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Article

40-year history: The development of agricultural research in China-a case study from one long-term experimental station

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Abstract: Over the past few decades, advancements in agricultural science and technology have driven significant changes in China's agriculture. This study uses the Wuqiao Experimental Station, established in 1983 in the North China Plain, as a case study to explore the trajectory of regional agricultural research in China over the past 40 years. By analyzing the keywords of all articles produced at this station, the study reveals shifts in research focus, methods, and agricultural practices over time. The analysis shows that the focus of agricultural research has shifted from yield-centered agricultural production and management (APM) to sustainability-oriented agroecology and environment (AE). Additionally, crop research has deepened, evolving from basic crop management to more detailed studies of plant anatomy, physiology, and advanced methods, including high-throughput sequencing and big data analysis. Despite these advances, concerns have emerged regarding the narrowing of research scope to a limited number of crops, primarily wheat and maize, which may reduce agricultural resilience. Furthermore, while research output has increased, a disconnect persists between scientific research and real-world agricultural challenges, such as heat stress and crop quality. This gap underscores the importance of ensuring that agricultural research remains relevant and addresses pressing issues related to food security and environmental sustainability. This study highlights the need to expand crop diversity, integrate sustainable practices, and adopt cutting-edge research methods to ensure the future resilience of China's agricultural systems. The findings provide valuable insights into trends and future directions in agricultural research in China, emphasizing the importance of a balanced approach to addressing current and future challenges.

Keywords: agricultural research process; long-term experimental station; research focus; crop management; climate change

1. Introduction

There's a Chinese idiom that says, "Food is the heaven to the people". China, as a populous country, attaches great importance to agricultural production and treats food security as a top priority. The past 40 years have witnessed the rapidly rising agricultural production in China. The total and unit production of staple crops such as rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) in China has continuously increased over the past decades [1,2]. Currently, China ranks first around the world in the production of cereals as well as in the production of cotton, fruit, vegetables, meat, poultry, eggs, and fishery products [3].

Scientific research is an important contributor to agricultural production. During the past decades, scientific research in crop science and technology contributed highyielding crop cultivars as well as improving crop management [4–6]. In China, the improvement of cultivars contributed over 40% of the yield increase in agriculture [7]. New fertilizer management is supposed to increase maize yield by 3.3%–8.6% in the North China Plain in the period of 1981–2009 [5]. New technologies and scientific products used in agriculture have reduced nitrogen and phosphorus emissions by over 60%, which facilitates agricultural sustainability and environmental protection [7]. As the climate changes, abiotic stresses become important factors limiting crop yield increase [8–10], and especially, drought and heat stresses are becoming more serious in recent years in a warming climate [11,12]. Hence, there is more focus on crop cultivars and management that can cope with the negative effects of these stresses in the current studies [13,14]. The relevant research studies dig deeper with time, ranging from plant population to molecular mechanisms [15,16], which is beneficial to precisely increase crop yield.

Improvements in research methods and instruments have provided important support for the advance in agricultural research in China and beyond. Previous studies concerning agriculture mainly focused on simple measurements such as plant height, leaf area, plant dry matter, and yield [17–19]. These measurements can reflect plant growth rate and production but cannot reveal the underlying mechanisms. With the improvement in experimental tools and devices, measures that can reflect plant physiology (e.g., leaf photosynthesis and activity of key enzymes) and organ microstructure then became the focus [20–22]. Simultaneously, root, soil nutrients, and their interaction started to receive attention in agronomy-related studies [23]. Nowadays, molecular techniques have facilitated uncovering the molecular basis of important plant morphological and yield traits [24,25]. The establishment of such research platforms greatly improves methods and theories when we aim at improving crop yield and quality. In addition, advances in mathematical and computational models for crop growth, organ morphogenesis, assimilate partitioning, and yield formation have significantly enhanced agricultural simulation and computational technology [26,27]. These developments effectively promoted agricultural research in China during the past decades. China is currently at a critical juncture, transitioning from traditional to modern agriculture. Reviewing the past is important for future agricultural research.

