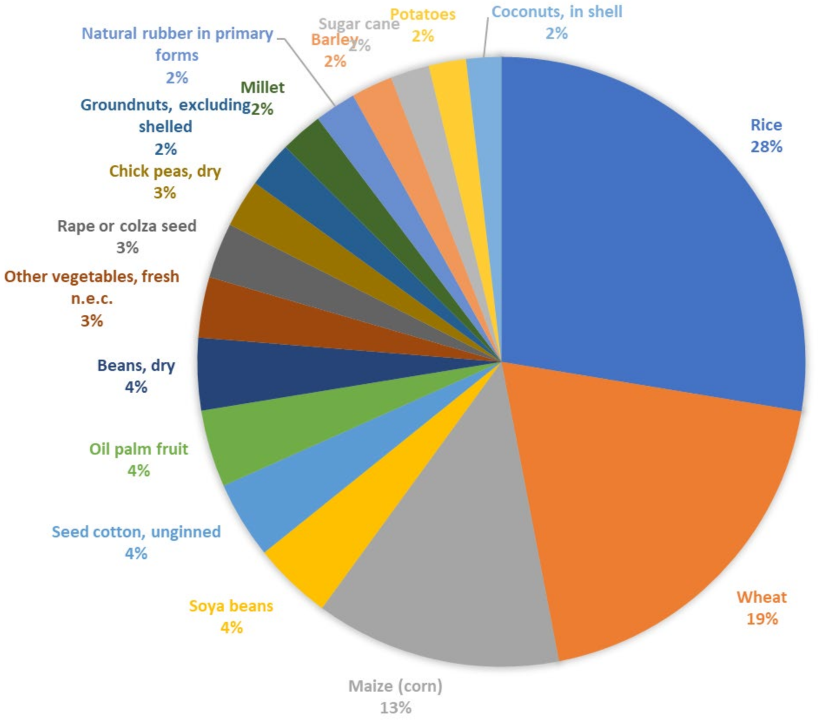
Introduction

Rice is unarguably among the most important food crops globally and in Asia (Figure 1). Globally, rice supports the calorie needs of over 3.5 Billion people. Within Asia are the world's two largest rice producers and consumers (China and India) and the three largest rice exporters (India, Vietnam, Thailand). Rice is thinly traded, though, in the sense that the amount of rice that is available for exports/trade is very small relative to the amount of rice that is produced globally, at less than 10% of global production each year. This also means that most rice is consumed close to where it is grown. Any shortfall in rice production impacts on the food security of millions.

Higher prices of rice are commonly seen as an indication of its scarcity as a commodity. Rice prices have been increasing since the beginning of the millennium. From 2000 to 2020, the price of Indica rice, which is the most commonly consumed type of rice, has more than doubled.[1] Generally, this has followed the prices of other cereals. For example, the **FAO Cereal Price Index** averaged 170.1 points in March 2022, up by 24.9 points (17.1 percent) from February 2022 (Figure 2).[2] The FAO Rice Price Index shows that for the "All rice category", prices rose from an index score of 97.9 in August 2021 to an index score of 103 in March 2022 amidst the Ukraine war, or an increase of 5.2%.[3]

Figure 1: Hectarage of Crops in Asia

(Covering top crops representing 1% or more of total hectarage)



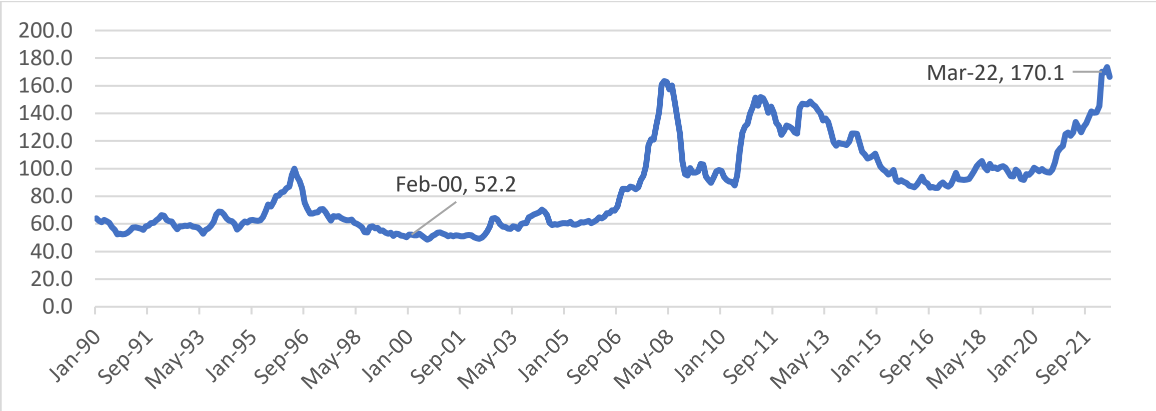
Source: UN FAO. 2023. "Crops and Livestock Products," FAOStat Database, accessed 1 December 2022. https://www.fao.org/faostat/en/#data/QCL

