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Research article

Learning from global research to analyze contributing factors in rice yield gap: Bibliometric approach towards Indonesia's self-sufficiency

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Abstract

Importance of the work: The rice yield gap is enormous and under ongoing pressure because consumption keeps increasing. Studies on the global reasons for this gap are inconclusive.

Objectives: To analyze the causative factors of the global rice yield gap and Indonesia's strategies to fulfill its food requirements.

Materials & Methods: Yield gap factors were identified from the Scopus database using the bibliometrics approach with the VOSviewer package, based on co-occurrence analyses to map the main factors. From this map, yield gap factors were calculated and reorganized. Articles from 2022 were used to identify future trends in research.

Results: In total, 275 documents were selected from the Scopus database, published in 256 journals (93%), with 7% from other sources, such as books, book chapters and proceedings. China, India and the USA were the top-three nations in this yield gap research. However, Indonesian-based research was still minimal. Yield gap was a major problem for smallholders (24%), in lowlands (56%) and for farmers in Asia (20%). The results showed that the rice yield gap was directly related to agricultural practices, farming systems and climate change. Nutrient was the primary factor contributing to the increased yield gap, followed by water management, cultivar, weed control and crop rotation. Increasing farmers' capacity to undertake good agricultural practices was the key to supporting rice self-sufficiency.

Main finding: Research connected to nutrients and water management should be future trends because they are the main factors in Indonesia's low paddy yield. Furthermore, future research regarding good agricultural practices is needed to support achieving self-sufficiency in Indonesia.

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Introduction

Rice is the primary food for more than 50% of people worldwide (Seck et al., 2010; Paresys et al., 2018), utilizing 11% of world cropland but accounting for 21% of global calorie consumption (Yuan et al., 2021). Asia is the largest consumer of rice, with 80 kg/person/yr, followed by South America, Africa and the Middle East who use 30–60 kg/person/yr, while Europeans and Americans have annual per capita consumption rates lower than 10 kg (Gnanamanickam, 2009). By 2050, the global population will have increased by 35%, necessitating a 70–100% increase in food production and consumption, given expected dietary and wealth trends (van Wart et al., 2013). As the world's population and economies continue to increase, experts predict that milled rice consumption will rise from its 2014 low of 480 million t to over 550 million t by 2030 (Yuan et al., 2021). Furthermore, a 60–110% rise in food yield (from 2005) is required to fulfill future demands in 2050 (Cui et al., 2018).

Increasing crop yields must be doubled on existing farmland to avoid expanding agriculture into rainforests, wetlands and grasslands (van Wart et al., 2013). Rice consumption is increasing due to population growth, household income, urbanization and shifting consumer trends (Senthilkumar, 2022). Thus, its high prices and substantial fluctuations affect global food security (Seck et al., 2010). Southeast Asia is a vital paddy area with a large home market and a substantial (40%) share of global rice exports (Yuan et al., 2022). However, rice is usually grown by subsistence farmers on small plots of land, where the yields are low and highly unpredictable over space and time (Niang et al., 2017)

Multiple studies worldwide indicate that the rice production differential is enormous. The rice yield gap in the African region is generally more significant than in other areas, with the paddy yield at the farm level still much below the yield potential (Yp). For example, in Burkina Faso, the yield gap (Yg) between the average farmer's productivity and the top farmer's yield were substantial at 4.3 t/ha in the wet season and 3.0 t/ha in the dry season (Segda et al., 2004). In Mauritania, grain yields averaging 4.4 t/ha are low compared to the average Yp of 8.6 t/ha (Haefele et al., 2001; Van Asten et al., 2003). In West Africa, the average yield is only 4.8 t/ha (Tanaka et al., 2013). In addition, typical yields in rainfed systems are frequently 50% or less of yield potential (Lobell et al., 2009). Current Yg in Bangladesh represents 50% (irrigated rice) and 48–63% (rainfed rice) of their Yp or water-limited yield (Yw) (Timsina et al., 2018). In Sub-Saharan Africa, Yg was in the range 2.0–10.0 t/ha (Dossou-Yovo et al., 2020), while in Southern and Eastern Africa it was in the range 0.8–3.4 t/ha (Senthilkumar et al., 2020). In Africa, the moderate Yg was 3.1% for irrigated lowlands, 2.0% for rainfed uplands and 3.1% for rainfed lowlands (Senthilkumar, 2022).

In China, the exploitable Yg for each crop was 44% higher in double-rice systems than in single-rice systems (Deng et al., 2019). In Southeast Asia, the average Yg was around 48% of the estimated Yp; however, countries have major variances (Yuan et al., 2022). In Indonesia, irrigated rice yielded 63% of its respective Yp (9.5 t/ha), while rainfed rice yielded 52% of its water-limited Yp (9.2 t/ha) (Agus et al., 2019). Uruguay's average Yg was only 2.8 t/ha (Carracelas et al., 2023). The disparity in rice yields is vast and varies in different places worldwide. This disparity could be attributable to differences in crop management and the identification of the causes of the high yield gap.

Based on the assessment of the relevant literature, the causes of rice yield difference are still quite diversified and no definitive conclusion identifies the primary source of the yield gap. No exhaustive evaluations or research have confirmed the primary causes of the rice production disparity. Based on the literature review, the following research issues were investigated: a) the current research conditions regarding the rice yield gap; b) the factors influencing the rice yield gap; c) efforts that could reduce the yield gap; and d) the research necessary to support rice self-sufficiency. Based on the literature, these issues were addressed using a bibliometric approach. Because this approach uses data from a vast number of databases, examining factors associated with the yield gap should be more comprehensive. This paper provided conclusions on the primary causes of the rice production disparity, actions to eliminate them, as well as identifying options for future research.

Several studies have applied this method to investigate a diverse range of topics, such as a bibliometric approach to solid waste in Iran (Mesdaghinia et al., 2015), global research trends in spinal ultrasound (Zhai et al., 2017), research spotlights in China (Hu et al., 2017), nanotechnology (Muñoz-Écija et al., 2017), human health through remote sensing applications (Viana et al., 2017), Covid-19 research (Hamidah et al., 2020) and the bioavailability of pesticide (Andreo-Martínez et al., 2020). In agriculture, bibliometrics has been successful in identifying key areas of interest in research of artificial intelligence and sustainable agriculture (Bhagat et al., 2022), in providing study recommendations for practitioners and scientists in the implementation of deep learning approach

(Coulibaly et al., 2022) and in summarizing drone research in agriculture and suggesting future research directions (Rejeb et al., 2022). Using bibliometric analysis, these studies have provided valuable insights into the current state of research in their respective fields and identified future research opportunities. Finally, this paper considered the causative factors of the global rice production gap and the strategies Indonesia might adopt to fulfill its food requirements.

Materials and Methods

Data collection and processing

The first step was a keyword search of conference papers, journal articles, book chapters and other media to obtain bibliographic data. The data collection, extraction and analytical procedures followed the procedure conducted by Syahri and Somantri (2022). A comprehensive search was conducted using the Scopus website (https://www.scopus.com) to identify relevant proceedings, articles, publications and reviews without restricting the publication year. An investigation was carried out based on titles, abstracts and keywords for a comprehensive literature review. The research query was carried out on 30 January 2023 with the following final keywords on the search documents tab: ((TITLE-ABS-KEY("yield gap") AND TITLE-ABS-KEY("paddy") OR TITLE-ABS-KEY("rice"))). The other screening step consisted of evaluating the titles and abstracts of the material to identify only those relevant to the issue. After a careful manual filtering procedure, 275 documents remain in the final dataset, consisting of 256 journal articles (93%), with 7% from other sources, such as books, book chapters and proceedings. The database was exported in both comma-separated values (CSV) and research information systems (RIS) formats. The Microsoft Excel 2016 software was used to analyze and visualize certain data, such as the most popular article and author, the publication growth trend and the percentages of the yield gap-related factors.