The North China Plain is the largest alluvial plain in China [28] and has a long history of cultivation (more than 8000 years). However, low fertility and soil salinization due to frequent floods have long plagued the area. Especially since the late 1950s, intensified cultivation practices and rapid expansion of irrigation have exacerbated soil degradation and its secondary salinization. Before the 1980s, 80% of the cropland in the North China Plain produced low or medium yields [29]. The region’s grain production could not meet regional food needs. Starting in the 1980s, a series of projects and supportive agricultural policies (i.e., the Huang-Huai-Hai agricultural campaign) were initiated in the region to improve soil fertility and grain production [30]. By around the year 2000, significant improvements had been made in soil desalination and drainage systems, leading to rapid agricultural development in the region [31]. Since then, various agricultural policies and projects have been implemented in the North China Plain during different periods to continue to ensure and improve food supply. Currently, the North China Plain contributes more than 50%

of the national wheat production and nearly 35% of the national maize production [32,33], making it one of the major croplands in China.

The research focus of the experimental station reflects the development of agricultural production. To trace the evolution of agricultural research in the North China Plain over the past decades, we focused on the Wuqiao Experimental Station, a long-term research station located in the North China Plain. Established in 1983 as part of the "Huang-Huai-Hai agricultural campaign". The station was initially established to address local issues such as soil salinization, water scarcity, and low crop yields. In this study, we conducted a detailed analysis of the station's annual publications over the past 40 years. We carefully examined the topics, keywords, key findings, and research methods in each publication. By reviewing the development of agricultural research in this specific region, we aimed to identify the strengths and weaknesses of the research at various stages of development and to offer recommendations for future agricultural studies.

2. Methods

2.1. Article collection and screening

We conducted a comprehensive analysis of peer-reviewed research articles that were supported by experimental data from the Wuqiao Experimental Station of China Agricultural University. The articles derived from two primary databases: the Web of Science (http://apps.webofknowledge.com/) for articles written in English and China National Knowledge Infrastructure (CNKI, https://www.cnki.net/) for articles written in Chinese. Google Scholar was also utilized to retrieve articles that may not have been included in the above two databases.

Rigorous screening procedures were employed to ensure that only articles derived from experiments conducted at Wuqiao Experimental Station were included. We searched all of the searchable fields using "Wuqiao Experimental Station" or "Wuqiao". Dissertations, theses, news reports, conference abstracts, and other unrelated articles were eliminated to ensure all the collected articles were peer-reviewed and published in academic journals. The publication time of these articles spanned from January 1983 to December 2023, aligning with the establishment of the station.

There were 665 articles obtained in total, of which 432 articles were in Chinese and 233 articles in English. Articles published in each year since the establishment of the experimental station were counted to reflect the changes in academic productivity with time.

2.2. Group classification of keywords

Keywords play an important role in representing research interests and topics. All the keywords listed in the articles were classified into five groups based on their roles in agricultural research, including crop species (CS), agricultural production and management (APM), agroecology and environment (AE), plant and organ (PO), and research methods (RM). The total number of keywords and their information in each group were analyzed, respectively.

2.3. Subgroup classification of keywords

Based on crop name and Latin name that appear in keywords or title, CS of all the collected articles were recorded. The appearance frequency of one given crop species was calculated as the percentage of this crop species appearance number over the appearance number of the total crop species in each year. The subgroup of APM includes the keywords concerning yield, water management, fertilizer management, and regulation of plant population. Plant population regulation is associated with the arrangement of plant density, lodging-resistance regulation, rowing distance, sowing date, canopy architecture, etc. The subgroup of AE mainly contains the keywords about agroecology and farming systems, abiotic stress, and soil nutrients and conditions. Crop rotation, tillage systems, and environmental factors that are below and above ground are involved in this subgroup. The subgroup of PO focused on keywords that are related to organ development and plant production. Plant growth, plant size, and organ structure and function are taken into account. The subgroup of RM mainly contained three aspects: data-acquisition technologies used in experiments, data analysis methods, and crop models.

To align with China's five-year plan and account for the scarcity of keywords per year, we aggregated keywords into five-year periods, facilitating observation of their temporal evolution.

3. Results

3.1. Number of published articles and keywords

Prior to 1995, only one publication was searched, which was published in 1987. Due to its limited relevance to agricultural research, this article was excluded from further analysis. Therefore, our study only covers literature published after 1995. All these articles were based on the experiments performed at the Wuqiao Experimental Station of China Agricultural University. The annual number of articles and keywords in total kept continuously increasing from 1995 to 2023, with a higher increasing rate in the last five years (**Figure 1a,b**). Their number in English remained at a very low level until 2015, and afterwards, the number sharply increased (**Figure 1c,d**). By contrast, the number of articles and keywords in Chinese increased first from 1995 to 2013 and then rapidly decreased in the last decade (**Figure 1e,f**).