Recent events have surfaced warnings about the many threats to food security arising from multiple factors, including supply chain challenges from the war in Ukraine,[4] as well as earlier challenges from the COVID-19.[5] However, these challenges should not distract from the long-term challenges in ensuring sufficient rice production. The reality is

[1] UN FAO (2022), "FAO Rice Price Update," *UN FAO Website*, https://www.fao.org/markets-and-trade/commodities/rice/fao-rice-price-update/en/, accessed 29 July 2022.
[2] UN FAO (2022), "FAO Food Price Index," *UN FAO Website*, https://www.fao.org/worldfoodsituation/ foodpricesindex/en/, accessed 29 July 2022.
[3] UN FAO (2022), FAO Rice Price Update, Op. Cit.
[4] Jose Ma. Luis Montesclaros and Mely Caballero-Anthony, 2022, "Asean should deal with food security concerns," *The Straits Times*, 28 May.
[5] Serpil Aday and Mehmet Seckin Aday, "Impact of COVID-19 on the food supply chain," *Food Quality and Safety* 4, no. 4 (2020): 167-180.

that more rice still needs to be produced in the long-term. This NTS Insight explores these long-term challenges, and the "wicked-challenge" in improving rice productivity to address both climate change adaptation of the rice sector, and objectives of mitigating emissions from the same sector. The concern on whether productivity growth can be sustained in the long-term to feed growing demand hinges on three key factors, namely, climate change, the unsustainability of rice intensification practices, and the industrialization/urbanization of economic landscapes. At the same time, as more rice production inevitably leads to greater carbon emissions, a complex mix of issues surrounding the future of rice production is therefore at play. Is there any sign that this "wicked problem" can be successfully tackled?

Figure 2: Cereal Price Index



Source: UN FAO. 2023. "FAO Food Price Index". UN FAO Website, https://www.fao.org/worldfoodsituation/foodpricesindex/en/, downloaded 18 September 2023.

Climate-Related Threats to Productivity in the "Rice Bowl of the World"

According to a report by the Intergovernmental Panel on Climate Change (IPCC) in 2023, rising global temperatures will increase the likelihood of heatwaves and floods in Asia, exposing the region to threats including food scarcity and health risks.[6] In fact, at the time of writing, NASA has declared the summer of 2023 as being the "hottest summer" on record since 1880.[7]

1. Climate Change Impacts on Productivity

Climate change could result in substantial modifications in land and water resources for rice production as well as the productivity of rice crops grown in different parts of the world.[8] Muehe et al. found for instance that rice yields could drop about 40 per cent by 2100 under future climate conditions.[9] The decline could potentially have devastating consequences for the world since about half of its 7 billion people depend on rice as their staple food. Warnings had been issued in 2022, about drought and floods affecting production in countries like Thailand[10] and China, and the general El Nino phenomenon as of September 2023 has been generally expected to remain through to early 2024,[11] and to have a negative effect on rice availability.[12]

[6] IPCC, 2023, *Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

[7] NASA, 2023, "NASA Announces Summer 2023 Hottest on Record," *NASA Website,* 14 September 2023. https://climate.nasa.gov/news/3282/nasa-announces-summer-2023-hottest-on-record.

[8] Vanessa Lim, "As temperatures rise, Singapore races to find solutions to secure its food supply," Channel News Asia, 22 April 2022, https://www.channelnewsasia.com/singapore/climate-change-singapore-food-supply-rising-temperature-heat-2638356.

[9] E. Marie Muehe, Tianmei Wang, Carolin F. Kerl, Britta Planer-Friedrich, and Scott Fendorf, 2019, "Rice production threatened by coupled stresses of climate and soil arsenic." *Nature Communications* 10, no. 1 (2019): 1-10. https://www.nature.com/articles/s41467-019-12946-4 .

[10] Jack Board, 2022, "Rice and the Climate Crisis: Thai rice farmers struggle against climate-driven challenges", *Channel News Asia*, 22 April. https://www.channelnewsasia.com/sustainability/thailand-rice-farming-climate-challenges-2627961.