Bibliometric analysis

The study was carried out using a bibliometric methodology. The bibliometric study was conducted using the VOSviewer software, version 1.6.18, developed by Leiden University, Leiden, the Netherlands (https://www.vosviewer.com). This software creates bibliometric maps to detect clusters and their reference relationships (van Eck and Waltman, 2010, 2014; Perianes-Rodriguez et al., 2016). VOSviewer is free software that can analyze large amounts of bibliometric data (van Eck and Waltman, 2011) and build networks from databases, including Web of Science and Scopus (Perianes-Rodriguez et al., 2016). It provides a quick summary of each region's widely researched topics (Hu et al., 2017), offers numerous styles of visualization (van Eck and Waltman, 2011), as well as allowing the user to choose between the full and fractional counting methods (Perianes-Rodriguez et al., 2016).

Analysis followed the modified protocol of Dang et al. (2021). Co-occurrence, co-authorship and citation analysis were the three primary types of analysis conducted in this study. Then, the CSV-formatted Scopus database was imported into the VOSviewer application. The analysis procedure was carried out based on the criteria of choosing the total counting method and deselecting "ignore documents with a significant number of authors". Co-authorship analysis describes the connection between entities determined by the number of co-authored publications, as assessed through VOSviewer analysis. The author and nation were selected as the unit of analysis for this study. Co-occurrence analysis demonstrates a linkage by counting the number of papers that appear together. In this term, we used all keywords as an analysis unit. Citation analysis determines the relation based on how often articles are cited. A thesaurus is defined to avoid repeating terms on the map. The output obtained as a map was then analyzed using the necessary criteria.

The current study primarily applied co-occurrence analyses to identify and map the key factors contributing to the yield gap. The resulting map was used to calculate and reorganize the causal factors and factors that were closely related to the yield gap. The percentage of dominant keywords connected to the yield was calculated. The same method was used to analyze the percentage of elements directly related to the rice Yg, its influence and the region affected by the Yg. The Pearson correlation coefficient (r) was to examine the links between variables such as the number of publications and citations, harvested area, production level and productivity. Finally, future research trends were analyzed and identified based on co-occurrence keywords in publications from the previous year.

Results and Discussion

Research on rice yield gaps worldwide

The rice yield gap is a globally important research topic. The yearly increase in population has a direct effect on the rising need for food, particularly rice. This increase in demand did not coincide with a substantial increase in rice production. There is still a considerable yield gap between the current level of rice production and the maximum yield that can be obtained.

Based on the current study, research on the rice yield gap began in 1982 and produced various articles (Fig. 1). Before 2000, yield gap-related papers were extremely rare, perhaps because rice supply was still sufficient to meet the needs of the world's population. In addition, there was still adequate land availability to increase the rice cultivation area. After that, the rice yield gap became a primary concern. Since 2005, the number of articles has increased while the average number of citations per year has tended to decline. One published work was mentioned 326 times in 2002.

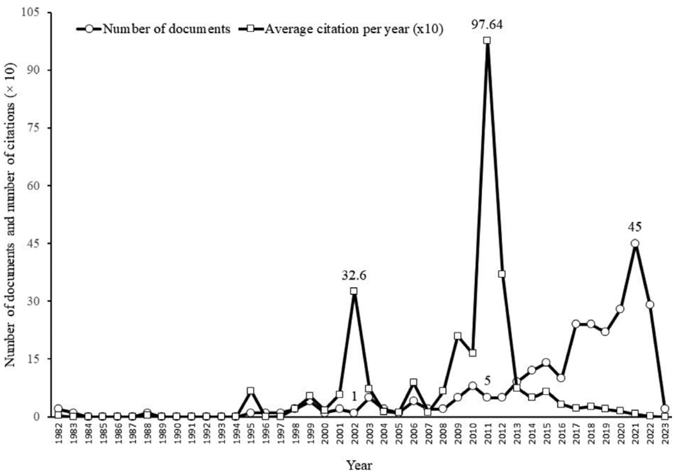

Fig. 1 Development of publications related to rice yield gaps 1982–2023

The highest average citations happened in 2011, with 976 citations from 5 publications. However, after this period, the number of citations to documents relating to the rice yield differential tended to decline. When analyzed, the article "Site-specific nutrient management for intensive rice cropping systems in Asia" (Dobermann et al., 2002) was the most cited in 2002.

Foley et al. (2011) was the most cited paper in 2011 with the title "Solutions for a cultivated planet" that was cited 4,671 times. That paper highlight that enormous gains may be made by pausing agricultural development, bridging Yg on weak areas, enhancing planting efficiency, modifying diets and decreasing waste. They claimed these measures might increase crop yields while substantially minimizing environmental effects.

The trending articles about rice yield disparities are comprehensively listed in Table 1 and showed that the top ten publications with the highest citation numbers were published primarily in well-known, highly reputable journals. Some articles discussed the significance, causes and potential solutions for closing the yield gap. The yield gap was deemed significant because it is intimately tied to food availability and the degree to which actual yield falls short of its potential yield.

The Scopus data indicated that Field Crops Research, with an h-index of 161, was the most sought-after publication for publishing articles on the rice yield gap (17.5% of articles), followed by Agricultural Systems (5.5%) and European Journal of Agronomy (4.4%), respectively. The rice yield gap was reported as a major problem in the Agricultural and

Table 1 Most popular articles related to yield gap study

Title	Source title	Year	Quartile/SJR	Cited by
Solutions for a cultivated planet (Foley et al., 2011)	Nature	2011	Q1/17.9	4,671
Closing yield gaps through nutrient and water management (Mueller et al., 2012)	Nature	2012	Q1/17.9	1,685
Crop yield gaps: Their importance, magnitudes, and causes (Lobell et al., 2009)	Annual Review of Environment and Resources	2009	Q1/4.66	915
Breeding and cereal yield progress (Fischer and Edmeades, 2010)	Crop Science	2010	Q1/0.65	459
When does no-till yield more? A global meta-analysis (Pittelkow et al., 2015)	Field Crops Research	2015	Q1/1.57	433
The yield gap of global grain production: A spatial analysis (Neumann et al., 2010)	Agricultural Systems	2010	Q1/1.55	361
Site-specific nutrient management for intensive rice cropping systems in Asia (Dobermann et al., 2002)	Field Crops Research	2002	Q1/1.57	326
Estimating crop yield potential at regional to national scales (Van Wart et al., 2013)	Field Crops Research	2013	Q1/1.57	277
Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic Plains (Pathak et al., 2003)	Field Crops Research	2003	Q1/1.57	211
Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment (Peng et al., 2006)	Field Crops Research	2006	Q1/1.57	194

Biological Sciences (Fig. 2). Cultivation practices (Stuart et al., 2016; Ibrahim et al., 2022), biotic and abiotic elements (Alam et al., 2013) in culture were considered to substantially affect the yield gap.

Research and publications on the rice yield gap have been conducted in numerous nations and continents worldwide. China, India and the USA, respectively, are the top-three nations in publication output. The USA is the main nation whose population does not consume rice as its primary food source, implying that the rice yield gap is not simply a worry in rice-producing countries but also in regions of the USA, where rice is a crucial food product. The rice yield gap must be studied to ensure economic stability, since more then one-half of the world's population eats rice. Rice yield gap research was intriguing for academics, particularly those from rice-related research organizations. Several researchers from AfricaRice and IRRI have been particularly active in publishing studies on the rice yield gap, making them the most prolific authors (see Fig. 3).