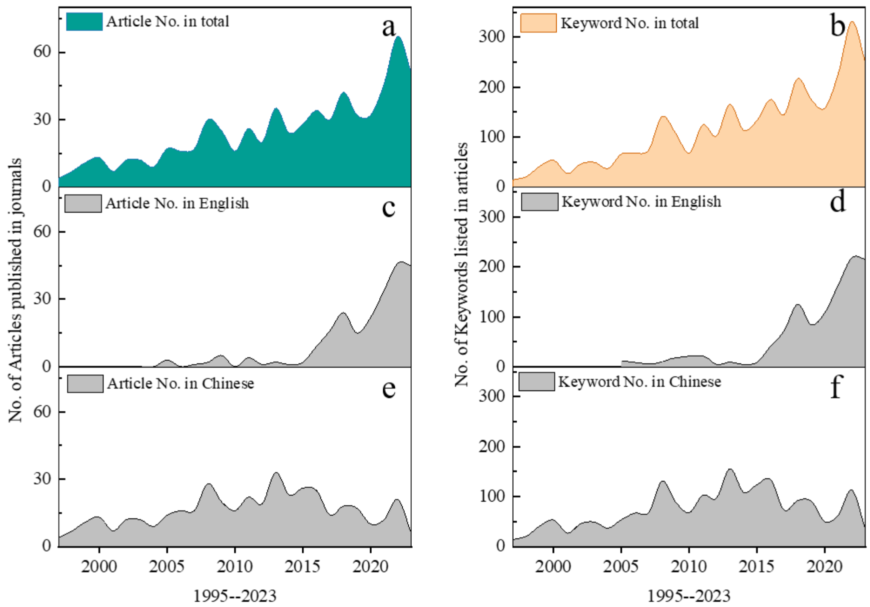


Figure 1. The annual number of peer-reviewed articles and associated keywords from 1995 to 2023 derived from the Wuqiao experimental station in China. **(a)** the annual total number of articles published from1995 to 2023; **(b)** the total number of associated keywords from 1995-2023; **(c)** the annual number of English articles from 1995 to 2023; **(d)** number of keywords in English articles from 1995 to 2023; **(e)** the annual number of Chinses articles from 1995 to 2023; **(f)** number of keywords in Chinese articles from 1995 to 2023.

3.2. Percentage ratio of keywords classified into five groups

All the keywords listed in the articles were classified into five groups based on their roles in agricultural research, including crop species (CS), agricultural production and management (APM), agroecology and environment (AE), plant and organ (PO), and research methods (RM), with each having 2–4 subgroups (**Figure 2a**). The overall percentage ratios of keywords in each group over the total keywords were 25.1% in CS, 40.1% in APM, 19.3% in AE, 11.7% in PO, and 3.8% in RM. However, the ratios in these five groups have distinct trends in the time span of 1995–2023 (**Figure 2b**). CS and APM both had decreasing ratios with time; AE and RM had increasing ratios, especially in the past 20 years, and PO had a relatively stable ratio (around 10%) in the past 20 years.

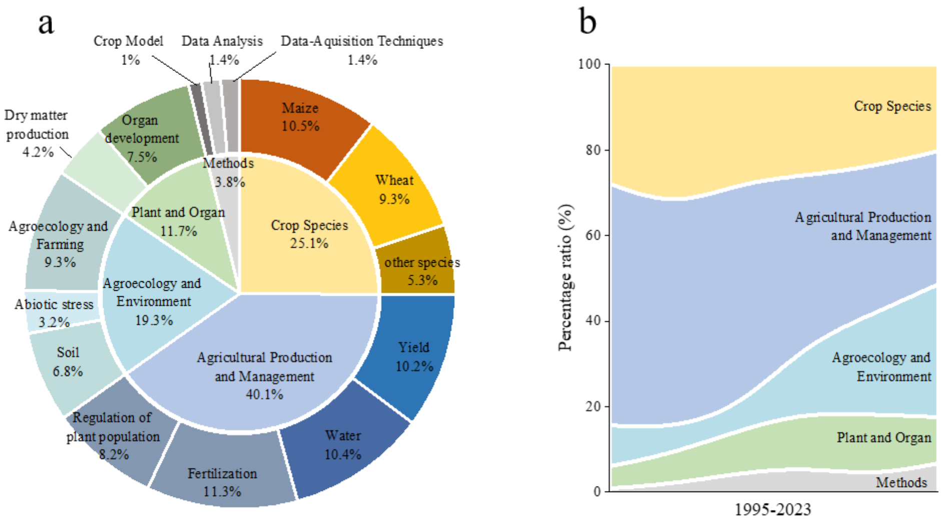


Figure 2. An overview of author keyword groups based on the total keyword number from 1995 to 2003, **(a)** grouping and sub-grouping of keywords; **(b)** trends in keyword groupings over time.

