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Agricultural socialized services in China's smallholder farming systems: a systematic review of service types, benefits, and measurement challenges

Rong Zeng[1], Meseret C. Abate[1]*, Cai Baozhong[1],
Amsalu K. Addis[2], Xiangyun Yi[1], Shaoping Jiang[1], Xu Yan[1],
Betelhem A. Geremew[3] and Amsalu N. Alamerew[4,5]

[1]Research Institute of Rural Revitalization, School of Tourism and Cultural Industry, Hunan University
of Science and Engineering, Yongzhou, China, [2]School of Economics and Management, Hanjiang
Normal University, Shiyan, China, [3]School of Public Administration and Law, Hunan Agricultural
University, Changsha, China, [4]Faculty of Forestry, University of British Columbia, Vancouver, Canada,
[5]College of Agriculture, Food and Climate Science, Injibara University, Injibara, Ethiopia

This review investigates the existing research on agricultural socialized services (ASS), focusing on their benefits to smallholder farmers and the barriers these farmers encounter in accessing such services. ASS are vital to modern agricultural systems, influencing both service providers and smallholder practices in various national contexts. Although previous studies have examined trends and levels of ASS development, there has been limited exploration of the specific types of services that warrant further research and the obstacles facing smallholders in their implementation. This deficiency in information heightens the vulnerability of smallholder farmers to ongoing and unpredictable risks. To address this issue, we employed a modified Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) technique to conduct a thorough literature search, applying eligibility criteria to identify pertinent studies. The selected literature was categorized by service type and their reported benefits to smallholders, without imposing restrictions on study methodologies. Our findings indicate that 66% of the analyzed studies concentrated on production-stage services, particularly machinery outsourcing, which is largely influenced by rural labor migration and aims to optimize yields. In contrast, only 16% of the studies explored multi-stage ASS integration (which includes pre-production, production, and post-production services), and none examined the concept of holistic service bundling. While mechanization services emerged as prominent due to their measurable productivity enhancements, significant gaps remain in assessing intangible benefits and understanding systemic trade-offs. Throughout the review, we identified challenges in measuring the effects of these services, such as difficulties in quantifying subjective impacts, data validation shortcomings, and the need for improved simulation models. Ultimately, this

review calls for a shift in research direction towards a wider array of service types, the development of cost-effective delivery mechanisms, and strategies to improve access, all of which are essential to enhancing the resilience and livelihoods of smallholder farmers.

1 Introduction

Smallholder farmers in low- and middle-income countries play a critical role in ad-dressing global food insecurity and malnutrition. Globally, there are approximately 570 million farms, with smallholder operations accounting for about 83% of these, primarily concentrated in Asia (74%) and Sub-Saharan Africa (9%) (Lowder et al., 2016; FAO, 2018). These farmers, who typically operate on less than 2 hectares of land, contribute 30% to 34% of the global food supply while utilizing only 24% of agricultural land (Ricciardi et al., 2018). Despite their significant contributions, smallholders face systemic barriers to accessing essential agricultural inputs, technologies, and markets. These constraints perpetuate cycles of poverty and undermine resilience, which further compromises their livelihoods (Choquette-Levy et al., 2021; Ola and Menapace, 2020). Concurrently, smallholder farming systems often generate significant environmental externalities, including soil degradation and biodiversity loss, driven by unsustainable practices that stem from limited resources (Alpízar et al., 2020; Chiwuikem et al., 2022). To address these intertwined challenges, public and private agricultural support programs known as agricultural socialized services (ASS) have emerged as innovative solutions aimed at transforming smallholder production systems (Zhang et al., 2016; Cui et al., 2018; Fan and Rue, 2020).

In this review, ASS are defined as institutionalized, non-farm intermediaries that facilitate smallholder farmers' access to productive resources, such as seeds and machinery, technical expertise like agronomic training, and market integration throughout the pre-production, production, and post-production cultivation phases (Wang et al., 2024). Comprised of both public and private entities such as state-led cooperatives, agribusiness firms, and grassroots farmer collectives, ASS mitigate systemic constraints related to fragmented landholdings, labor shortages, and input costs through mechanisms that include mechanization, advisory services, and financial support (Qiu and Luo, 2021). ASS can achieve economies of scale, enabling adoption of modernized agricultural practices without necessitating capital-intensive investments from individual farmers (Xia et al., 2017). Their multidimensional objectives encompassing enhanced productivity, environmental sustainability like precision input application, and

diversification of rural livelihoods. However, the effectiveness of ASS mediated by factors such as agro-ecological het-erogeneity, policy coherence, and socioeconomic inequalities (Zhang et al., 2020; Shroff, 2022). Importantly, ASS differ from conventional extension services by focusing on the promotion of outsourced service markets over unilateral knowledge dissemination, thereby acting as hybrid institutions that align state-driven developmental goals with market efficiency paradigms.

ASS have garnered significant scholarly attention due to their wide-ranging implications for socioeconomic development, environmental sustainability, and agricultural provision. Recent interdisciplinary research, spanning agronomy, development economics, and rural sociology increasingly examines how ASS reshape smallholder agricultural practices and outcomes. Key research areas include transformations in farm-level adaptation to changing market dynamics through value-chain integration, the adoption of eco-friendly practices including precision nutrient management), and enhanced productivity and resilience amidst socioeconomic inequities and climate-induced stressors (Cai et al., 2022; Chen C. et al., 2022; Cheng J. et al., 2022; Huan et al., 2022; Wang and Huan, 2023; Wu et al., 2024). These studies underscore ASS as a critical mechanism for fostering sustainable agricultural transitions, however, gaps persist in understanding their context-specific trade-offs and scalability across heterogeneous agro-ecological contexts.

Ultimately, ASS is increasingly seen as vital for optimizing technical efficiency and fostering synergies between smallholder farmers and modern agricultural systems. ASS improves crop yields and agricultural productivity by providing high-quality inputs such as improved seeds and fertilizers and promoting modern farming methods. This effect is strongest in areas with limited resources (Shi et al., 2023). ASS reduces operational challenges for smallholder producers by offering advisory support, financial services, and skill-building programs. These efforts strengthen farm resilience and enhance long-term economic sustainability (Zhu et al., 2022; Lu et al., 2022). Furthermore, ASS play a critical role in integrating smallholders into modern agricultural value chains by establishing institutional networks that link them to markets, supply chains, and technological innovation ecosystems, thereby reducing their marginalization in rapidly commercializing economies (Guo et al., 2022). Notably, ASS is emerging as a strategic response to structural challenges in Chinese agriculture, such as labor shortages driven by

TABLE 1 Search strings in the literature search.