[11] National Oceanic and Atmospheric Administration, United States, 2023, "El Niño/Southern Oscillation (Enso) Diagnostic Discussion issued by CLIMATE PREDICTION CENTER/NCEP/NWS", *NOAA Website*, 14 September 2023. https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/ensodisc.html

[12] Elyssa Ludher and Paul Teng, 2023, "Rice Production and Food Security in Southeast Asia under Threat from El Niño." *ISEAS Perspective,* No. 53. 12 July 2023

2. Modest Productivity Improvements in Recent Decades

While farming practices can potentially be adapted to changing climates to maintain productivity growth, it has been found that actual rice productivity in Asia, measured in yields or tonnes of rice production per hectare, has grown very little despite changes in rice farming practices of cultivation, inputs, diseases, pests, and weeds.[13] This was based on observations of over 456 rice fields spread out across the eight eco-regions within Asia, over a 24-year period. In the case of Southeast Asia, Shen Yuan et al.,[14] have given a stark warning that the "rice bowl" status of the region is under severe threat because of the large yield gaps which exist when farmers are only able to obtain about half the yields that they should be getting from their seeds.[15] SE Asia accounts for 40% of the world's rice exports and is a region highly prone to climate change effects.

Therefore, despite the recent clamour for addressing supply-chain challenges from the war in Ukraine and the COVID-19 pandemic, the long-term challenge of adapting rice farming practices to climate challenges remains. These findings suggest the urgency for rice producers in Southeast Asia, as well as across the broader Asian region, to make concerted efforts now to narrow the yield gaps. This is also to ensure that Southeast Asia remains a major rice bowl to supply import dependent countries like Singapore, Indonesia and the Philippines.

Unsustainability of Rice Intensification Practices: A "Wicked Problem"

Even as climate change negatively impacts on productivity in agriculture, the task of addressing such impacts presents a "wicked problem" since the very act of increasing rice production can aggravate the climate change, through an increase in greenhouse gas emissions. Given rising land constraints from industrialisation and urbanisation which pose a barrier to expanding agricultural land areas, the remaining mechanism for improving rice production levels lies in improving rice farming productivity, an important part of the intensification of rice production. Yet even should countries take efforts to improve their productivity levels, a further issue is that processes of rice intensification can themselves have negative impacts on the rice-growing environments, harming long-term yield growth prospects. The sustainability of rice intensification practices for improving productivity over time thus forms an important part of the "wicked problem," with unsustainability considerations such as those discussed below:

1. Rice as a Source of Greenhouse Gas Emissions

Methane (CH_4) is a key greenhouse gas (GHG) produced by flooded rice fields. For every kilogram of rice grain produced, 100 g of methane are released into the atmosphere, with methane emissions of 1.3 kg CH4 per hectare per day in continuous flooding rice cultivation. Compared to carbon dioxide (CO_2), methane has a much higher global warming potential that is 25 times higher than that of carbon dioxide.[16] Within the UN FAOstat database, in fact, each kilotonne of methane contributes 28 times or 28 kilotonnes of carbon gas emissions (Figure 3).

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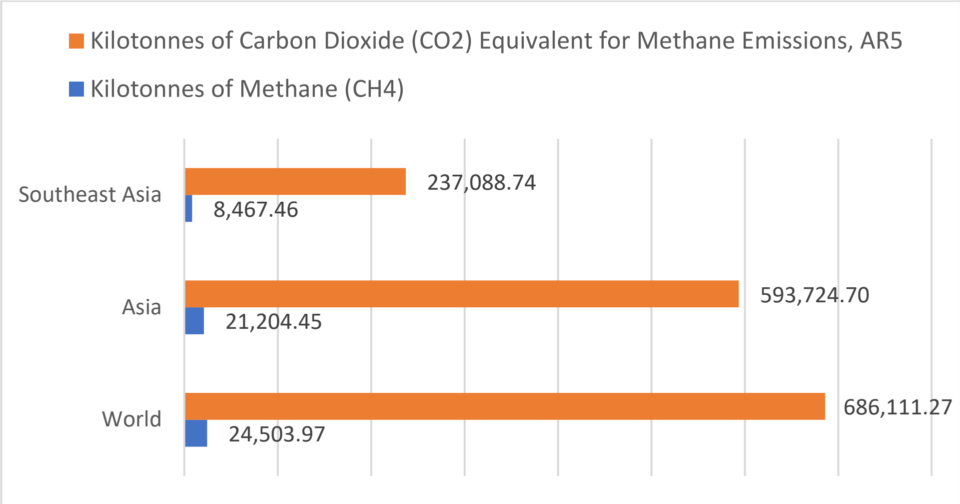
[13] Serge Savary, Laetitia Willocquet, Nancy Castilla, Andy Nelson, Uma Shankar Singh, Jatinder Kumar, and Paul S. Teng, 2022, "Whither rice health in the lowlands of Asia: Shifts in production situations, injury profiles, and yields," *Plant Pathology* 71:1 (2022): 55-85.