The percentage ratio represents the ratio of keyword number in one group over the total keyword number.

3.3. Trends in percentage ratio of keywords in subgroups in 1995–2023

In the group of CS, the percentage ratio of the keyword "wheat" accounted for 62.1% of the total keywords, "maize" accounted for 6.9%, and the rest of the species together accounted for 31% in 1995–2000 (**Figure 3**). In 2021–2023, however, the ratio of "wheat" reduced to 43.3%, "maize" increased to 52.5%, and the rest reduced to 4.2%. In this group, crop species that were listed in keywords reduced from 10 in the 2000s (2000-2010) to nearly 3 in 2021–2023.

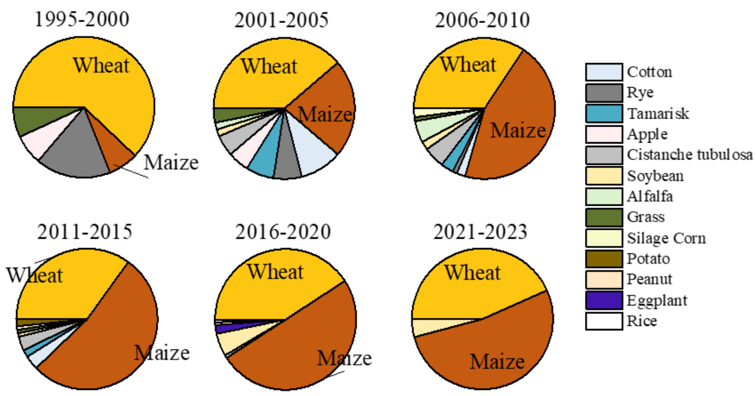


Figure 3. Trends in crop species used in experimental study with time from 1995 to 2023.

The area in the pie chart represents the ratio of occurrences of a specific crop species relative to the total occurrences of all crop species.

In the group of APM, representative keywords were selected in subgroups of "yield", "water", and "fertilization" related keywords based on the first appearance in the past 30 years (**Figure 4**). The subgroup of "regulation of plant population" was not specifically shown due to its stable trend in 1995–2023. With the increase in yield of maize and wheat in China, the representative keyword in the subgroup "yield" changed from "tons of grain yield" in 1995–2000 to "ultra-high yield" (**Figure 4a**). Likewise, in the subgroup "irrigation", the representative keyword changed from "water-saving" in 1995–2000 to "new water-saving cultivation system" in 2020–2023 (**Figure 4b**). By contrast, agricultural nitrogen application amounts steadily increased from 1995 to 2015 and afterwards, rapidly decreased (**Figure 4c**). Correspondingly, the representative keyword in the subgroup "fertilization" changed from "nitrogen utilization" in 1995–2005 to "organic fertilizer" in 2015–2020 and "reduced nitrogen application" in 2020–2023.