Search name	Search focus	Search number	Search string
ASS general scope	Core terminology for agricultural socialized services	1	TS=("agriculture* socialized service*" OR "rural service* system*" OR "farm* service* cooperative*" OR "agriculture* extension service*") AND SU=(agriculture OR economics OR "environmental studies") NOT WC=(forestry OR fisheries)
Pre-production services	Input access, machinery leasing, training, seed distribution	2	TS=("pre-production service*" OR "input access" OR "seed distribution" OR "machinery leasing" OR "soil testing" OR "farmer training" OR "credit access" OR "land preparation") AND TS=(smallholder* OR "small-scale farmer*" OR peasant*)
Production services	Cultivation support, pest control, machinery use, irrigation	3	TS=("production service*" OR "cultivation technique*" OR "pest management" OR "fertilizer application" OR "machinery sharing" OR "irrigation service*" OR "crop monitoring") AND TS=(yield OR productivity OR efficiency)
Post-production services	Processing, storage, marketing, cooperatives	4	TS=("post-production service*" OR "post-harvest processing" OR "storage facility*" OR "market linkage*" OR "branding support" OR "e-commerce platform*" OR "cooperative* marketing") AND TS=(profit* OR "value chain" OR "income diversification")
Smallholder benefits	Income, productivity, sustainability, poverty alleviation	5	TS=("benefit*" OR impact OR outcome*) AND TS=("smallholder*" OR "small-scale farmer*" OR peasant*) AND TS=("income increase" OR "poverty reduction" OR "risk mitigation" OR "resource efficiency" OR "sustainability" OR "livelihood improvement")
ASS trends in China	Temporal, policy, and adoption trends in China	6	TS=("trend*" OR "temporal change*" OR "policy evolution" OR "adoption rate*") AND TS=("agriculture* socialized service*" OR "rural service* system*") AND TS=(China OR "People's Republic of China" OR PRC OR "Chinese province*" OR "Yangtze River Basin" OR "North China Plain") AND PY=(2000-2023)

Search strings employed in the systematic literature review on ASS, focusing on service typologies (pre-production, production, post-production), benefits for smallholder farmers, and temporal trends in China. TS, Topic Search (title, abstract, keywords); SU, Subject Category (database-specific research areas); WC, Web of Science Categories; PY, Publication Year. Search strings combine Boolean operators (AND, OR), truncation (*), and field-specific syntax to optimize precision and recall across multidisciplinary databases (e.g., Web of Science, Scopus).

rural aging and feminization, through scalable mechanization and technology adoption (Cao et al., 2023; Yang et al., 2023). These developments align with China's national agenda to modernize agriculture and revitalize rural economies, which has spurred rapid ASS proliferation (Cai et al., 2022; Yang et al., 2023).

Despite all this, previous studies recognizes that the full potential of ASS has yet to be exploited. The distribution pattern of ASS is found to be uneven. Moreover, the methodological approach to investigate how ASS influence the farming system is not well under-stood, as this review reveals aims to show the sources (Cheng L. et al., 2022; Huan et al., 2022; Peng et al., 2022; Yi and Gu, 2022; Zhou et al., 2023). The type of ASS needed, their accessibility, and outcomes have not been compiled. This information provides policymakers with a pictorial illustration to set policies to optimize the development level of ASS. Prior studies also suggested that, in some cases, ASS moves in an uncertain direction, complicating the farming system, basically due to a lack of proper monitoring systems (Zhu et al., 2022). These gaps in previous studies motivate the conduct of this systematic review.

This systematic review compliments earlier reviews that have investigated the trends and evolution of ASS to examine the development level of ASS in the current agriculture production system (e.g., Yang L. et al., 2022). This review also examines pertinent issues of ASS system, including inefficient government management, the absence of targeted policies, and slow progress in developing a new ASS system, low service quality, an imbalanced personnel structure, and a shortage of professionals. Additionally, our review highlight the inadequate service supply and the uneven organizational capacity of ASS. Researchers have recognized that the multidimensional nature, the temporal dynamics, contextual variations and interdisciplinary nature of ASS has emerged as a barrier to fully understand how ASS can support smallholder farmers. Investigating this barrier and suggesting solutions possibly provides more opportunities for long-term agricultural sustainability. Our review, therefore, investigates this reflection through a detailed and systematic analysis of recent literature according to the current demand for government to transform into modern agriculture and revitalized rural areas.

2 Methodology

To establish a comprehensive evidence base, we conducted a systematic literature review across multidisciplinary databases to identify peer-reviewed studies on ASS. PRISMA guided this review. All retrieved records underwent a rigorous eligibility screening process, during which they were evaluated against predefined inclusion criteria, including empirical focus on ASS, methodological rigor, and peer-reviewed status. Studies failing to meet these criteria were excluded through iterative screening rounds, resulting in a refined analytical dataset. For the studies retained in our analysis, we systematically extracted and cataloged four primary variables: (1) the specific ASS typology examined, (2) the geographic scope of implementation categorized by administrative boundaries, and (3) the benefit scope of each service for smallholder farmers (4) measurement of ASS impact in each study. This multi-dimensional coding framework, based on the extracted variables of service typology, geographic scope, and benefit scope, enabled a granular systematic synthesis of ASS research trends, facilitating analysis across functional, spatiotemporal, and impact dimensions.
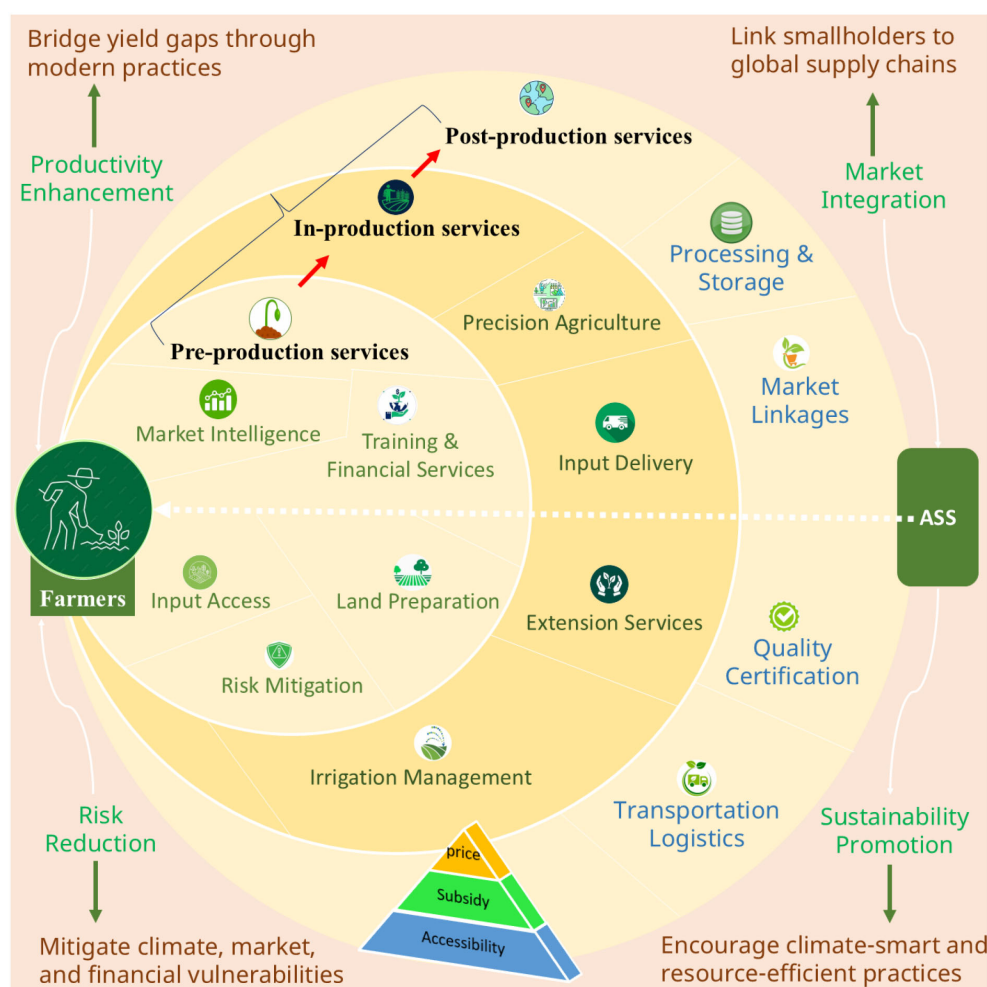
FIGURE 1
The wheel of the major types of ASS across production stages including the pre-production, production, and post-production and their contributions towards sustainable agriculture. The triangle at the bottom of the wheel shows the three important factors affecting smallholder farmers' ability to access ASS. The wheel was developed based on the preliminary search and analysis of studies.