[14] Shen Yuan, Alexander M. Stuart, Alice G. Laborte, Juan I. Rattalino Edreira, Achim Dobermann, Le Vu Ngoc Kien, Lưu Thị Thúy et al., 2022, "Southeast Asia must narrow down the yield gap to continue to be a major rice bowl," *Nature Food* 3:3 (2022): 217-226.

[15] Ibid.

[16] Mohammed Mahabubur Rahman and Akinori Yamamoto, 2020, "Methane Cycling in Paddy Field: A Global Warming Issue," *In* Ed. R.S. Meena (Ed.),*Agrometeorology*, DOI: 10.5772/intechopen.94200, accessed 26 April 2022 at https://www.intechopen.com/chapters/74264.

Figure 3: Greenhouse Gas (CO2) Equivalents of Methane (CH4) Emissions as of 2020



Source: UN FAO (2023). "Emissions Totals". UN FAOStat Database. Accessed 18 September 2023, https://www.fao.org/faostat/en/#data/GT.

2. Negative Climate Impacts of Intensification

A further aspect of this problem lies in negative impacts of intensification of inputs on future land productivity. While Asia's First Green Revolution resulted from the increase in use of synthetic inputs for boosting rice productivity, including nitrogen fertilizers, as well as pesticide applications in addressing plant pests and diseases, these can have negative impacts on the fertility of soils and on ecosystem health in the long-term.[17]

One of the ways intensification has occurred is the shortening in fallow periods, i.e. the periods when soils are allowed to rest in between cropping seasons. Fallowing allows for a form of "eco-system restoration" towards greater biodiversity recovery and absorption of excess carbon within soils ("carbon sequestration"). However, the practice of fallowing has been seen as wasteful, leading to state policies that incentivise more frequent farming with shorter fallow periods, or the adoption of permanent crops, as in the case of Chiang Rai (Thailand) and of Nagaland (India), for instance.[18] Within Asia, the reduction in fallow period durations was also observed to occur alongside a massive increase in the use of synthetic inputs.[19]

3. Accentuated Risks of Pests and Diseases from Monoculture

Beyond the increased carbon emissions, the intensification of rice production can have further impacts in the form of diminishing returns to intensification. For instance, shortening fallowing periods leads to a reduction in soil fertility over time (soil fertility exhaustion), since some of the essential, natural elements within soils are lost.[20] A further challenge relates to the risks of large areas of genetically similar high-yielding varieties through monoculture practices (i.e., the predominant use of a single high yielding variety or a few varieties). While modern plane breeding is a key means of boosting rice productivity, by producing better seed varieties that allow for higher-yield crop varieties, a key challenge

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[17] M.A. Sutton, A. Bleeker, C.M. Howard, M. Bekunda, B. Grizzetti, W. de Vries, H.J.M. van Grinsven, Y.P .Abrol, T.K. Adhya, G. Billen, E.A. Davidson, A. Datta, R. Diaz, J.W. Erisman, X.J. Liu, O. Oenema, C. Palm, N. Raghuram, S. Reis, R.W. Scholz, T. Sims, H. Westhoek & F.S. Zhang, 2013, "Our Nutrient World: The challenge to produce more food and energy with less pollution.*" Global Overview of Nutrient Management*. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

[18] Yoji Natori, Pia Sethi, Prasert Trakansuphakon, and Siddharth Edake, 2023, "Traditional Regenerative Agriculture as a Sustainable Landscape Approach: Lessons from India and Thailand." In *Ecosystem Restoration through Managing Socio-Ecological Production Landscapes and Seascapes (SEPLS)*, pp. 117-135. Singapore: Springer Nature Singapore.

[19] Serge Savary et al., Whither rice health in the lowlands of Asia, Op. Cit.

[20] Tiziano Gomiero, "Soil and crop management to save food and enhance food security," *Saving food* (2019): 33-87.

brought about by having higher-yielding varieties is the risk of a monoculture of high yield varieties succumbing to a common threat. The reduction in genetic and cultural biodiversity accentuates the impacts of pest and disease outbreaks and allow faster spread across biologically similar crops. However, techniques from modern biotechnology have also allowed more accurate mapping of pest genomes so that appropriate crop resistance can be developed to match the pests.