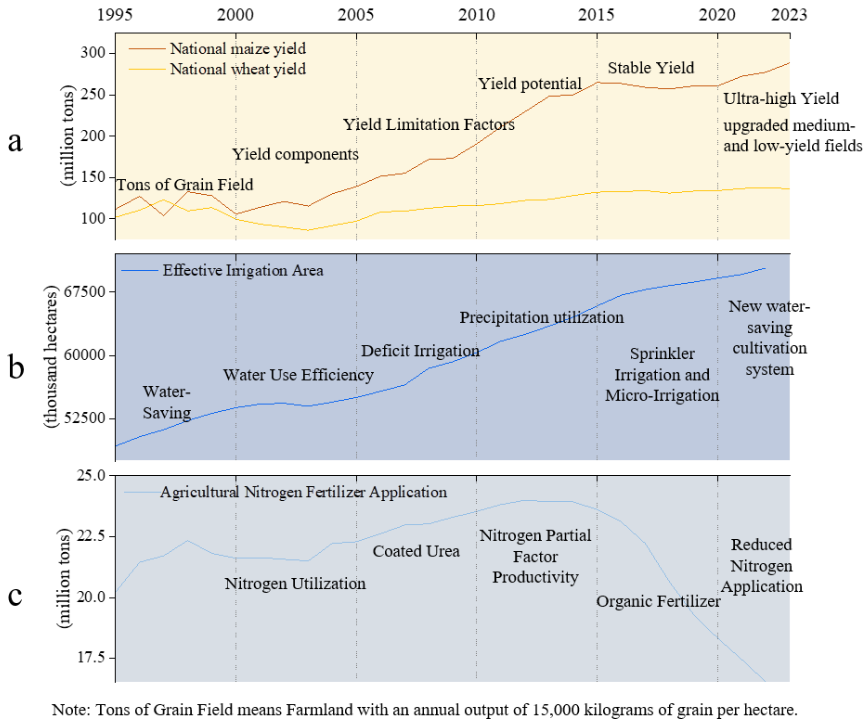


Figure 4. The shift of research focus on agricultural production and management from 1995 to 2023, **(a)** yield-related keywords; **(b)** water-related keywords; **(c)** fertilization-related keywords.

The curves represent the trends of maize and wheat, respectively. The term of Tons of Grain Field means farmland with an annual output of 15,000 km of grain per hectare.
The curve represents the effective irrigation area.
The curve represents the amount of nitrogen fertilizer. The first appearance of a new critical keyword that was frequently referred in the subsequent studies represents the shift of research.

With regard to the group of AE, there are three subgroups, i.e., "agroecology and farming", "abiotic stress", and "soil" (**Figure 5**). In these subgroups, the relevant keyword number remained at a low level until 2010 and then greatly increased (**Figure 5(a1–c1)**). In the subgroups "agroecology and farming" and "soil", the ratio of the relevant keyword number over the total keyword number also greatly increased after 2015 (**Figure 5(a1,c1)**). The representative keywords were "crop rotation" in 1995–2010 and became "climate warming", "greenhouse gas emissions", "straw return", and "no tillage" in 2011–2023 (**Figure 5(b1)**). "Drought" was always one of the most important keywords at every stage in the past 30 years in the subgroup "abiotic stress", but in recent years, "heat" and "lodging" also became important keywords (**Figure 5(b2)**). "Saline Alkali" had a large ratio in 1995–2005, but the ratio became very low afterwards. In the subgroup "soil", keyword number in relation to soil organic carbon, microorganisms, and amelioration increased after 2010, but simultaneously, keyword number concerning soil basic properties rapidly decreased (**Figure 5(c2)**).

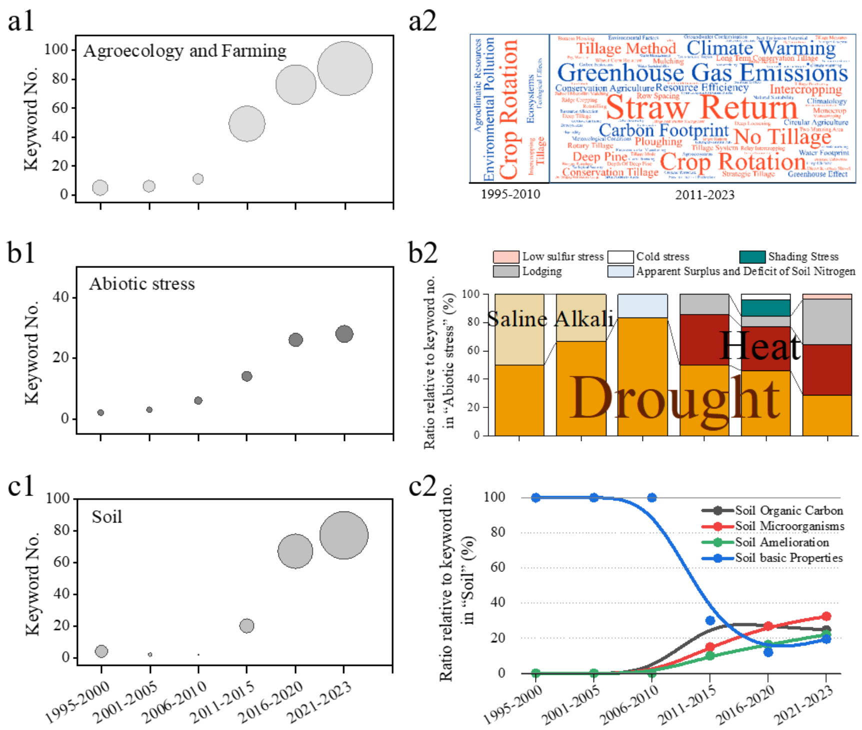
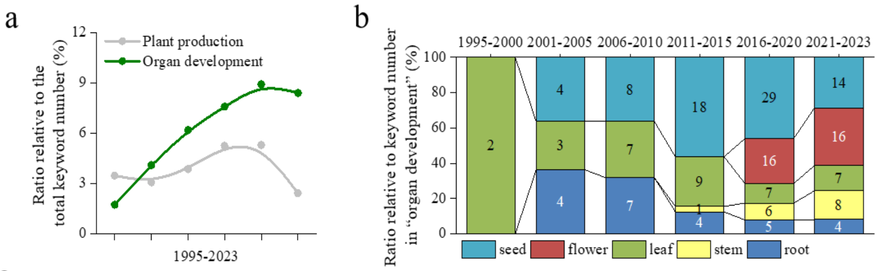