2.1 Terminology for definitions of risk and risk types

To provide context to our literature search, we first conceptualize ASS and explore some of its definitions, followed by an overview of the general types of ASS available to smallholders. Multiple types of ASS within a single category provided by service providers. For example, pre-production services are a type of ASS that includes various services including land preparation, soil management, and subsidies for inputs like grants or discounts for seeds, fertilizers, or machinery. These could bridge gaps in knowledge, resources, and infrastructure, empowering farmers, especially smallholders, to adopt modern, efficient, and sustainable agricultural practices.

To identify studies on ASS types, we focused on keywords and terminology specifically linked to ASS categories. Existing conceptualizations and definitions of ASS in the literature guided the development of our search terms (Table 1). Huan et al. (2022) and Wang and Huan (2023) defined ASS as the broad range of

services provided across all stages of agriculture, pre-production, production, and post-production, under the system of family contract management. This definition implies that ASS function as an integrated, multistage support system for family-contract-managed farms, addressing chains of agricultural production that needs to enhance efficiency and sustainability in smallholder agriculture. The development of ASS has been influenced by the shift from a planned economy to a market-oriented economy (Jian et al., 2021). ASS can be provided by government agencies and other private companies.

There are mainly three general types of agricultural socialized services for smallholder farmers across production stages (Figure 1). These ASS are explicitly described as follows:

1. Pre-production agricultural socialized services encompass institutional mechanisms providing smallholder farmers with critical inputs and technical guidance prior to cultivation cycles (Yuan et al., 2022). Core offerings include access to certified seeds, soil testing, mechanized

land preparation, subsidized credit, and agronomic training programs. These services are designed to address foundational challenges associated with input affordability, soil suitability, and knowledge gaps in modern farming practices, thereby enhancing the adoption of improved agricultural practices (Ye et al., 2013; Zhu et al., 2022).

2. Production-stage agricultural socialized services have emerged in response to logistical and technical demands of crop and livestock management, with primary interventions addressing mechanized cultivation, integrated pest control, and precision irrigation (Sun et al., 2023; Shi et al., 2023; Chen et al., 2023). Further support is provided through on-demand machinery rentals and digital advisories for fertilizer application or disease diagnosis, thereby enhancing resilience against operational inefficiencies (Du et al., 2023; Guo et al., 2022).

3. Post-production agricultural socialized services arise from the economic and logistical challenges of transforming harvests into marketable goods, with central functions aimed in addressing storage infrastructure, cooperative marketing networks, and value-added processing. These services helped to mitigate losses from price volatility, spoilage, and market isolation (Zhu et al., 2022; Lu et al., 2022). In this stage, expanded provisions are offered through branding support, e-commerce platforms, and traceability systems, countering barriers such as fragmented supply chains and limited bargaining power (Zhou et al., 2023; Huan et al., 2022).

2.2 Literature search and search strings

Our systematic review was conducted using structured search strings (Table 1). Peer-reviewed studies were identified and collected from Web of Science Core Collection (WoS CC), a multidisciplinary database encompassing the Science Citation Index Expanded, Social Sciences Citation Index, and Emerging Sources Citation Index. Publications published between 2000 and 2023 in English were the targets of our search. This is to catch all studies related with ASS following the post-2000 China's institutional reforms in rural service systems. We restricted the search to the Agriculture and Business & Economics research categories, excluding Forestry and Fisheries to align with our focus on crop and livestock systems. Initial searches were executed on March 15, 2024, using data base-specific syntax (e.g., TS for topic searches, SU for subject areas) to optimize precision.

The search strategy employed six modular strings (see Table 1) that incorporated Boolean operators (AND, OR), truncation (*), and proximity operators (NEAR/2). The first-string was designed to defined core terminology related to ASS, such as "agriculture socialized service." Subsequent strings were developed to isolate specific service stages, namely pre-production, production, post-production, as well as to identify smallholder benefits and trends

specific to China. To mitigate the occurrence of false positives in the search results, we strategically linked service typologies (e.g., #2: Pre-Production Services) with benefit-related terms (e.g., #5: Smallholder Benefits) using the NEAR/2 operator. This approach ensured contextual relevance while avoiding excessive restrictions on the search parameters. For instance, the syntax #1 AND (#2 NEAR/2 #5) effectively captured studies that associated pre-production services with income or productivity gains. Iterative testing of proximity thresholds ranging from 1 to 3 words confirmed that NEAR/2 was optimal for balancing recall and precision in our research results. The finding consistent with previous reviews on rural service systems, which support the effectiveness of proximity searching in enhancing the relevance of retrieved literature (Zhang W. et al., 2021).

Temporal trends were analyzed across three policy-relevant periods: 2000–2007 (early ASS pilot programs), 2007–2016 (national scaling under the Rural Revitalization Strategy), and 2016–2024 (e-commerce integration and digital ASS platforms). This structured approach allows for a comprehensive understanding of how agricultural support services have evolved in response to changing policies and market dynamics. The selection of these specific periods is crucial, as each represents significant shifts in China's agrarian policy landscape, which directly influences the adoption and implementation of ASS. While the search encompassed all years, post-2000 publications dominated the corpus, reflecting China's accelerated ASS institutionalization. This periodization aligns with major agrarian policy shifts, enabling granular analysis of service adoption drivers and spatial diffusion patterns.

2.3 Eligibility criteria

The literature search generated an initial database of studies whose titles, abstracts, or keywords suggested relevance to ASS. Each study underwent manual screening against the following eligibility criteria, with full-text review conducted where metadata provided insufficient clarity. Studies were retained only if they satisfied all criteria:

- The study provided a quantitative, qualitative, or conceptual analysis of ASS typologies (pre-production, production, post-production) or their impacts. Eligible analyses included empirical case studies (e.g., adoption rates of machinery leasing), econometric evaluations of income effects, policy assessments of state-led service programs, or qualitative examinations of cooperative-led initiatives. Conceptual studies, such as frameworks for ASS institutional design or systematic reviews of service delivery models, were included if they explicitly theorized ASS mechanisms.

- ASS constituted a central focus of the study's analysis or argumentation. We excluded studies that referenced ASS only in peripheral manner, such as those that mentioned it as background context or in introductory remarks without

conducting a substantive investigation. For example, a study that stated "socialized services are critical for rural development" but focused only land tenure reforms was excluded from our analysis. In contrast, we retained studies that explicitly linked ASS to measurable outcomes, such as "mechanization services reduced smallholders' labor inputs by 30%") or critically evaluated service delivery systems related to ASS. This approach ensured that our analysis was grounded in research directly addressing the implications of ASS on agricultural productivity and rural development.

- Studies unrelated to ASS operationalization were excluded, even if terminology overlapped. For instance, investigations of "socialized healthcare" or "agricultural subsidies" (without service component analysis) were removed. Similarly, studies using terms like "cooperative networks" to describe marketing channels unrelated to ASS functions (e.g., storage, training) were excluded.