There is some evidence though that crops in countries become more vulnerable to pests and diseases alongside the increasing monoculture practices in rice production accompanied by loss in biodiversity.[21] In fact, the UN FAO's 2010 report on the State of the World's Plant Genetic Resources for Food and Agriculture noted that from 1990-2000, over 75% of crop plant biodiversity was lost globally.[22] This was further supported in the case of Asia within rice-based agrosystems over the past 24 years (1987-2011).[23]

4. Higher Emissions from Lowland Rice Ecosystems

Lowland rice ecosystems are the main areas where majority of rice is produced for domestic consumption and for export. However, the sustainability of the lowland rice agrosystems of Asia in the long-term is held in question given the negative impacts of rice intensification. They further lead to questions on whether more needs to be done as far as boosting rice productivity is concerned, beyond the traditional applications of synthetic fertilizers and pesticides. A further danger lies in how an increase in the misuse of some of these synthetic inputs and seed-based technology for boosting rice productivity, are leading to further challenges in food safety in the form, for instance, of plant diseases associated with mycotoxins (i.e., related to moulds and fungi).

5. Declining Pool of Farm Labour, Drudgery Issues and Competing Demands for Water

Paddy rice that is transplanted requires a long period of puddling/flooding and it has been estimated that under such conditions, 1 kg of rice requires between 3,000 to 5,000 litres of water.[24] The uncertainty of water availability, and actual declines in fresh water present important issues to sustaining rice production growth in the long-term. These bring to fore the problems behind practices such as puddling, which can have further negative effects by creating conditions favouring methane production. Another issue relates to the declining pool of farm labour, which is in heavy demand during rice transplanting phases of production (a tedious task commonly done by women during the early planting season).

Science-Based Solutions to the "Wicked Problem:" Growing More while Managing GHG Emissions

Much advanced scientific research has been undertaken in improving the resilience of agriculture to climate change. Most of the research in the previous decades has focused on increasing rice yields by national research programmes and international centres such as the International Rice Research Institute in the Philippines.[25] The focus has been on developing new rice varieties with high yield potential and resistance to stresses, both biotic and abiotic. For instance, IRRI has released submergence tolerant rice varieties in several countries.

However, such solutions did not initially seek to address the significant contributions of rice production to climate change. This has led to a relatively recent shift in research in determining mitigation measures of GHGs and developing

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[21] Brenda B. Lin, "Resilience in agriculture through crop diversification: adaptive management for environmental change," *BioScience* 61, no. 3 (2011): 183-193.
[22] UN FAO, 2010, "Crop biodiversity: Use it lose it," *UN FAO Website,* accessed 2 October 2023, *https://www.fao.org/news/story/en/item/46803/icode/*.
[23] Serge Savary et al., Whither rice health in the lowlands of Asia, Op. Cit.
[24] Sustainable Rice Platform (SRP). 2023. *SRP Website*, https://sustainablerice.org/, accessed 27 September 2023.
[25] IRRI, 2016, "Climate Change-Ready Rice," *IRRI Knowledgebank Website*, http://www.knowledgebank.irri.org/step-by-step-production/pre-planting/rice-varieties/item/climate-change-ready-rice, accessed 18 September 2023.

practices which minimize release of methane in rice production.[26] At the crux of this research is the identification of the pathways through which methane is generated and emitted in the rice production process, and the development of DeNitrification-DeComposition (DNDC) models for quantifying gas fluxes in paddy fields.[27] DNDC models have further become important tools for estimating carbon credits accruing from practices which reduce methane emissions and have therefore become an important part of the Measurement, Reporting, and Verification (MRV) system for carbon credits.[28]

1. Alternate Wetting and Drying

One promising solution lies in controlling the amount of water in a ricefield. This is part and parcel of many of the key practices previously recommended by IRRI for greenhouse gas (GHG) mitigation in rice.[29] Controlled irrigation feeds into practices such as **Alternative Wetting and Drying (AWD)**, in which the water level is controlled through irrigation and drainage practices, to minimise the amount of flooding and duration of flooding. This is unlike the traditional practice where rice fields are kept flooded throughout the growth process of the crop.

The AWD practice can potentially minimise the amount of methane production in rice fields and their emission into the atmosphere. This recommendation builds on earlier research to understand methane production, an anaerobic (occurs in the absence of oxygen) microbiological process. Methanogens, or methane-producing bacteria, are most active in the soil of flooded rice paddies to convert organic carbon biomass into methane.

Current practices like "straw incorporation" result in more substrate or soil surface where methanogens can grow. On one hand, straw incorporation is an important aspect of rice farming wherein rice straws from previous harvests are kept in the fields with the belief that more organic carbons are recycled and may increase crop yields. Yet, this also leads to more soil organic biomass, which further feeds methanogens (methane-producing bacteria) especially within flooded conditions. [30]

Beyond this, farmers in some rice areas burn straw to get rid of it but this serves to increase the release of carbon dioxide into the atmosphere as well as cause air pollution. Moreover, the later growth stages of paddy production are also important sources of CH4 production (through root exudates and degrading roots).[31] Therefore, overall, AWD helps to minimise the amount of methane emitted by reducing and controlling the extent of flooding in rice fields.