However, research and publications produced by researchers and research organizations in Indonesia were very limited, with only 15 documents identified that were associated with the country. Indonesia is the fourth most populous nation, where rice is a necessary food item for more than 90% of its population. Logically, Indonesia imports rice to meet domestic demand because the rice yield disparity remains substantial. Rice cops grown using irrigation 63% of their 9.5 Mg/ha potential, while rainfed crops yielded 52% of their water-limited yield potential of 9.2 Mg/ha (Agus et al., 2019). According to the FAO research, of the total harvested area of 10,411,801 ha in 2021, only 54,415,294 t of rice would be produced, with Indonesia having productivity of only 5.2 t/ha (FAOSTAT 2022). Consequently, if Indonesia wishes to achieve food self-sufficiency, it must utilize the research conducted by wealthy nations on lowering the rice production gap as a learning resource. Collaboration in related research is also essential so that research does not have to be repeated from scratch.

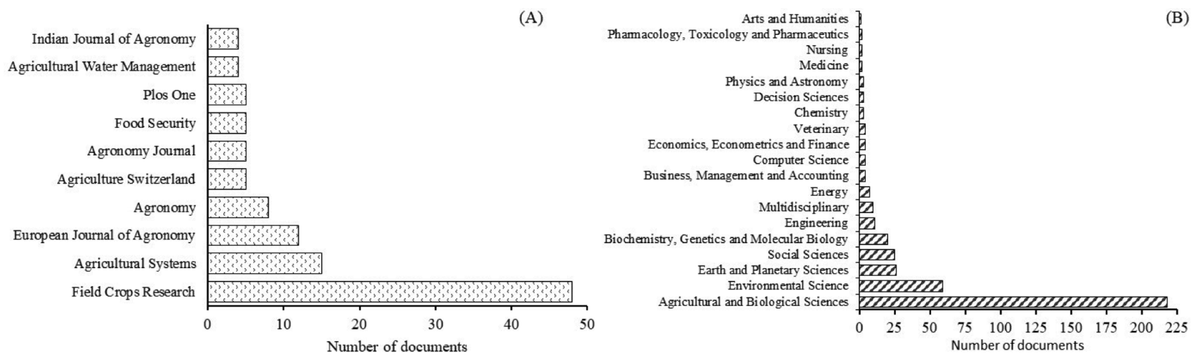

Fig. 2 Yield gap study: (A) most popular journals; (B) most common subject areas

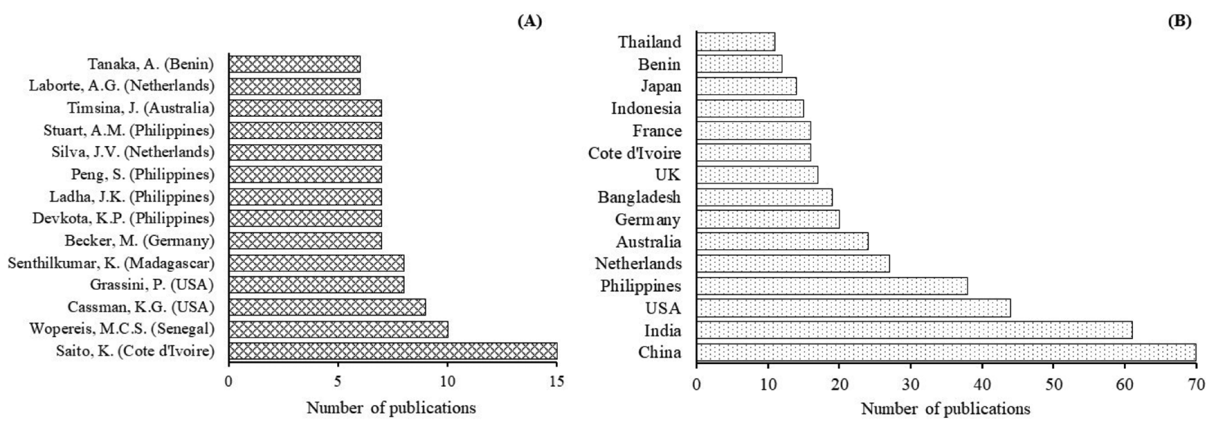

Fig. 3 Yield gap study: (A) most productive authors based on published articles; (B) top-15 countries with most articles

Factors restricting rice yields

In 2010–2021, rice productivity in Indonesia was still very low at average 5.14 t/ha (Fig. 4), despite the yield potential being 9.2–9.5 t/ha. This result has limited Indonesia's rice production to 54 million t and 61 million t over the past decade because productivity has not grown. Increases in the harvested area have a greater effect on rice output in Indonesia (r = 0.93), whereas harvested area had less impact on rice productivity (r = 0.23). Improving national production can improve if the rice yield gap can be closed or productivity increased. Several aspects of the cause of the high yield gap must be investigated and changes must be implemented so that productivity approaches the possible results.

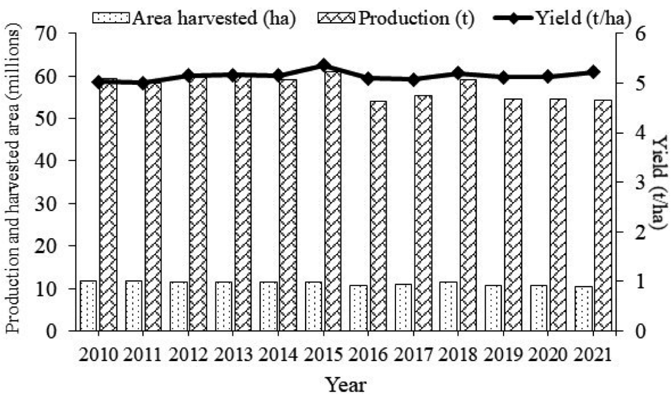

Fig. 4 Trends in Indonesian rice yield, harvested area and production

Numerous studies have analyzed the causes of rice yields in several regions. Diverse authors demonstrated that the scheduling from several planting activities (sowing, transplanting, weeding and fertilizer application) was commonly inaccurate, resulting in significant production gaps (Van Asten et al., 2003). There was a 75% difference in yields explained by two edaphic factors (slope and sand content) and five agronomic factors (fallow residue management, water stress, plowing technique, rat damage and N application rate) (Tanaka et al., 2013). Different production systems require different approaches to various agricultural activities, such as plowing, sowing, nutrient management and weed and pest management (Niang et al., 2017). Large yield gaps in rice in South Africa were commonly attributed to a lack of macronutrients and poor nutrient management (Saito et al., 2019). Identified contributing factors included: drought, nutritional deficiencies or toxicity, temperature, humidity and biotic stresses contributed to low rice production among smallholders (Senthilkumar et al., 2020). Mismatches between N fertilizer treatments and N-requiring growth stages of rice, P deficient soils, a general disregard of or poor weed management, as well as late harvesting (frequently due to a lack of combine harvesters) (Haefele et al., 2001). According to these findings, rice production can be restricted due to abiotic stresses, such as plant nutrition.

For the anticipatory efforts to be successful, it is necessary to study the critical causal components from many published studies. Based on the bibliometric analysis, several factors were related to the yield gap (Fig. 5). As depicted in Fig. 5, the bibliometric analysis of 275 Scopus-published documents indicated that the rice yield disparity was due to several factors that could be grouped in four clusters (#1–#4): yield and yield gap, agricultural practices, food supply and security and smallholders, respectively.