- The study focused on smallholder farmers (≤2 hectares operational land) within China or provided comparative insights relevant to the Chinese context. We excluded analyses exclusively targeting large-scale agribusinesses or non-agricultural sectors. Studies covering mixed farming systems were retained if ASS adoption by smallholders was evaluated. For multinational comparisons, studies were included only if China represented ≥30% of the analytical scope.

- The study prioritized practical ASS implementation over purely theoretical models. We excluded conceptual papers proposing abstract service frameworks without empirical validation (e.g., algorithmic models for ASS optimization untested in field settings). Studies combining theory with policy case studies or farmer surveys were retained.

2.4 Study classifications

Following eligibility screening, retained studies underwent systematic data extraction and classification to synthesize findings on ASS in smallholder farming systems. For each eligible study, key characteristics and findings were extracted, including (1) the specific typology of ASS investigated; (2) the reported impacts of the ASS in smallholders, and (3) relevant contextual information such as geographic location, study period, and research methodology. Data extraction involved reviewing titles, abstracts, keywords, and full texts as necessary to capture these details accurately.

Studies were then systematically categorized into three service stages: Pre-production; Production; and post-production. Additional classifications included smallholder benefit quantification (example, sustainability production and so on) and temporal trends. Studies addressing multiple stages or themes were assigned to all relevant categories.

Geographic scope was coded using China's National Bureau of Statistics administrative divisions (National Bureau of Statistics of China, 2023), distinguishing between regions. For comparative

studies spanning multiple countries, only those with ≥50% focus on China were retained. Theoretical frameworks, agent-based models without regional specificity, or studies with ambiguous geographic contexts were labeled Not Applicable (NA).

We use Mixed Methods Appraisal Tool (MMAT) to ensure this systematic review is rigorous, transparent, and trustworthy, making it indispensable for synthesizing diverse evidence effectively. Detailed frameworks are in Table 4A of the Appendix.

3 Results

Our systematic review identified 4,654 studies published between 2000 and 2023 that potentially examined ASS. The PRISMA flow diagram presented in Figure 2 illustrates the process used to identify relevant studies for this review. Following a through eligibility screening, 2,810 studies were excluded based on specific criteria; 2,717 were deemed relevant to China, 38 were in non-English language, 55 lacked peer-reviewed status, and 118 exhibited thematic mismatches with our research focus. From the remaining pool of 178 studies, we conducted a rigorous quality assessment, which resulted in the exclusion of 134 studies due to insufficient methodological rigor or relevance. This assessment yielded a final database of 44 studies that met all inclusion criteria and were deemed suitable for synthesis. See Table 2A in the Appendix section for details on the geographical distributions of articles.

Figure 3 shows the proportion of studies in the three types of ASS. A total of 29 studies (66%) focused exclusively on production-stage services, which include mechanized cultivation and pest management. These services are critical components of agricultural production, as they directly impact crop yields and quality. Pre-production services, which include activities such as soil preparation and seed selection, were examined in isolation by six studies (14%). Post-production services, which include activities such as storage and transportation, constituted 4% of the sample (2 studies). The remaining 16% (7 studies) analyzed combinations of ASS stages, with production and post-production services forming the most frequent pairing (4 studies; 9% of total). Notably, no study addressed all three service stages simultaneously. See Table 1A in the Appendix section for the proportion of all three ASS types by region and time period.

ASS research surged post-2014, aligning with China's Rural Revitalization Strategy. Figure 4 illustrates distinct temporal trends in research focus across pre-production, production, and post-production stages. An analysis of data from 2000 to 2007 reveals that studies predominantly emphasized production-stage ASS, accounting for 57% of the research efforts. In contrast, pre-production and post-production phases received considerably less attention, comprising only 27% and 16%, respectively. From 2007–2016, there was a notable increase in pre-production research, which rose to 35%. During this same period, production-stage studies declined to 43%, while post-production research saw a slight increase to 22%. This shift indicates a growing recognition of the importance of pre-production factors in agricultural
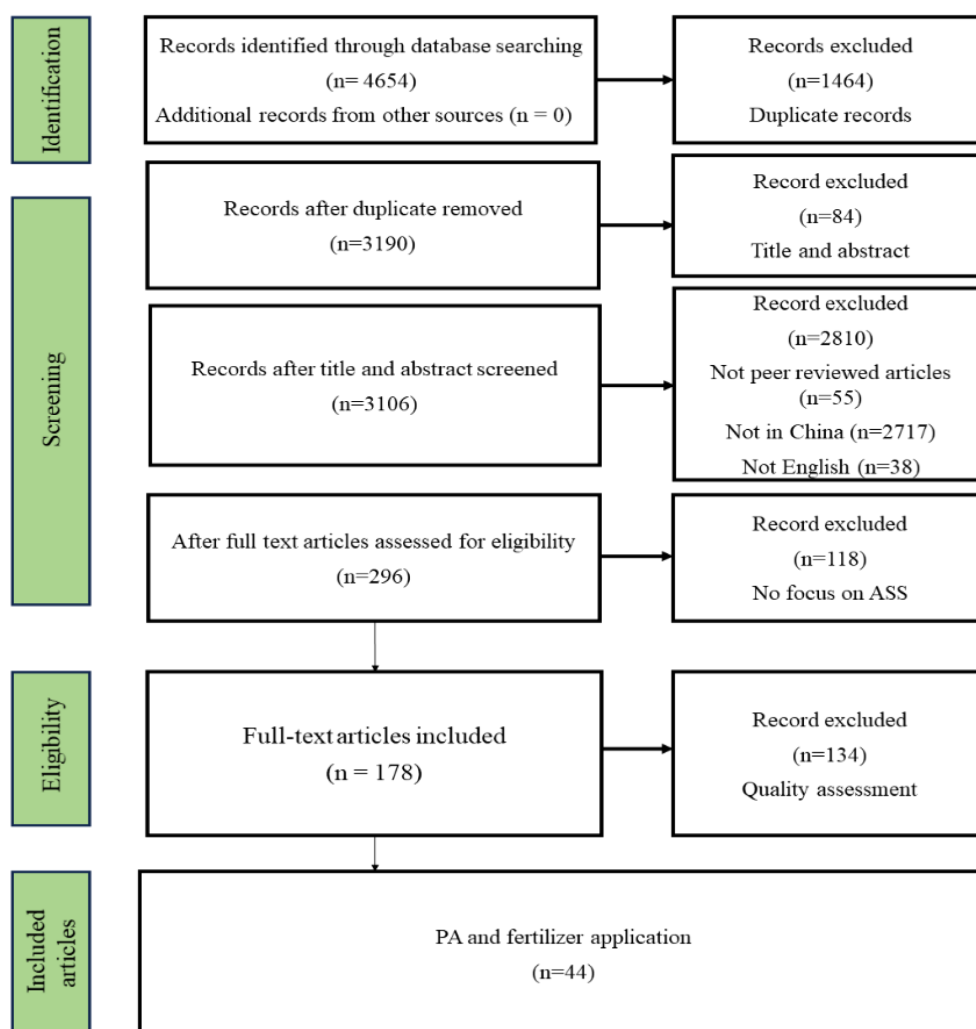
FIGURE 2
PRISMA flow diagram based on Moher et al., 2009 and Page et al., 2021.

sustainability. However, between 2016 and 2024, there was a marked resurgence in focus on production-stage ASS, which surged to 71%. Concurrently, attention to pre- and post-production stages diminished significantly, falling to just 15% and 14%, respectively. This pattern highlights a persistent dominant focus on production interventions, contrasting with fluctuating and comparatively low attention to pre- and post-production services, suggesting critical gaps in holistic value-chain research. Such gaps highlight the need for more balanced research efforts that encompass all stages of agricultural production to ensure holistic improvements in sustainability practices.