2. Direct Seeded Rice

Another pertinent approach that has been incorporated within IRRI's guidelines, is Direct Seeding (DS). This involves planting the rice seeds and controlling the amount of water used to grow the crop, instead of transplanting the rice plants (puddle transplanted rice or PTR) grown in a nursery. Susilawati et al., for instance, found that Direct Seeded Rice (DSR) can lead to a 46% reduction in methane-related carbon emissions, to the tune of 4.4 tonnes of carbon emissions per hectare in DS settings, as opposed to emissions of 8.2 tonnes of carbon emissions within PTR.[32]

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[26] IRRI, 2019. "Greenhouse Gas Mitigation in Rice," *IRRI Website,* https://ghgmitigation.irri.org/, accessed 18 September 2023.

[27] M Shaukat, S Muhammad, E. D. Maas, T. Khaliq and A. Ahmad, 2022, "Predicting methane emissions from paddy rice soils under biochar and nitrogen addition using DNDC model," *Ecological Modelling*, *466*, 109896.

[28] World Bank, 2022,"What You Need to Know About the Measurement, Reporting, and Verification (MRV) of Carbon Credits". *World Bank Feature Story*, 27 July. https://www.worldbank.org/en/news/feature/2022/07/27/what-you-need-to-know-about-the-measurement-reporting-and-verification-mrv-of-carbon-credits.

[29] Ibid.

[30] Pauline Chivenge, Francis Rubianes, Duong Van Chin, Tran Van Thach, Vu Tien Khang, Ryan R. Romasanta, Nguyen Van Hung, and Mai Van Trinh, 2020, "Rice straw incorporation influences nutrient cycling and soil organic matter," *Sustainable rice straw management* (2020): 131-144.

[31] Mohammed Mahabubur Rahman and Akinori Yamamoto, 2020, "Methane cycling in paddy field: a global warming Issue." *Agrometeorology –IntechOpen*, p. 21.

[32] H. L. Susilawati, P. Setyanto, R. Kartikawati, and M. T. Sutriadi, 2019, "The opportunity of direct seeding to mitigate greenhouse gas emission from paddy rice field." In *IOP conference series: Earth and environmental science*, vol. 393, no. 1, p. 012042. IOP Publishing.

Additionally, both methods, of AWD and DS, contribute to reducing the amount of water required for rice production, thus further reducing the costs of production and increasing the amount of water available for alternative uses, whether for urban consumption or industrial uses. While the water-saving benefits of DS are less as it applies mostly to the initial planting phases, the overall benefits of both can be drawn from earlier studies which have shown that controlled irrigation through AWD can lead to water savings of as much as 38%.[33] This indicates that a greater area of rice farming can potentially be supported, potentially expanding rice production by a further 38% with the water saved.

Moreover, DSR systems have a shorter period under water and commonly early in the growing season are not submerged, so reducing the methane-forming favourable period. This method can also help alleviate drudgery conditions in the fields. As mentioned earlier, the transplanting phases of rice production (where germinated seeds are transplanted or transferred unto rice paddy fields), can also be a tedious task which requires farming labour which is in high demand but in increasingly scarce quantity. With the availability of off-farm employment at higher remunerations now possible in many rice rowing regions, it has become clear that DSR has this advantage of lower labour demand.

Technical and Policy Challenges to and Opportunities for Implementing Science-Based Solutions

While the solutions offer much potential to address the "wicked problem" raised earlier concerning the rice sector, there are implementation issues. Some of the related challenges cited below are drawn from an earlier study behind the ASEAN Regional Guidelines for Promoting Climate Smart Agriculture (CSA) Practices.[34]

1. Addressing Disparities in Access to Irrigation

A key challenge in implementing controlled irrigation is the lack of sufficient facilities to control the amount of water released to crops, or to drain it, in a regular fashion with limited human intervention.

One of the prerequisites for controlled irrigation is in having sufficient areas where irrigation is accessible. Only 39% of agricultural land areas in Asia are irrigated.[35] In the case of key rice producing areas in Southeast Asia, significant differences exist between rice-growing countries. As much as 89% of rice land areas are irrigated in Vietnam, while in the Philippines it is 59%. A much smaller proportion is irrigated in the case of Thailand (21%), Myanmar (17%), and Cambodia (16%).[36] **Expanding irrigation investments in controlled irrigation among farmers, therefore provides a key initiative not only for water savings, but also for the possibility to practise AWD and thereby reduce GHG emissions.**

2. Improving Financial Support Framework for Implementation of Controlled Irrigation

A further challenge lies in the gaps in technology usage for controlling the release of water. The aforementioned earlier study behind ASEAN's CSA practices has also noted the presence of "(o)lder irrigation systems or unreliable systems, which may not be set up for controlling water at the level required for AWD" and the lack of confidence farmers have that "they can re-flood fields once drained." [37]

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[33] Rubenito M. Lampayan, Roderick M. Rejesus, Grant R. Singleton, and Bas AM Bouman, 2015, "Adoption and economics of alternate wetting and drying water management for irrigated lowland rice." *Field Crops Research* 170: 95-108.