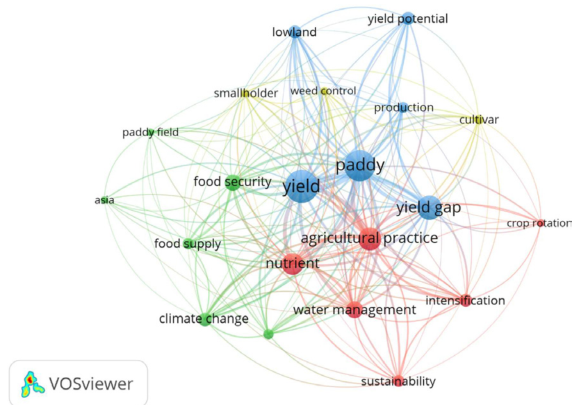

Fig. 5 Map of factors contributing to rice yield gap, where Cluster #1 = yield and yield gap (●), Cluster #2 = agricultural practices (●), Cluster #3 = food supply and security (●) and Cluster #4 = smallholders (●), where the bigger the node size, the greater the element's importance and line size reflects strength of connection between nodes

The results of the bibliometric analysis showed that the rice yield gap was directly related to agricultural practices, farming systems and climate change. Agricultural practices were the main parameter directly related to the yield gap (64%). Integrated good agricultural practices (GAPs) were considered the most effective and sustainable approach to increasing rice yields in any growing environment. Through integrated GAPs, such as enhanced variety, land preparation, line transplanting, fertilizer application and weed and water management, production increased by 45% in the first year and 150% in the second year. Similarly, the yield improved by 166% when combining bundling, herbicide application and application of N at 60 kg/ha. Applying integrated GAPs from land preparation through to harvesting, including improved varieties and crop protection, resulted in a 50% increase in yield (Senthilkumar, 2022).

The high yield gap in rice would affect food security (52%), food supply (25%) and ultimately impact production (23%). The yield gap analysis in several studies showed that the yield gap was still a dominant problem in the Asian region and lowland areas and for smallholders. The yield gap in the lowland region remained the main focus of research (56%). Of the 145 documents discussing the causes of the rice yield gap, 47% stated nutrients as the primary cause, followed by water management (30%) and cultivar (10%), respectively (see Fig. 6).

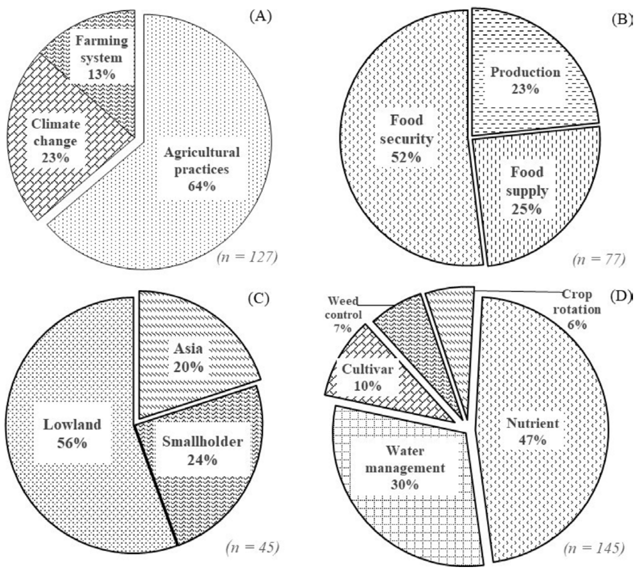

Fig. 6 (A) Percentage of elements directly related to rice yield gap; (B) influence of yield gap; (C) areas impacted by yield gap; (D) main factors causing yield gap

Agricultural practices were the dominant component closely related to the yield gap because agricultural practices will decrease or even increase the influence of the main factor (the high yield gap). Good agricultural practices will minimize the harmful effects of biotic and abiotic factors that can reduce productivity. The magnitude of the influence of the yield gap on smallholders, lowland areas and farmers in Asia was also closely related to the lack of good agricultural practices. Of the world's arable land area, 60% is farmed by 2.5 billion smallholders (Cui et al., 2018), who each grow less than 2 ha of rice on average (Abdul-Rahaman and Abdulai, 2018). The biggest challenge was in locations where smallholder farming dominates the agricultural landscape. In these places, food production and resilience rely on smallholders, who are often resource-constrained and knowledge-poor (Cui et al., 2018). Their rice is grown using traditional methods with minimal inputs (Kwesiga et al., 2020). Smallholders cannot gain from recent innovations because of resource limitations, local preferences and low access to technology (Kwesiga et al., 2020). There has been great efforts to improve their production; however, it has been impossible to mobilize millions of smallholder farmers and urge them to embrace management technologies that solve productivity and pollution issues. This is crucial in countries with high-input, low-efficiency smallholder systems (Cui et al., 2018).

The current analysis identified five main factors contributing to the rice yield gap: nutrient, water management, cultivar, weed control and crop rotation. Of the five factors, nutrients predominated in causing the high yield gap; 47% of publications stated that nutrients were the main cause. Research on N-P-K fertilizer usage in five West African nations (Senegal, Mali, Guinea, Gambia and Benin) reported a 46–48% increase in crop productivity (Senthilkumar, 2022). Nutrient management—optimal fertilizer application and timing—reduced crop yield gaps. The best nutrient management techniques increased the profitability of rice-producing fields (Bhatta et al., 2022). Water management was the second important factor contributing to the yield gap and was mentioned in 30% of articles. In Indonesia, rice-producing regions with wetland and tidal land agroecosystems had a major problem in terms of water management because the macro water system network was not in overall good condition and was poorly managed, typically experiencing siltation and being overgrown with grass and bushes. In addition, several systems lacked tertiary canals and water gates; even where they did, they often did not work efficiently regarding agricultural requirements (Hutahaean et al., 2015). At the same time, water and soil management technology was the most critical factor for agrarian success in lowlands (Suriadikarta, 2012; Hutahaean et al., 2015). It seemed that regulating the entry and exit of water from the land would virtually guarantee agricultural success and *vice versa*. On the other hand, several irrigated-area-and-fertilizer combinations could close yield gaps in specific locations. Yield gaps in all underachieving areas might be narrowed with 30%, 27% and 54% increases in N, P_2O_5 and K_2O applications, respectively, and a 25% increase in irrigated hectares (Mueller et al., 2012).

Cultivar was the third factor that caused the rice yield gap. Superior varieties contributed significantly to the growth of rice production. In Indonesia, usage of superior varieties contributed 56% to the rise in national rice output. In contrast, the interplay between irrigation water, superior varieties and fertilization contributed 75% to the rate of increase (Syahri and Somantri, 2016). These yield differences were primarily attributable to annual variations in weather conditions and a variety's ability to survive a specific degree of pest and disease pressure, fluctuating from season to season and year to year (Zhu, 2000).

Bangladesh's government research organizations are creating shorter-duration rice varieties with great production potential to fit farmers' planting patterns (Zhu, 2000). Yet, in Indonesia, the adoption of improved varieties is still extremely limited. Approximately 30% of Indonesia's seeds are labeled and high-quality (Pujiharti, 2010). Therefore, the rapid adoption of high-yielding varieties of rice would be supported by the provision of local regulations to increase rice production, guaranteed sources of capital, provision of inputs (especially sourced seed), guarantees of marketing and selling prices for grain, harmonious partnerships between stakeholders, strengthening of attractive relations with sources of information on technology and output markets, reform, reorientation and revitalization.