Figure 5 reveals the three key trends in ASS. First, pre-production ASS declined across all regions over time, likely due to standardized input access and mechanization becoming widely adopted. Second, production-stage ASS dominated in grain-focused regions like North and Northeast China, driven by national policies prioritizing staple crops (e.g., wheat, maize) for food security. Third,

post-production ASS (e.g., market links, e-commerce) grew fastest in East and South-Central China, supported by tech-driven platforms. Regional disparities persist: post-production growth lagged in mountainous Northwest/Southwest China due to logistical barriers, while North China maintained a strong production focus. These patterns highlight the interplay of geography, policy, and technology in shaping ASS adoption. However, empirical validation through regional agricultural surveys or policy reports is critical to confirm these trends.

Among studies examining multiple ASS stages, 93% employed quantitative studies paired with policy analysis, while 7% utilized qualitative studies (Table 4A). These works emphasized synergies between mechanization services and cooperative-led marketing, though none quantified cross-stage interdependencies. Questionnaire-based studies (82%) predominated, often measuring yield or income outcomes, whereas participatory approaches (18%) explored smallholder perceptions of service accessibility.
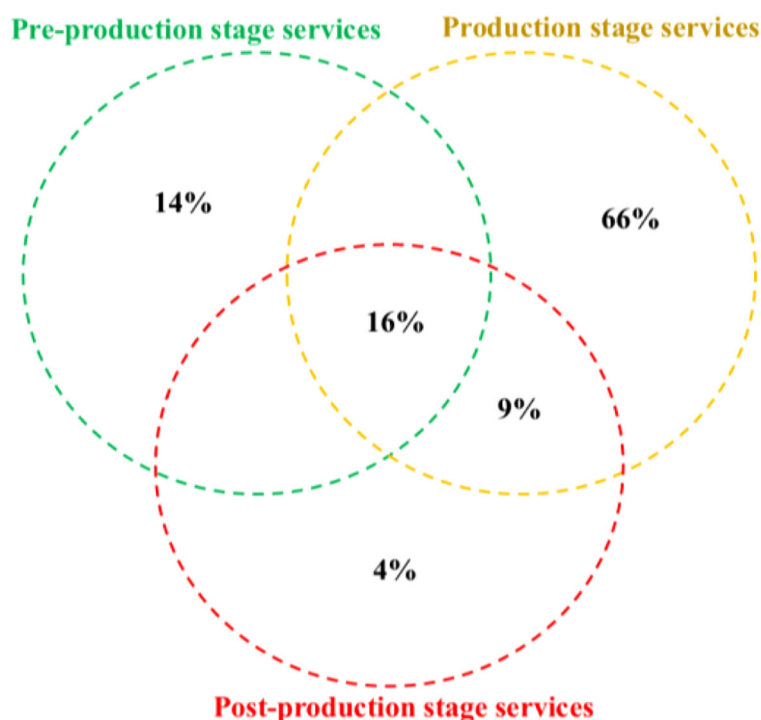
FIGURE 3
Venn diagram for distribution of the number of studies across three types of agricultural socialized services between 2000 and 2023. Data from authors' literature search.

4 Discussion

Our literature search, covering the period from 2000 to 2023 and based on well-defined databases and inclusion criteria, reveals significant patterns regarding the types of ASS studied, their impacts on smallholder farmers, and the challenges associated with measuring these systems. Previous reviews indicate a notable evolution in ASS research, with a marked increase in studies published from 2020 to 2023. This surge can be attributed to an expansion in service offerings and a diversification of service models and providers (Yang et al., 2022). Nevertheless, our analysis indicates that recent ASS research exhibits a disproportionate focus on production-stage mechanization, a trend likely influenced by China's 2018 Rural Revitalization Strategy, which emphasizes yield-enhancing technologies aimed at improving agricultural productivity. In contrast, this emphasis diverges from global ASS frameworks that advocate for integrated service provision encompassing entire cultivation cycles (Zhang et al., 2021). This discrepancy highlights the need for a more holistic approach in the study and implementation of ASS, which could enhance the sustainability and resilience of smallholder farming systems.

4.1 Types of agricultural socialized services studied

The reviewed studies demonstrate a pronounced focus on production-enhancing ASS, particularly mechanization services including machinery leasing, pest control and technical training. These services collectively constituted 66% of the analyzed interventions (Figure 3). This emphasis aligns with China's policy prioritization of yield optimization and labor substitution, as mechanized cultivation directly addresses labor shortages in aging rural populations (Wang and Huang, 2022; Yang and Li, 2022). Studies widely use quantitative metrics like yield gains and cost reductions to strengthen the focus on these services. These metrics support controlled field experiments and econometric modeling (Peng et al., 2022; Chen T. et al., 2022).

However, this focus risks overshadowing critical pre- and post-production services, such as input access and cooperative-led marketing, which represented only 14% and 4% of studies, respectively. While the tangible impacts of mechanization are easily quantifiable, systemic barriers to input affordability, such as fragmented land tenure (Zang et al., 2022) and credit constraints (Ye et al., 2013), remain understudied despite their foundational role in smallholder decision-making. For instance, Qu et al. (2022) identified a significant divergence between farmers' willingness to adopt green technologies and their actual behavior, largely attributed to unaddressed pre-production bottlenecks like upfront financing. Similarly, post-production services, including e-commerce platforms, storage infrastructure, were examined in fewer than 5% of studies, despite their proven role in mitigating post-harvest losses (Zhou et al., 2023).

The academic literature exhibits a notable limitation in the comprehensive analysis of multi-type ASS frameworks. This is evidenced by a prevalence of studies that focus narrowly on
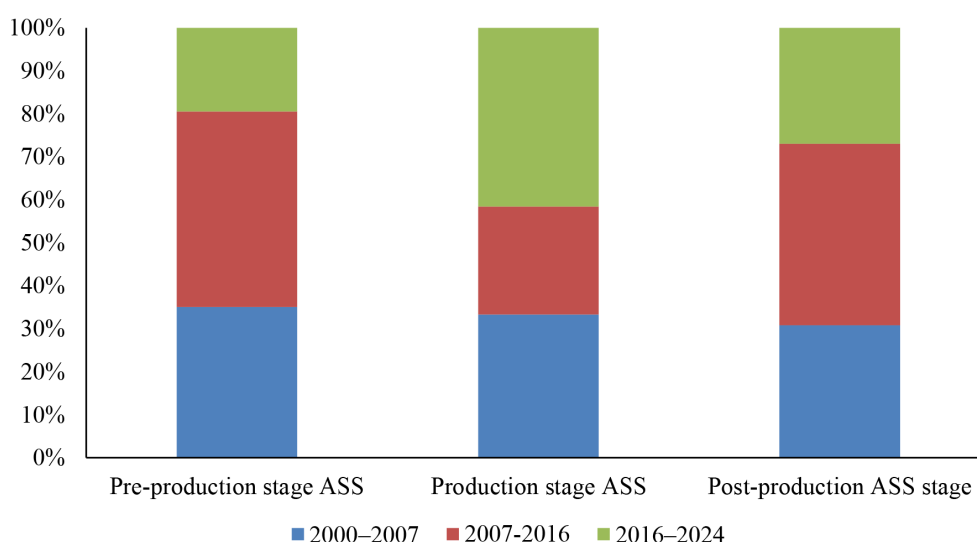
FIGURE 4
The temporal distribution of studies in each category of ASS.