[34] ASEAN, 2015, *ASEAN Regional Guidelines for Promoting Climate Smart Agriculture (CSA) Practices, Volume 1*. Endorsed in Makati City, the Philippines, on 10 September 2015, 46.

[35] Kei Kajisa, 2021, "Contemporary Irrigation Issues in Asia," Background Paper for *Asian Development Outlook 2021 Update: Transforming Agriculture in Asia*. https://www.adb.org/sites/default/files/institutional-document/731791/adou2021bp-irrigation-issues-asia.pdf

[36] Global Yield Gap Analysis, 2021, "Rice production in the five Southeast Asian countries, Vietnam, Thailand, Myanmar, Philippines, and Cambodia," *GYGA Website,* https://www.yieldgap.org/philippines, accessed 2 October 2023.

[37] ASEAN, 2015, ASEAN Regional Guidelines for Promoting CSA Practices, Op. Cit., 46.

Digital technologies which allow for automating the release of water according to the requirements of specific crops at different stages of crop growth, do exist today. However, their adoption is limited owing to capitalisation-related challenges of smallholder farmers which dominate the rice sector. A related barrier lies in tracking and valuing the usage of water. Leveraging high-quality sensors and sampling devices will undoubtedly come at a cost, while capital is often scarce in farmers settings. The ability to effectively monitor and assess the value of water usage (both in quantity and in monetary value) offers a potential "game-changer" to coping with water scarcity in water-scarce settings.[38] This highlights the need for a **viable financial framework that supports farmers' adoption of controlled irrigation technologies.**

3. Rationalising Water-Saving Fees

Building on the previous recommendation, another way forward is to change the way water fees are measured. Even if the use of controlled irrigation offers the benefit of water savings for farmers, not all farmers may be able to monetise this benefit owing to existing practices by pump owners of charging farmers a fixed fee based on the areas covered by irrigation, rather than based on the amount of water usage. Yet, the ones who pay for greater water usage ultimately are other sectors of society, through greater water scarcity and higher water costs. **Governments may thus contribute to reducing GHG emissions in agriculture indirectly, by encouraging the use of usage-based rather than area-based water fees**.

4. Incentivising Farmers and Private Sector Involvement to Reduce GHG Rice Emissions

While the societal good from reducing GHG emissions is obvious, the benefit to individual smallholder rice farmers is less so. Smallholder farmers commonly require to be incentivised to adopt new practices shared with them by either public extension agents or private sector, company staff. Many of the practices proposed to mitigate GHG by rice farmers requires additional effort on the part of the farmers themselves. **Governments will need to initiate special programmes that can incentivise smallholders to adopt practices such as AWD or DSR with assurance that their production will not decrease**. Policies and regulations will need to be present to allow the private sector to function as technology transfer agents and perform *de facto* extension.

5. Measuring Status Quo Greenhouse Gas Emissions

A further challenge to incentivising farmers to increase their adoption of GHG-reducing technologies and practices is the general lack of available baseline data on the amount of GHG emissions, and the need for further intervention to measure the reduction in carbon emissions. Without such data, governments face challenges in convincing farmers to change their practices, and farmers would not be able to receive compensation for adopting the said technologies. Governments may therefore **explore the potential of tapping on technologies such as soil-testing which can track the amount of carbon content in soils over time, from which the emissions can be measured**. Alternatively, they may also invest in ground **sensors that can track the amount of methane and other GHGs released on the ground.** Investments in such GHG-measuring technologies should therefore form part of the approaches taken by governments to meet their pre-committed **Nationally Determined Contributions (NDCs)** to reduce GHG emissions. Vietnam, for instance, has committed to reduce emissions by 34%.

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[38] UN FAO, 2021, "Director-General highlights valuing water as a 'game changer' in Near East," *UN FAO Website Post*, 13 March 2021, https://www.fao.org/news/story/en/item/1380873/icode/, accessed 18 September 2023.

Conclusion: Gazing into the Rice Crystal Ball — What is possible?

Modern history has shown how human ingenuity in agriculture has helped overcome the spectre of a Malthusian disaster. Can the required 8% increase in rice production estimated by IRRI be met by 2040? While forces such as those from climate change and supply chain disruptions may increase in intensity in the intervening years, there is still a glimmer of hope. The pandemic in fact has re-focussed the world's attention on food insecurity as an existential threat.