Indonesia's nutrient concerns and water management

Multiple indicators of climate change can be observed, including a rise in global temperatures, changes in precipitation, the melting of polar ice caps, more frequent extreme weather and an increase in sea level (Dhamira and Irham, 2020). Java, Bali and Sumatra will experience a 1°C increase in surface temperatures between 2020 and 2070 compared to the basal period of 1961–1990, as predicted by Hadi (2010) in Dhamira and Irham (2020). During the 2030s, Sulawesi and Nusa Tenggara are expected to experience a temperature increase of 0.8°C. Extreme weather conditions, such as flooding and droughts, pose an important risk to those whose livelihoods are dependent on rice (Bairagi et al., 2021). Rice production is significantly influenced by climatic factors that continue to evolve (Marsetio et al., 2013; Dhamira and Irham, 2020; Khairulbahri, 2021). The threat of flooding has been one of the obstacles confronted by farmers, particularly lowland rice producers in Indonesia. Floods significantly impact a decrease in rice production, affecting farmers' earnings (Pirngadi and Rahmawaty, 2022). The Directorate General of Land and Water Management (2006) recorded data showing that in 2005 and 2006, the total paddy fields affected by flooding in Indonesia were 245.5 ha and 263.0 ha, respectively, with 32.74% or 80.4 ha and 39.85% or 104.8 ha, respectively, resulting in crop failures. Approximately 13,3 million ha are flooded annually in Indonesia. The flooding reduces the quality and quantity of rice, particularly when the panicle fills after the reproductive and maturation stages (Marsetio et al., 2013). Drought is another factor contributing to the disruption of rice production caused by climate change. A significant decrease in precipitation will induce drought in Indonesia, including on the island of Java, which is most susceptible to drought, having had 510 drought events (55.1% of the total events in Indonesia) between 2008 and 2018 (National Disaster Management Agency, 2018).

Water management is the key to successful rice cultivation in conditions influenced by climate change. Water management techniques for rice plants in Indonesia vary widely depending on the land conditions. For technically irrigated land, the organization of the irrigation system makes water management relatively simpler. During dry conditions, intermittent irrigation alternates between dry and flooded land. An intermittent irrigation system can optimize water management and increase the efficiency of water resources in paddy fields (Purba, 2011; Uphoff et al., 2011). The intermittent irrigation method only uses about 11.55% water, which is lower than the continuous flooding method, which can use up to 38.49% water (Rejekiningrum, 2013). Water efficiency is crucial to increasing rice production and economic value in integrated land systems (Taufik et al., 2014). Some farmers in irrigated land also apply an irrigation system known as alternate wetting and drying (AWD), which produced greater growth, yield and profits, with AWD attaining rice productivity of 8.3 t/ha, whereas intermittent and continuous irrigation methods only reached 7.8 t/ha and 7.6 t/ha, respectively (Taufik et al., 2014).

In lowlands dominated by a swamp ecosystem, effective water management is uncommon. Under these conditions, typically, the farmers schedule planting times based on available water. The first planting season for paddy typically occurs between April and September, or close to the dry season, while the second planting season occurs between October and March, during the peak of the rainy season. Until then, typical water management on land under a tidal ecosystem is conducted via micro-water management systems. The micro-watering systems in these fields must be adequately managed so that the high pyrite content of the water entering the fields does not poison the plants. Farmers anticipate flooding by constructing quarter channels in the planting area (known as worm channels) so that water does not perpetually inundate their rice. Typically, with upland or land dominated by arid ecosystems, rice is planted during the rainfall season (September to March) or by sowing resistant rice varieties to drought (known as 'padi gogo'). As a form of adaptation to the impact of climate change, the Ministry of Agriculture of Indonesia has also released an application called SI KATAM Terpadu (an integrated cropping calendar). This Android-based application contains information, such as estimated planting times, areas prone to flooding and drought, varieties and fertilization recommendations.

In addition to the physicochemical constraints in the form of flooding and drought during the dry season, high acidity and low soil fertility are the main obstacles to rice cultivation (Djamhari, 2012). Halliday and Trenkel (1998) stated that currently cultivated plants generally require nutrients of various types and in relatively large quantities, so it is almost certain that without fertilization, the plants will not be able to produce the expected results. Fertilization is one important component in efforts to increase rice production. However, excessive fertilizer application can also reduce fertilization efficiency and endanger plants and the environment (Siska and Lenin, 2020). Until now, the use of fertilizers for rice plants, especially N, P and K fertilizers, has not been used rationally according to plant needs, the ability of the soil to provide nutrients, soil properties and the quality of irrigation water and of the land management by farmers (Sofyan and Suryono, 2002). Maps of the status of P and K nutrients in paddy fields at a scale of 1:250,000 are available in almost all provinces in Indonesia. These maps have has been used to compile rice fertilizer recommendations, although it has been less accurate due to the small scale (Hidayanto, 2019). For accurate fertilization, the Ministry of Agriculture of the Republic of Indonesia has issued several soil nutrient tests kits, such as PUTS (lowland soil test kit) and PUTK (upland soil test kit). These kits are easy to use and can determine the recommended fertilization dose quickly and accurately.

Narrowing the rice production gap

In a recent study in Indonesia by Agus et al. (2019), some possibilities for rice self-sufficiency in 2035 were offered. First, Indonesia will produce 104 million t in 2035 based on historical yield and crop-harvested area patterns. An additional 3.4 million ha of the harvested area is needed for this scenario, with rice production being lower than 89% without changes in the harvested area, nearly reaching self-sufficiency. The next option is increasing the actual yield to a level equivalent to 80% of yield potential for irrigated crops (or 70% for rainfed crops) that would lead to an annual production of 101%. Finally, combining changes in crop sequences with yield gap closure would lead to slightly higher (3%) rice production (Agus et al., 2019). Yuan et al. (2022) proposed three scenarios: current yield trends, full exploitable yield gap closure and half closure. With the population growth rate and the high rate of land conversion, it will be difficult to increase the harvesting area, as suggested in the first scenario. Technological assistance is required to raise productivity to the level of its potential yield.

Two methods to improve rice production are increasing the cultivated area and increasing yield productivity (Tanaka et al., 2017). Many cultivation technologies, such as plant nutrition management, water management and superior cultivars, can increase the rice yield. In key rice-producing regions such as the USA, Indonesia, South Korea and China, yield growth rates have slowed and plateaued. The use in rice cultivation of 14%, 30% and 10% of the world's fertilizers, irrigation water and insecticides, respectively, is a source of environmental concern (Yuan et al., 2021). Late weeding significantly reduced fertilizer-induced yield gains. Fertilizer treatment yielded large yield gains, if weed management is perfect. The rice yield in several experiments increased by using appropriate leveling and bunds to prevent weeds and control water within plots, followed by N treatment. Thus, better weed control by smallholder farmers, which depends on time, labor and capital, could increase grain yields and minimize yield discrepancies. Policymakers should design, test and promote locally appropriate weeding technologies to improve weed management labor efficiency. Line transplanting would improve the efficacy of such easy-to-use weeding tools (Awio et al., 2022).

There was a clear need to design long-term P and K treatments on all sites, perhaps by applying local P and K sources (Wopereis et al., 1999). Additionally, future rice systems must provide more yields while reducing environmental implications (Yuan et al., 2021). Certified seed also positively impacted yield on irrigated lowland. In contrast, this effect was not evident in other production systems, possibly because only a small proportion of farmers utilized certified seed. Certified seed should reduce weeds and enhance rice productivity (Niang et al., 2017).