specific components or stages of the agricultural value chain, often reflecting a disciplinary siloing among agronomic, economic, and institutional research perspectives rather than integrating them. For example, a study by Li et al. (2023) effectively demonstrated the positive impact of specialized labor division on production efficiency within a specific context. However, their analysis, while valuable, did not extend to critical upstream factors such as credit access or downstream elements like market linkages, both of which are fundamental determinants of long-term sustainability and farmer viability. This narrow focus mirrors global trends where mechanization dominates policy agendas, yet contrasts with evidence from India's integrated ASS models, where bundled services (e.g., input provision + mechanization + branding support) raised smallholder incomes by 40%.

4.2 The role of ASS in advancing environmental sustainability

The synthesis of evidence underscores ASS as pivotal enablers of environmental sustainability within smallholder systems, operating through mechanization-driven input optimization, circular resource management, and institutional mediation of agroecological transitions. A dominant theme across studies is ASS's capacity to decouple productivity gains from chemical intensification (Yuan et al., 2022; Yang et al., 2022). By facilitating precision input application including, fertigation and integrated pest management, ASS reduces nitrogen surplus and pesticide use in rice-wheat systems (Li and Zhu, 2023; Sun et al., 2023), aligning with the Agriculture Green Development (AGD) framework's emphasis on input substitution (Chen J et al., 2022). These outcomes are mechanistically linked to ASS's role in bridging knowledge asymmetries: technical extension services lower

adoption thresholds for soil testing (Cheng C. et al., 2022) and straw-returning practices (Lu et al., 2022), which enhance soil organic carbon (SOC) annually in intensively cultivated regions.

Notably, ASS mediates socio-metabolic transitions by reconfiguring smallholders' resource loops. Cooperative-led machinery pooling, for instance, diminishes diesel consumption per hectare through optimized equipment utilization (Peng et al., 2022), while centralized pest monitoring cuts redundant spraying cycles (Zhou et al., 2023). Such efficiencies yield a reduction in greenhouse gas (GHG) intensity across staple crops (Chen T. et al., 2022), though spatial heterogeneities persist. In water-scarce regions (e.g., North China Plain), ASS-driven drip irrigation adoption lowers blue water footprints, yet paradoxically increases energy-linked, a trade-off underscoring the need for spatially adaptive service models (Guo et al., 2022).

The literature identifies ASS as a pivotal leverage point for advancing circular agriculture. By consolidating fragmented smallholdings, ASS facilitates economies of scale in the application of organic fertilizers (Ren, 2023) and promotes the recycling of crop residues (Lu et al., 2022). This approach effectively redirects straw biomass from open burning to beneficial soil amendment pathways, thereby significantly reducing particulate matter emissions (PM2.5) in peri-urban areas and enhancing nutrient cycling efficiencies (Huan et al., 2022). Nonetheless, the effectiveness of these interventions is highly dependent on institutional complementarities. For instance, subsidies for conservation tillage demonstrate diminishing returns when they are not linked to secure land tenure (Cheng C. et al., 2022). Additionally, existing gender disparities in access to agricultural services restrict the diffusion of innovative technologies, particularly among female-headed households (Guo et al., 2022). Addressing these institutional and gender-related barriers is crucial for maximizing the potential benefits of ASS in fostering sustainable agricultural practices.
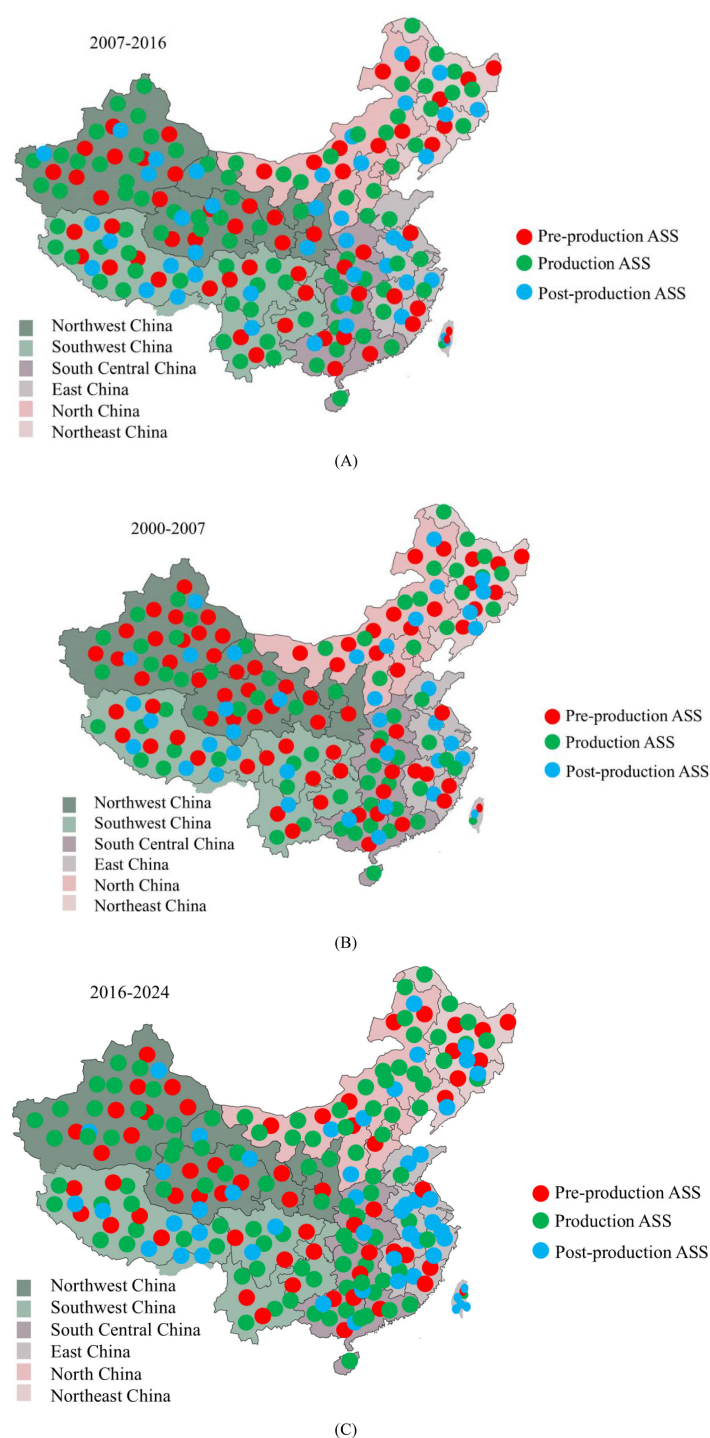
FIGURE 5
(A–C). Temporal and spatial distribution of type of ASS in China.