The role of disruptive technologies in safeguarding agricultural production will be key.[39] But these will have to be accompanied by supportive public sector policies, sufficient private investment and an environment which incentivizes farmers to produce more, as highlighted above, and concurrently, the assurance that any technology-centred approach does not discount the importance of sustainability considerations.

Among the set of disruptive technologies are two which offer much promise – biotechnology and digital technology. Biotechnology through the tools of genetic modification and gene editing are providing farmers with better crop varieties and animal breeds to tolerate climate change, pests and inherently yield more. Importantly these tools are also improving the nutritive value of plant produce. The use of digital technologies in improving smallholder rice farming has been seen in countries like China, India and the Philippines with the use of drones, sensors and the "Internet of Things" systems. Much effort and investment are also going into both mitigation and climate change adaptation, with some 12 measures having been identified by IRRI as potential GHG remedial measures.[40] But a key challenge is how to change the mindsets and practices of the millions of smallholder rice farmers to adopt the evidenced-informed recommendations. As noted earlier, rice is the largest contributor to GHGs by crop and offers the most opportunity to make a dent on GHG emissions from agriculture.

Although rice lands are declining all over Asia from urbanization and industrial demands for land, several exciting pilot trials offer hope that new environments may partially make up for the loss of land. Growing rice in the sea using salt-tolerant rice varieties is an exciting new technology which has potential to increase rice supply but also decrease methane emissions.[41] Even in urban areas like Singapore, pilot trials have been conducted to show that rice can be successfully grown and harvested in vertical farms adjoining tall residential buildings.[42] This latter accomplishment comes on demonstrations of roof top rice growing in China. The combined increase in rice availability from developing new rice-growing environments and using new varieties assisted by digital technology is just one of many integrated approaches to address the rice conundrum.

Another optimistic point is that as economies develop, the rice consumption per capita declines, often by as much as half. Households with higher incomes tend to diversify their diets and depend less on rice for their calories. The average South Korean in 2021 consumed only 57 kg of rice[43] while in Bangladesh, the average consumption was over 170 kg. But this may also put pressure on non-rice staples like wheat, potato and corn.

Rice investments historically have been viewed as a public sector responsibility with governments often using FDIs to build infrastructure like irrigation systems. However, in more recent times, and partly accelerated by the COVID pandemic, private equity has poured into the development of digital technologies like "agtech" and "fintech" to improve the productivity and profitability of rice farming.[44] With large private equity funds increasing their presence in agriculture, there is likely to be an increase in the adoption of innovations by rice farmers to produce more. And beyond just production,

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[39] Paul Teng, 2019, 'Disruptive technologies' transform Asian agriculture', SciDev.Net, 17 September, https://www.scidev.net/asia-pacific/opinions/disruptive-technologies-transform-asian-agriculture/.

[40] IRRI, Greenhouse Gas Mitigation in Rice, Op. Cit.

[41] A.F. Santiaguel, 2020, A new wave of rice farming," *Rice Today*, 18 September. https://ricetoday.irri.org/a-new-wave-of-rice-farming/

[42] J. Lim, 2022, "First batch of Temasek Rice grown in the community harvested in Tampines," *The Straits Times*, 12 February. https://www.straitstimes.com/singapore/environment/first-batch-of-temasek-rice-grown-in-the-community-harvested-in-tampines.

[43] Yonhap News Agency, 2022, "S. Korea's rice consumption hits another low in 2021," *The Korea Herald*, 27 January, http://www.koreaherald.com/view.php?ud=20220127000737.

[44] P.S. Teng and G.-D. May. 2021. "Covid-19 Has Accelerated New Agtech Development and Adoption in Asia-Pacific!" *Inter Press Service*, 20 December. https://www.ipsnews.net/2021/12/covid-19-accelerated-new-agtech-development-adoption-asia-pacific/.

it is likely that similar private investment will be seen to help rice farmers reduce their carbon footprint and derive credit form their efforts, ultimately improving the attractiveness of rice farming as a profitable means of livelihood.

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Professor Paul S. Teng, PhD serves as Adjunct Senior Fellow (Food Security) with the Centre for Non-Traditional Security Studies (NTS Centre), S. Rajaratnam School of International Studies (RSIS), Nanyang Technological University (NTU), Singapore, while serving also as Dean and Managing Director of the National Institute of Education International Pte Ltd ("NIE International") at NTU. He has over thirty years of experience in developing countries holding positions at the World Fish Centre and the International Rice Research Institute among others, and has conducted research on new agri-technologies, science-based entrepreneurship, food security and sustainable development, with recent focus on urban food security and agtech. He received the Eriksson Prize in Plant Pathology, among others, and has published over 250 technical papers.

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