Figure 5. The shift of research focus on agroecology and environment from 1995 to 2023, **(a1)** trend in agroecology and farming-related keyword number; **(a2)** word cloud of all keywords related to agroecology and farming; the size of keyword represents its frequency of occurrence; **(b1)** trend in abiotic stress-related keywords; **(b2)** ratio of keyword number related to different abiotic stresses; **(c1)** trend in soil-related keywords; **(c2)** changes in keywords in different soil categories with time. (a1,c1) bubble size represents the ratio of the relevant keyword number over the total keyword number.

The ratio of keyword number concerning organ development to the total keyword number increased from ~1% to ~9% in the past 30 years, but the ratio about plant production remained stable (~3%) and rapidly decreased in recent years (**Figure 6a**). Hence, we mainly focused on the keywords about organ development in the group of PO. In the subgroup of "organ development", leaf-related keywords were mainly detected in 1995–2000, but keywords related to leaf, stem, root, seed, and especially flower all appeared in the following eras (**Figure 6b**). All the keywords in this group demonstrated the depth of the research in vegetative and reproductive organs (**Figure 6c**). Leaf-related keywords ranged from leaf area index to leaf morphology and components. Root-related keywords derived from root distribution, traits, and function of primary and secondary roots. Stem-related keywords are mainly related to internode morphology and strength. Comparatively, keywords about reproductive organs were more abundant, including flower development, flowering dynamics, fertilization, and grain filling. Flower and grain, such as pollen, ovary, embryo, and endosperm, frequently appeared.



c

	Vegetative organs (root, stem, leaf)			Reproductive organs (flower, seed)	
Main research topics	Leaf area index (8) Chlorophyll (8) Leaf morphology (6) Leaf senescence (3))	Root distribution (5) Root traits (7) Root vigor (7) Root anchorage strength (3)	Internode-morphology (8) Stem strength (7)	Flower morphogenesis (18) Flowering period (6) Fertilization (4)	Grain filling (25) Grain formation (18) Kernel abortion (10) Fruiting (14)
Research level	Flag leaf; Ear leaf; Chloroplasts; Stomata	Primary roots; Secondary root		Male and female Flowers; Pollen; Pollen tube; Spikelet; Floret; Filaments; Pistil; Glumes; Awn	Seeds; Embryo; Endosperm; Endosperm cells; Ovary

Note: The number in parentheses represents the frequency of each word appearing as a keyword (or as part of a keyword).

Figure 6. The shift of research focus on plant and organ from 1995 to 2023, **(a)** Changes in the number of keywords related to plant production and organ development over time; **(b)** Ratio of keyword number related to plant organs; **(c)** Critical keywords that represent main research topic and research level.

The number in parentheses represents the frequency of the keyword.