The current review proposed increasing farmers' capacity to undertake good agricultural operations as the key to minimizing the rice yield gap. Transforming farmer behavior takes more than scientifically sound and evidence-based solutions. Trust, participatory innovation, human capacity and farming community coherence are essential for sustained change. To achieve an equal and sustainable world, small-scale farmers must be empowered with better management tools to increase production and environmental sustainability (Cui et al., 2018). The government, development agencies and private agribusiness enterprises should encourage farmer group establishment when adopting agriculture and value chain development interventions because farmer groups improve smallholder farm yield and technical efficiency (Abdul-Rahaman and Abdulai, 2018).

Future outlook to reduce rice yield gap

The current study applied bibliometric examination of the most recent research (in 2022) to map out future research (Fig. 7). There were three main research clusters (#1–#3) yield, yield gap and food supply and security, respectively. Although several studies have been conducted to date, research connected to nutrients and water management remains a future trend. In Indonesia, there is a need for further research on these two problems,

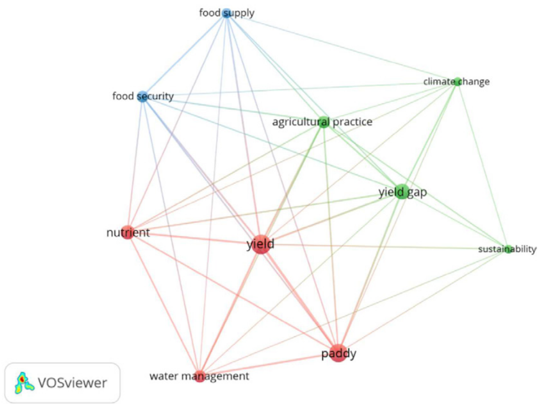

Fig. 7 Future research trends on rice yield gap, where Cluster #1 = yield (●), Cluster #2 = yield gap (●) and Cluster #3 = food supply and security (●), where the bigger the node size, the greater the element's importance and line size reflects strength of connection between nodes

as they are the primary causes of the country's low rice production. In addition, research on the effects of climate change and sustainable agriculture on the rice yield gap is exceptionally rare and will become a new trend in global study. Furthermore, due to the large rice yield difference, the food supply and security issue will be an important topic of study concerning the rice yield gap. This topic is important because these two things will directly influence the economic and social life of the community.

Past research constraints and future opportunities in Africa were identified (Ibrahim et al., 2021). Initially, it seemed that agricultural research for development lacked proper effect channels, theories of change and monitoring and evaluation procedures. Second, the focus of development-oriented agronomic research has been narrow, focusing on yield, water productivity, weeds and the relationships among these factors. Third, there have been only limited studies on farming and cropping systems based on irrigated rice. Fourth, crop residues, such as rice straw, have recently emerged as essential animal-feeding materials. Fifth, machinery can minimize the difficulty of farm work, alleviate time and labor constraints and lessen agriculture's environmental footprint. Sixth, pest and disease management have received minimal attention. Seventh, continuous climate change poses a growing threat to irrigated rice production via temperature rises (Ibrahim et al., 2021). Therefore, good future research support is needed to support the achievement of self-sufficiency.

Conclusions

The current study identified that the high yield gap in rice will affect food security, food supply and ultimately impact production. Several previous yield gap analyses indicated that the yield gap remains a significant issue in the Asian region, lowland areas and among smallholders. Lowland areas are highly impacted by yield disparity, which currently stands at 56%. There are five main factors contributing to the rice yield gap: nutrient (47%), water management (30%), cultivar (10%), weed control (7%) and crop rotation (6%). Future research must focus on nutrient and water management because these are primary causes of Indonesia's low paddy yield. Additional research on good agricultural practices is required if Indonesia is to attain self-sufficiency. Enhancing farmers' capacity to conduct efficient agricultural operations is the key to reducing the rice yield disparity.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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References

Abdul-Rahaman, A., Abdulai, A. 2018. Do farmer groups impact on farm yield and efficiency of smallholder farmers? Evidence from rice farmers in northern Ghana. Food Policy 81: 95–105. doi.org/10.1016/j.foodpol.2018.10.007

Agus, F., Andrade, J.F., Edreira, J.I.R., et al. 2019. Yield gaps in intensive rice-maize cropping sequences in the humid tropics of Indonesia. Field Crops Res. 237: 12–22. doi.org/10.1016/j.fcr.2019.04.006

Alam, M.M., Karim, M.R., Ladha, J.K. 2013. Integrating best management practices for rice with farmers' crop management techniques: A potential option for minimizing rice yield gap. F Crop Res. 144: 62–68. doi:10.1016/j.fcr.2013.01.010

Andreo-Martínez, P., Ortiz-Martínez, V.M., García-Martínez, N., López, P.P., Quesada-Medina, J., Cámara, M.Á., Oliva, J. 2020. A descriptive bibliometric study on bioavailability of pesticides in vegetables, food or wine research (1976–2018). Environ Toxicol. Pharmacol. 77: 103374. doi.org/10.1016/j.etap.2020.103374

Awio, T., Senthilkumar, K., Dimkpa, C.O., Otim-Nape, G.W., Struik, P.C., Stomph, T.J. 2022. Yields and yield gaps in lowland rice systems and options to improve smallholder production. Agronomy 12: 552. doi.org/10.3390/agronomy12030552

Bairagi, S., Bank, C., Durand-Morat, A. 2021. The impacts of droughts and floods on the global rice market. The 2021 Agricultural & Applied Economics Association Annual Meeting. Austin, TX, USA.

Bhagat, P.R., Naz, F., Magda, R. 2022. Artificial intelligence solutions enabling sustainable agriculture: A bibliometric analysis. PLoS One 17: e0268989. doi.org/10.1371/journal.pone.0268989

Bhatta, R.D., Paudel, M., Ghimire, K., et al. 2022. Production and profitability of hybrid rice is influenced by different nutrient management practices. Agriculture 12: 4. doi.org/10.3390/agriculture12010004

Carracelas, G., Guilpart, N., Cassman, K.G., Grassini, P. 2023. Distinguishing between yield plateaus and yield ceilings: A case study of rice in Uruguay. Field Crops Res. 292: 108808. doi.org/10.1016/j.fcr.2023.108808

Coulibaly, S., Kamsu-Foguem, B., Kamissoko, D., Traore, D. 2022. Deep learning for precision agriculture: A bibliometric analysis. Intell. Syst. Appl. 16: 200102. doi.org/10.1016/j.iswa.2022.200102

Cui, Z., Zhang, H., Chen, X., et al. 2018. Pursuing sustainable productivity with millions of smallholder farmers. Nature 555: 363–366. doi.org/10.1038/nature25785

Dang, Q., Luo, Z., Ouyang, C., Wang, L. 2021. First systematic review on health communication using the Citespace software in China: Exploring its research hotspots and frontiers. Int. J. Environ. Res. Public Health 18: 13008. doi.org/10.3390/ijerph182413008

Deng, N., Grassini, P., Yang, H., Huang, J., Cassman, K.G., Peng, S. 2019. Closing yield gaps for rice self-sufficiency in China. Nat. Commun. 10: 1725. doi.org/10.1038/s41467-019-09447-9

Dhamira, A., Irham, I. 2020. The impact of climatic factors towards rice production in Indonesia. Agro Ekonomi 31. doi.org/10.22146/ae.55153