4.3 Agricultural mechanization services for agrarian transformation

This review identifies agricultural mechanization services (AMS) as the predominant modality of ASS, serving a dual role as both a technical and institutional intermediary within smallholder farming systems. Empirical studies included in this review confirms that the adoption of AMS significantly elevates land productivity in wheat-dominated systems through precision seeding and harvest timing optimization (Yang and Li, 2022), though agro-ecological determinants, notably topography and soil fragmentation, modulate efficacy, yielding higher variability in yield gains across loess plateau versus deltaic regions (Peng et al., 2022). This productivity enhancement is mechanistically tied to AMS's

capacity to resolve socio-metabolic rifts inherent in smallholder production. Machinery pooling reduces diesel consumption per hectare through load-optimized routing (Chen et al., 2023), while AI-driven fault diagnostics lower downtime, enhancing operational reliability (Sun et al., 2023).

The adoption of AMS does not increase steadily but instead follows a rise-and-fall pattern, peaking on moderate-sized farms (Qiu and Luo, 2021). Marginal farms (<2 ha) face prohibitive transaction costs in service contracting, while large-scale entities internalize mechanization via capital investments, mirroring Williamson (2010) transaction cost economics. This bifurcation underscores a systemic paradox. AMS, while lauded for democratizing access to scale economies, inadvertently entrenches dualistic agrarian structures, thereby privileging mid-sized holdings. Labor reallocation dynamics further reflect this tension, with AMS displacing a large proportion of on-farm labor in maize systems (Yang and Li, 2023). This accelerates rural-urban migration but exacerbates geriatric labor dependencies in left-behind households.

This review found spatial heterogeneities in AMS uptake, are compounded by both environmental factors and institutional frameworks. In some regions, state-subsidized cooperatives leverage vertically integrated supply chains to enhance service coverage, thereby achieving greater efficiency in resource allocation and distribution (Cheng L. et al., 2022). The environmental externalities associated with AMS practices remain a subject of debate within the scientific community. For instance, while precision pesticide application has been shown to reduce agrochemical inputs significantly in rice production systems (Sun et al., 2023), the reliance on diesel-powered machinery can negate these benefits by contributing substantially to greenhouse gas emissions. Studies indicate that the carbon footprint associated with such machinery often offsets the gains achieved through reduced chemical usage (Chen Z. et al., 2022).

4.4 Multidimensional roles of ASS in rural restructuring

This review found ASS function as a multifaceted institutional innovation, transcending their foundational role in mechanization and ecological modernization to mediate complex socio-economic transitions within China's smallholder systems. At the microeconomic level, ASS reconfigure production cost structures by rationalizing input allocation and operational workflows, thereby attenuating the financial burdens of fragmented landholdings (Wang and Huang, 2022). This cost rationalization is contingent upon integrated decision-making frameworks that offset marginal increases in logistical expenditures, such as service access travel, through systemic reductions in labor and input redundancies. Concurrently, ASS catalysis collective action in communal resource governance, exemplified by enhanced irrigation coordination and attenuated rural-urban labor migration, which collectively stabilize agrarian livelihoods (Wang and Huan, 2023). These outcomes are institutionally mediated by village-level leadership efficacy, agrarian resource dependencies, and intra-

community equity dynamics, though divergent behavioral norms between ASS providers and beneficiaries, marked by asymmetrical commitment to service quality, introduce friction in trust-based engagements (Qu et al., 2022).

The interplay between ASS and land tenure restructuring emerges as a critical lever in rural labor reallocation, facilitating non-farm employment and entrepreneurial diversification while mitigating underemployment in peri-urban zones (Cheng L. et al., 2022). However, the atomized adoption of ASS across discrete production stages engenders systemic inefficiencies, underscoring the necessity for vertically integrated service platforms that synchronize pre-production, cultivation, and post-harvest interventions (Xu and Yao, 2022). Digitalization further amplifies ASS efficacy, as ICT-driven service portals enhance adoption rates through real-time decision-support systems and demand-responsive resource matching (Yang et al., 2023). Such platforms concurrently empower agrarian entrepreneurship by bridging professional farmers with scalable agricultural projects, thereby fostering innovation in value chain integration (Zhang et al., 2023).

Macroscopically, ASS operates as a linchpin in China's urban-rural integration agenda, reconciling infrastructural disparities and embedding smallholders within globalized agro-food networks. This integration is predicated on ASS's dual role in cost containment, counteracting labor and input inflation, and human capital augmentation, particularly through skill-transfer mechanisms that countervail demographic aging (Zhu et al., 2022; Du et al., 2023). Yet, the institutional architecture underpinning ASS remains fraught with structural incongruities. Cooperative models, while instrumental in aggregating marginal producers, exhibit pronounced supply-demand mismatches and elite capture tendencies, privileging specific demographic cohorts (Wu and Ding, 2018). These disparities are compounded by suboptimal public investment in rural welfare infrastructure, which stifles equitable service access in economically disadvantaged localities (Dong, 2000; Xia et al., 2017).

4.5 Systemic barriers to equitable ASS access

Figure 6 illustrates the barriers and solution for accessing ASS by smallholder farmers. Accessibility of ASS is influenced by a matrix of structural, socio-economic, and institutional factors. Financial constraints are a significant barrio; prohibitive service fees, stringent collateral requirements, and liquidity shortages disproportionately affect marginalized groups, particularly micro-landholding households (Wang and Huan, 2023). Spatial disparities in service infrastructure further exacerbate exclusion, with remote agro-ecological zones facing chronic undersupply of mechanized and advisory services (Guo et al., 2022). Institutional architectures, including top-down subsidy regimes and rigid cooperative membership criteria, often prioritize medium-scale producers over subsistence-oriented smallholders (Zhang et al., 2023). Concurrently, socio-cultural barriers, such as distrust in external service providers or gendered norms restricting women's decision-
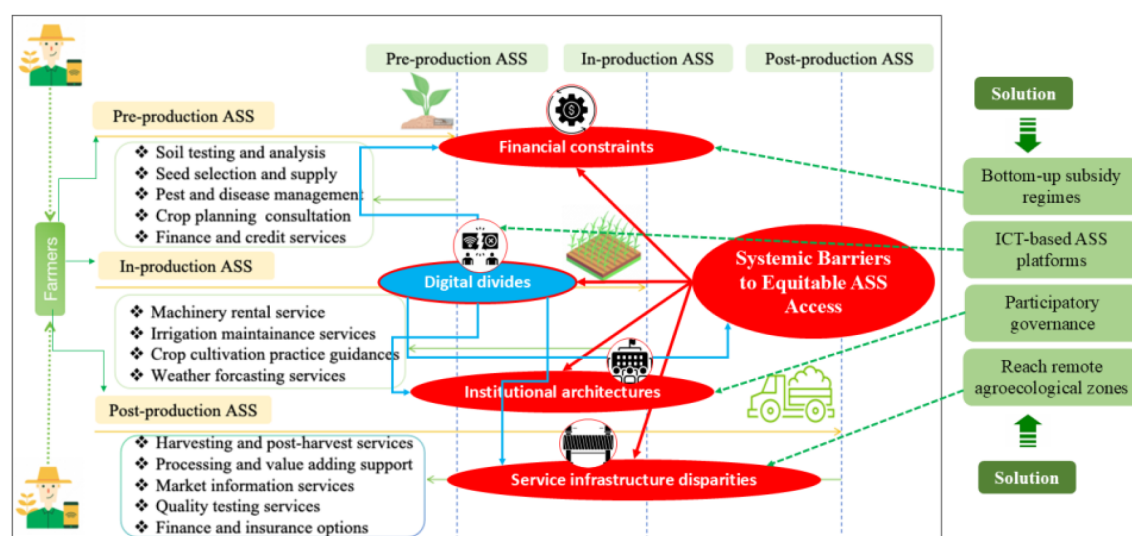
FIGURE 6
Systemic barriers and enablers shaping smallholder farmers' access to ASS.

making autonomy, undermine utilization rates. Digital divides compound these challenges, as ICT-based ASS platforms frequently assume literacy and connectivity thresholds unmet in resource-constrained settings (Zhou et al., 2023). To democratize access, ASS frameworks must adopt adaptive targeting mechanisms that recognize heterogeneous smallholder typologies, from semi-subsistence farmers to market-oriented producers, while embedding participatory governance to align service design with localized needs and capacities.