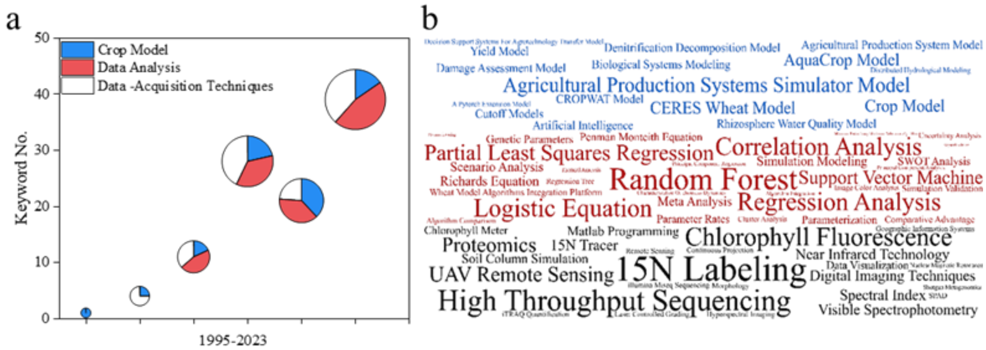


Figure 7. Trend in keyword related to research method, **(a)** trends of keyword number related to different research methods with time; **(b)** word cloud of keywords related to research methods; keywords for data analysis, crop model, and data acquisition technology are shown in red, blue, and black, respectively.

Blue, red, and white represent crop model, data analysis, and data-acquisition technique, respectively, in (**a**). Bubble size represents the ratio of the number of research methods-related keywords to the total keyword number. The colored area within each bubble represents the proportion of keywords associated with a specific research method relative to the total number of keywords across all research methods. The size of keyword in the word cloud represents its frequency of occurrence in (**b**).

Keyword number about RM linearly increased at a fast rate in the past 30 years (**Figure 7a**). The respective ratio of keywords about data-acquisition technology, data analysis, and models to the total keyword number in methods remained relatively stable from 2011 to 2020, but the ratio about data analysis rapidly increased afterwards. Keywords related to high-throughput sequencing, isotope labelling, and random forests appeared more frequently with time (**Figure 7b**).

4. Discussion

Over the past 40 years, crop yield in the North China Plain continuously increased with the intensified agricultural management [34,35], but soil quality and crop species kept declining in the Huang-Huai-Hai Plain [36,37]. The increases in yield are attributed to crop varietal changes, optimized crop management, and integrated pest and disease management [38–40]. To clearly reflect these trends, we focused on Wuqiao Experimental Station, one long-term experimental station that has continuously conducted field research, persistently tackling various agricultural challenges. Analyzing the station's research history provides a comprehensive understanding of agricultural development in this region and offers scientific guidance for future sustainable agriculture.

4.1. Shifts in research focus

One of the most notable changes over time is the contrasting trends between agricultural production and management (APM) and agroecology and environment (AE) (**Figure 2b**). In the early years, research heavily focused on APM. During this period, keywords related to basic crop management practices, such as "water-saving" and "fertilization" dominated the discourse, reflecting a primary focus on maximizing crop yields using available resources. In this section, there are more articles concerning nitrogen management, out of which optimizing the timing and amount of nitrogen are the key focuses [41]. However, as agricultural production advanced, the emphasis on APM gradually decreased, and research focus shifted, particularly after 2015, towards more environmentally friendly agricultural practices. This shift is evident in the emergence of keywords like "new water-saving cultivation system" and "reduced nitrogen application" (**Figure 4**). During this shift, irrigation modes changed from surface flooding to dripping irrigation and sprinkling irrigation, and nitrogen input amount intended to decrease [42]. Correspondingly, the keyword number about organic fertilizer increased (**Figure 4c**). In contrast to APM, early research showed limited attention to ecological and environmental issues. However, as the impacts of climate change and ecological degradation became more apparent, research in these areas increased, with a growing focus on the sustainability of agricultural ecosystems, the effects of climate change, greenhouse gas emissions, and soil health (**Figure 5**), consistent with findings of other studies [43,44]. In recent years, "heat stress" has become more prominent (**Figure 5(b2)**), reflecting the increasing threats posed by extreme weather events as global warming intensifies.

The comparison between research trends in APM and AE highlights a broader shift from a yield-focused approach to a sustainability-oriented one. Early research was primarily concerned with maximizing crop yields, while the rise of ecological studies represents a response to the environmental challenges caused by high-yield farming practices [45]. This evolution in research focus demonstrates the transition in Chinese agriculture from a singular focus on yield growth to a balanced approach that integrates productivity with environmental protection. Sustainable agriculture that protects natural resources and the ecological environment while ensuring food security will continue to be the key to agricultural research [46].