Directorate General of Land and Water Management. 2006. Land and water management bulletin December 2006. Directorate General of Land and Water Management. Jakarta, Indonesia. [in Indonesian]

Djamhari, S. 2012. Developing agricultural land outside of Java Island by increasing rice production in swampy regions. J Sains dan Teknol Indones. 11: 64–69. [in Indonesian]

Dobermann, A., Witt, C., Dawe, D., et al. 2002. Site-specific nutrient management for intensive rice cropping systems in Asia. Field Crops Res. 74: 37–66. doi.org/10.1016/S0378-4290(01)00197-6

Dossou-Yovo, E.R., Vandamme, E., Dieng, I., Johnson, J.M., Saito, K. 2020. Decomposing rice yield gaps into efficiency, resource and technology yield gaps in sub-Saharan Africa. Field Crops Res. 258: 107963. doi.org/10.1016/j.fcr.2020.107963

Fischer, R.A., Edmeades, G.O. 2010. Breeding and cereal yield progress. Crop Sci. 50: 85–98. doi.org/10.2135/cropsci2009.10.0564

Foley, J.A., Ramankutty, N., Brauman, K.A., et al. 2011. Solutions for a cultivated planet. Nature 478: 337–342. doi.org/10.1038/nature10452

Gnanamanickam, S.S. 2009. Rice and its importance to human life BT-Biological control of rice diseases. In: Gnanamanickam, S.S. (Ed.). Springer. Dordrecht, the Netherlands, pp. 1–11.

Haefele, S.M., Wopereis, M.C.S., Donovan, C., Maubuisson, J. 2001. Improving the productivity and profitability of irrigated rice production in Mauritania. Eur. J. Agron. 14: 181–196. doi.org/10.1016/S1161-0301(00)00094-0

Halliday, D.J., Trenkel, M.E. 1998. IFA World Fertilizer Use Manual. International Fertilizer Industry Association. Paris, France.

Hamidah, I., Sriyono, Nur Hudha, M. 2020. A bibliometric analysis of COVID-19 research using vosviewer. Indones. J. Sci. Technol. 5: 209–216.

Hidayanto, H. 2019. Recommendations of specific fertilizers dosage for lowland rice (*Oryza sativa* L.) in Malinau City-Regency Malinau. Jurnal Agroekoteknologi Tropika Lembab 2: 1. [in Indonesian]

Hu, Z., Guo, F., Hou, H. 2017. Mapping research spotlights for different regions in China. Scientometrics 110: 779–790. doi.org/10.1007/s11192-016-2175-z

Hutahaean, L., Ananto E.E., Raharjo, B. 2015. The development of agricultural practices for tidal land to increase food production: the case of South Sumatra. In: Pasandaran, E. (Ed.). Strengthen Food Self-sufficiency. Indonesian Agency for Agricultural Research and Development Press. Indonesia, pp. 89–108. [in Indonesian]

Ibrahim, A., Saito, K., Bado, V.B., Wopereis, M.C.S. 2021. Thirty years of agronomy research for development in irrigated rice-based cropping systems in the West African Sahel: Achievements and perspectives. Field Crops Res. 266: 108149. doi.org/10.1016/j.fcr.2021.108149

Ibrahim, A., Saito, K., Kokou, A., et al. 2022. Seizing opportunity towards sustainable rice cultivation in sub-Saharan Africa. Environ. Sustain. Indic. 15: 100189. doi: 10.1016/j.indic.2022.100189

Khairulbahri, M. 2021. Analyzing the impacts of climate change on rice supply in West Nusa Tenggara, Indonesia. Heliyon 7: e08515. doi.org/10.1016/j.heliyon.2021.e08515

Kwesiga, J., Grotelüschen, K., Senthilkumar, K., Neuhoff, D., Döring, T.F., Becker, M. 2020. Rice yield gaps in smallholder systems of the kilombero floodplain in Tanzania. Agronomy 10: 1135. doi.org/10.3390/agronomy10081135

Lobell, D.B., Cassman, K.G., Field, C.B. 2009. Crop yield gaps: Their importance, magnitudes, and causes. Annu. Rev. Environ. Resour. 34: 179–204. doi.org/10.1146/annurev.environ.041008.093740

Marsetio, Djali, M., Nurhasanah, S., Lembong, E., Rahmat, R. 2013. The effect of flooding on rice characteristics of “Cilamaya Muncul” on various days after planting during the last reproductive and maturation phase. Acta Hortic. 1011: 285–292. doi: 10.17660/ActaHortic.2013.1011.35

Mesdaghinia, A., Mahvi, A.H., Nasseri, S., Nodehi, R.N., Hadi, M. 2015. A bibliometric analysis on the solid waste-related research from 1982 to 2013 in Iran. Int. J. Recycl. Org. Waste Agric. 4: 185–195. doi.org/10.1007/s40093-015-0098-y

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N., Foley, J.A. 2012. Closing yield gaps through nutrient and water management. Nature 490: 254–257. doi.org/10.1038/nature11420

Muñoz-Écija, T., Vargas-Quesada, B., Chinchilla-Rodríguez, Z. 2017. Identification and visualization of the intellectual structure and the main research lines in nanoscience and nanotechnology at the worldwide level. J. Nanopar. Res. 19. 62. doi.org/10.1007/s11051-016-3732-3

National Disaster Management Agency. 2018. Indonesia disaster information. National Disaster Management Agency. Jakarta, Indonesia. https://bnpb.go.id/informasi-bencana, 28 March 2023.

Neumann, K., Verburg, P.H., Stehfest, E., Müller, C. 2010. The yield gap of global grain production: A spatial analysis. Agric. Syst. 103: 316–326. doi.org/10.1016/j.agsy.2010.02.004

Niang, A., Becker, M., Ewert, F., et al. 2017. Variability and determinants of yields in rice production systems of West Africa. Field Crops Res. 207: 1–12. doi.org/10.1016/j.fcr.2017.02.014

Paresys, L., Saito, K., Dogliotti, S., Malézieux, E., Huat, J., Kropff, M.J., Rossing, W.A.H. 2018. Feeding the world while reducing farmer poverty? Analysis of rice relative yield and labour productivity gaps in two Beninese villages. Eur. J. Agron. 93: 95–112. doi.org/10.1016/j.eja.2017.10.009

Pathak, H., Ladha, J.K., Aggarwal, P.K., et al. 2003. Trends of climatic potential and on-farm yields of rice and wheat in the Indo-Gangetic plains. Field Crops Res. 80: 223–234. doi.org/10.1016/S0378-4290(02)00194-6

Peng, S., Bouman, B., Visperas, R.M., Castañeda, A., Nie, L., Park, H.K. 2006. Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment. Field Crops Res. 96: 252–259. doi.org/10.1016/j.fcr.2005.07.007

Perianes-Rodriguez, A., Waltman, L., van Eck, N.J. 2016. Constructing bibliometric networks: A comparison between full and fractional counting. J Informetr. 10: 1178–1195. doi.org/10.1016/j.joi.2016.10.006

Pirngadi, R.S., Rahmawaty. 2022. The impact of flooding on rice production in the Krueng Kluet Watershed, Aceh Province, Indonesia. IOP Conf. Ser. Earth Environ. Sci. 977: 012113. doi: 10.1088/1755-1315/977/1/012113

Pittelkow, C.M., Linquist, B.A., Lundy, M.E., et al. 2015. When does no-till yield more? A global meta-analysis. Field Crops Res. 183: 156–168. doi.org/10.1016/j.fcr.2015.07.020

Pujiharti, Y. 2010. Ongoing assessment of the supply system (> 90%) for superior quality, less expensive rice, maize, and soybean seeds to support strategic programmes to increase rice production (> 10%), maize production (> 20%), and soybean production (> 20%) in the Lampung region. Lampung AIAT research report. Lampung Assessment Institute for Agricultural Technology (AIAT), Lampung, Indonesia. [in Indonesian]

Purba, J.H. 2011. Irrigation water requirements and application methods for rice plant (*Oryza sativa* L.). Jurnal Sains dan Teknologi 10: 145–155.