Another significant change is the continuous improvement in the depth and precision of agricultural research. In the subgroup of plant and organ (PO), the research focus has shifted from basic organ morphology to a more detailed understanding of organ function and development, extending into more complex areas of plant anatomy and physiology. Simultaneously, research methods (RM)-related keywords have shown linear growth (**Figure 7**), which indicates a clear transition towards more advanced technologies. For instance, "High-throughput sequencing" has emerged frequently in recent years as a data acquisition technology, suggesting that genetics and genomics have become indispensable components of agricultural research [47,48]. Also, there has been a rapid rise in keywords related to data analysis, which is likely driven by the explosive growth of agricultural big data. The previous simple data analysis methods cannot meet the demands of big data analysis. Advancements in sensor technology, remote sensing, and other data-intensive methods have, in turn, fueled this growth [49–51]. These advances result in the appearance of some new keywords such as "high throughput data acquisition" and "machine learning". Exploring complex biological processes at finer scales will undoubtedly become a major trend in precision agriculture [52,53], and the evolution of research keywords at the Wuqiao Experimental Station also reflects and aligns with this trend.

4.2. Potential threats

However, this research also reveals some concerns for the future. First, crop species receiving attention has become increasingly limited in recent years, particularly after 2020, with almost only maize, wheat, and a small number of soybeans being cultivated for scientific research (**Figure 3**). While major crops like wheat and maize are crucial to China's food security, the reduction in crop diversity could negatively impact the resilience of agriculture [54,55]. The decrease in crop diversity also necessitates broader attention to threats such as pests, diseases, and climate change, in order to mitigate associated risks [56].

Moreover, although the number of published articles has rapidly increased after 2015, particularly in English, indicating fast-paced development in agricultural research and integration with the international community, the ongoing scientific research has not been able to address the current practical challenges in agricultural production. For example, although research has already focused on heat stress and analyzed the response mechanisms of crops, there are currently no effective countermeasures in place [21,57,58]. Moreover, research has not given sufficient attention to crop quality and pest control, failing to comprehensively address the issues facing national food security [59]. A disconnect remains between scientific research and practical agricultural production. In contrast, early research at the Wuqiao Experimental Station, along with other experimental stations located in the North China Plain, effectively addressed practical issues such as salinization [30]. The fact that "saline alkali" no longer appears as a keyword after 2010 (as shown in **Figure 5b2**) strongly demonstrates the success of these early efforts, despite the lack of peer-reviewed academic articles. The recent surge in publications may be linked to how research outcomes of younger researchers are evaluated. Nevertheless, this underscores the potential risk of prioritizing publication output over addressing urgent agricultural challenges.

4.3. Limitations of this study

This study has several limitations that should be acknowledged. First, the analysis is limited to publications from a single experimental station, which may not fully represent broader trends in Chinese agricultural research. While Wuqiao is a highly influential station, its focus and outcomes might differ from those of other regions or institutions, limiting the generalizability of the findings. Additionally, relying solely on keyword analysis may oversimplify the complexity of research trends and focus areas. Keywords provide useful but limited snapshots of research content and may overlook subtle or emerging themes not captured by these terms. Nevertheless, the trends over the past decades concerning crop species, agricultural production and management, and agroecology and the environment that were detected in our study are able to reflect the overall changes in agricultural production and research, at least in the Huang-Huai-Hai Plain. Hence, this study has important potential, especially for improving scientific research in agriculture.

5. Conclusions and perspectives

The findings from the Wuqiao Experimental Station offer valuable insights into the future direction of agricultural research, at least in some regions of China. While focusing on staple crops is vital for food security, expanding research to cover a broader range of crop species is equally important to enhance resilience against climate change and other challenges. Sustainability-oriented studies are also necessary, including microbial, rhizosphere plant-associated microbe, and chemical pesticide management. In the past 40 years, there have been more studies focusing on plants above ground, resulting in studies that focus on roots, rhizosphere microbiota, and soil nutrient dynamics that are limited. Recent studies have uncovered that the use of microbial consortia can improve crop yields and environmental protection [60]. Additionally, prioritizing sustainable practices, such as water-saving irrigation, reducing nitrogen fertilizer application, and advancing agroecological research, will be essential to minimize agriculture's environmental impact. Encouraging the adoption of cutting-edge research methods and technologies will further deepen our understanding of agricultural systems and improve crop management practices. Monitoring of research trends is necessary to ensure that agricultural research remains aligned with the evolving challenges and opportunities in China's agricultural sector. Together, the experimental stations need to strike a balance between addressing current issues and preparing for potential future challenges.

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writing—review and editing, XL and SH; visualization, XL; supervision, SH. All authors have read and agreed to the published version of the manuscript.

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