Rejeb, A., Abdollahi, A., Rejeb, K., Treiblmaier, H. 2022. Drones in agriculture: A review and bibliometric analysis. Comput. Electron. Agric. 198: 107017. doi.org/10.1016/j.compag.2022.107017

Rejekiningrum, P. 2013. Optimum allocation of water needs for agriculture with innovations in intermittent irrigation technology: Case study of the Citarum watershed, West Java. Prosiding Seminar Nasional Matematika, Sains. dan Teknologi 4: 23–37. [in Indonesian]

Saito, K., Vandamme, E., Johnson, J.M., et al. 2019. Yield-limiting macronutrients for rice in sub-Saharan Africa. Geoderma 338: 546–554. doi.org/10.1016/j.geoderma.2018.11.036

Seck, P.A., Tollens, E., Wopereis, M.C.S, Diagne, A., Bamba, I. 2010. Rising trends and variability of rice prices: Threats and opportunities for sub-Saharan Africa. Food Policy 35: 403–411. doi.org/10.1016/j.foodpol.2010.05.003

Segda, Z., Haefele, S.M., Wopereis, M.C.S., Sedogo, M.P., Guinko, S. 2004. Agro-economic characterization of rice production in a typical irrigation scheme in Burkina Faso. Agron. J. 96: 1314–1322.

Senthilkumar, K. 2022. Closing rice yield gaps in Africa requires integration of good agricultural practices. Field Crops Res. 285: 108591. doi.org/10.1016/j.fcr.2022.108591

Senthilkumar, K., Rodenburg, J., Dieng, I., et al. 2020. Quantifying rice yield gaps and their causes in Eastern and Southern Africa. J. Agron. Crop Sci. 206: 478–490. doi.org/10.1111/jac.12417

Siska, W, Lenin, I. 2020. Fertilization of NPK and nitrogen on rice crop in lowland fields with high phosphorus content of West Sumatera. Jurnal Pengkajian dan Pengembangan Teknologi Pertanian 22: 175. [in Indonesian]

Sofyan, A., Suryono, J. 2002. Technical Instructions for Generating a Map of the Nutrient Status of P and K in a 1:50,000 Scale Paddy Field and Fertilisation Experiment. Research Center for Soils and Agroclimate Development. IAARD Press. Bogor, Indonesia. [in Indonesian]

Stuart, A.M., Pame, A.R.P., Silva, J.V., Dikitanan, R.C., Rutsaert, P., Malabayabas, A.J.B., Singleton, G.R. 2016. Yield gaps in rice-based farming systems: Insights from local studies and prospects for future analysis. Field Crops Res. 194: 43–56. doi.org/10.1016/j.fcr.2016.04.039

Suriadikarta, D.A. 2012. Technology for sustainable management of tidal swampy areas: Case study in former PLG in Central Kalimantan Povince. Jurnal Sumberdaya Lahan 6: 45–54. [in Indonesian]

Syahri, Somantri, R.U. 2016. The use of improved varieties resistant to pests and diseases to increase national rice production. Jurnal Penelitian dan Pengembangan Pertanian 35: 25–36. [in Indonesian]

Syahri, Somantri, R.U. 2022. A scientometric and bibliometric analysis for actinomycetes research-current status and future trends. Jurnal Perlindungan Tanaman Indonesia 26: 93–106. doi.org/10.22146/jpti.77558

Tanaka, A., Johnson, J.M., Senthilkumar, K., et al. 2017. On-farm rice yield and its association with biophysical factors in sub-Saharan Africa. Eur. J. Agron. 85: 1–11. doi.org/10.1016/j.eja.2016.12.010

Tanaka, A., Saito, K., Azoma, K., Kobayashi, K. 2013. Factors affecting variation in farm yields of irrigated lowland rice in southern-central Benin. Eur. J. Agron. 44: 46–53. doi.org/10.1016/j.eja.2012.08.002

Taufik, M., Arafah, Nappu, B., Djufry, F. 2014. The water management analysis of rice farming on irrigated land in South Sulawesi. Jurnal Pengkajian dan Pengembangan Teknologi Pertanian 17: 61–68. [in Indonesian]

Timsina, J., Wolf, J., Guilpart, N., et al. 2018. Can Bangladesh produce enough cereals to meet future demand? Agric. Syst. 163: 36–44. doi.org/10.1016/j.agsy.2016.11.003

Uphoff, N., Kassam, A., Harwood, R. 2011. SRI as a methodology for raising crop and water productivity: Productive adaptations in rice agronomy and irrigation water management. Paddy Water Environ. 9: 3–11. doi.org/10.1007/s10333-010-0224-4

Van Asten, P.J.A., Wopereis, M.C.S., Haefele, S., Isselmou, M.O., Kropff, M.J. 2003. Explaining yield gaps on farmer-identified degraded and non-degraded soils in a Sahelian irrigated rice scheme. Netherlands J. Agric. Sci. 50: 277–296.

van Eck, N.J., Waltman, L. 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84: 523–538. doi.org/10.1007/s11192-009-0146-3

van Eck, N.J., Waltman, L. 2014. Visualizing bibliometric networks. In: Ding, Y., Rousseau, R., Wolfram, D. (Eds.). Measuring Scholarly Impact. Springer, Cham, Switzerland, pp. 285–320.

van Wart, J., Kersebaum, K.C., Peng, S., Milner, M., Cassman, K.G. 2013. Estimating crop yield potential at regional to national scales. Field Crops Res. 143: 34–43. doi.org/10.1016/j.fcr.2012.11.018

Viana, J., Santos, J.V., Neiva, R.M., Souza, J., Duarte, L., Teodoro, A.C., Freitas, A. 2017. Remote sensing in human health: A 10-year bibliometric analysis. Remote Sens. 9: 1225. doi.org/10.3390/rs9121225

Wopereis, M.C.S., Donovan, C., Nebié, B., Guindo, D., N'Diaye, M.K. 1999. Soil fertility management in irrigated rice systems in the Sahel and Savanna regions of West Africa Part I. Agronomic analysis. Field Crops Res. 61: 125–145. doi.org/10.1016/S0378-4290(98)00154-3

Yuan, S., Linquist, B.A., Wilson, L.T., et al. 2021. Sustainable intensification for a larger global rice bowl. Nat. Commun. 12: 7163. doi.org/10.1038/s41467-021-27424-z

Yuan, S., Stuart, A.M., Laborte, A.G., et al. 2022. Southeast Asia must narrow down the yield gap to continue to be a major rice bowl. Nat. Food 3: 217–226. doi.org/10.1038/s43016-022-00477-z

Zhai, X., Cui, J., Shao, J., et al. 2017. Global research trends in spinal ultrasound: A systematic bibliometric analysis. BMJ Open 7: e015317.

Zhu, D.F. 2000. Bridging the rice yield gap in China. In: Papademetriou, M.K., Dent, F.J., Herath, E.M. (Eds.). Bridging the Rice Yield Gap in The Asia-Pacific Region. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific. Bangkok, Thailand, pp. 69–83.