The diagram illustrates interlinked structural, socio-economic, and institutional barriers including financial exclusion, spatial disparities, rigid institutional architectures, socio-cultural norms, and compounding digital divides, that restrict equitable ASS utilization. Proposed solutions emphasize adaptive targeting mechanisms, participatory governance frameworks, and context-sensitive service bundling to bridge access gaps. The digital divide emerges as a cross-cutting challenge, exacerbating existing inequities in remote and resource-constrained settings. Arrows denote pathways for policy and institutional reforms to align ASS delivery with heterogeneous smallholder needs. Information extracted from authors' literature analysis.

4.6 Challenges in quantifying and measuring ASS

We advocate for increased research focus on studying ASS types, benefits for smallholder farmers, and barriers to accessing these services. However, challenges in measuring and quantifying ASS have emerged as one of the most significant obstacles (see Table 3A in the Appendix). Here we offer our thoughts on the origin of some of these important challenges, mainly regarding with methodological and conceptual complexities.

- Subjectivity in impact assessment: A key challenge in evaluating ASS lies in the subjectivity of impact assessments. This arises because many studies rely on self-reported data, such as farmers' recall of yield improvements or perceived satisfaction (Qu et al., 2022). Personal biases, for example, a farmer's optimism about a new service or differing interpretations of survey questions (e.g., what constitutes improved decision-making) can skew results, making them inconsistent or overly optimistic. Additionally, social outcomes like trust in cooperatives or empowerment are inherently qualitative and lack standardized measurement tools, unlike objective metrics such as crop yields or soil pH levels. This subjectivity creates mixed evidence, where personal opinions dilute factual trends, complicating comparisons across studies.

- Complexity of impacts: ASS effects are non-linear and contingent on synergistic interactions between service stages (e.g., input access × mechanization × market linkages). Current methodologies, however, atomize these interdependencies, employing reductionist models that isolate variables (Xu and Yao, 2022). For instance, econometric analyses of mechanization services often disregard feedback loops between labor displacement and post-harvest cooperative engagement. Integrated assessment models, adapted from climate resilience studies, could better capture cascading effects across ASS value chains.

- Data constraints and validation: The absence of harmonized ASS metrics, such as service coverage ratios or smallholder retention rates, significantly hinders the ability to conduct meaningful cross-regional comparisons. While digital platforms generate real-time usage data (Yang et al., 2023), validation remains problematic due to infrastructural asymmetries: remote mountainous regions often suffer from

inadequate digital connectivity, skewing datasets toward tech-accessible zones. Furthermore, ASS providers often conflate "service delivery" (e.g., machinery leasing contracts) with "service utilization," obscuring adoption-efficacy distinctions. Triangulating administrative records with ethnographic fieldwork could mitigate these gaps.

- Intangible and latent benefits: ASS generates diffuse socio-institutional externalities, such as strengthened communal trust or gendered empowerment that evade conventional cost-benefit analyses. For example, cooperative membership may enhance collective bargaining power without immediate yield gains, a benefit marginalized in productivity-centric evaluations (Wu and Ding, 2018). Composite indices, akin to the Multidimensional Poverty Index, could aggregate these intangibles by weighting social capital metrics alongside agronomic indicators.

- Temporal dynamics: ASS outcomes often take years to materialize, especially for slow-acting interventions like improving soil health (e.g., conservation tillage) or building farmer skills through training programs (Du et al., 2023). Most studies use short-term snapshot methods that miss long-term effects, such as gradual soil improvements or knowledge passed between generations. Long-term tracking is rare due to inconsistent policies and funding. New tools like remote sensors (to monitor soil quality) and blockchain (to track service use over time) could help measure impacts continuously, even across decades.

- Contextual variation: ASS effectiveness depends heavily on local conditions like climate, soil type, economic status, and government policies. This means there's no "one-size-fits-all" measure for success. For example, tractor rental programs that work well in flat farming regions often fail in mountainous areas, where steep terraces make machinery use impractical (Peng et al., 2022). To avoid oversimplification, measurement tools must account for these differences. Solutions include using satellite data to group similar regions and involving local farmers and officials in setting realistic, place-specific goals.

- Interdisciplinary nature of ASS: ASS research spans fields such as agricultural science, economics, and social studies, but researchers often work in isolation. Most studies focus on economic data (e.g., costs and yields), neglecting social factors like older farmers hesitating to use machinery (Yang et al., 2022; Guo et al., 2022; Li and Zhu, 2023). To fully understand ASS impacts, methods should combine surveys, computer models, and on-the-ground observations with farmers. This mix helps capture both numerical data and human behaviors shaping ASS success.

Methodological constraints further distort the evidence base surrounding ASS. A significant number of studies have relied primarily on quantitative surveys or experimental trials, which prioritize measurable outcomes at the expense of exploring qualitative insights into underlying institutional barriers. Notable exceptions, such as the work by Shi et al. (2023), employed mixed-methods approaches by integrating yield metrics with participatory assessments. This combination revealed a substantial proportion of farmers' distrust in outsourced pest management services, stemming from previous contractual violations. Despite these valuable contributions, mixed-methods studies remain relatively scarce in the literature. This gap restricts policymakers' capacity to design interventions that are culturally relevant and responsive to the needs of diverse agricultural communities. Enhancing the methodological diversity of ASS research is essential for generating a more comprehensive understanding of the systemic challenges and opportunities faced by smallholder farmers.

5 Conclusion

Our review examines the trajectory of studies on the type of ASS in China's smallholder agricultural system between 2000 and 2023. We conducted a structured search of the Web of Science and Scopus databases, identifying a total of 4,654 peer-reviewed articles. Out of these, 44 articles met our eligibility criteria for synthesis. The challenges associated with smallholder farmers always remain uncertain and they need support to overcome these challenges in each agricultural production chain. Thus, this review focuses on the distribution of studies by the type of ASS (pre-production, production, and post-production) and the benefit and measurement challenges of these ASS. We found that previous studies focused on the ASS production type due to the government's emphasis on yield optimization and labor substitution. While the reviewed literature reflects scholarly priorities regarding ASS typology, benefit quantification, and developmental trends, it often fails to align with the lived realities and perceived needs of smallholders themselves. This disconnect suggests a need for more participatory research approaches that incorporate the voices and insights of smallholder farmers to ensure that ASS initiatives are effectively tailored to their nuances and realities.

A substantial body of research underscores the critical role of ASS in mitigating environmental externalities, particularly through mechanized services such as machinery rentals and precision agrochemical application. These services are especially relevant in addressing labor shortages exacerbated by rural youth outmigration. However, the prevailing focus on productivity-centric metrics often overshadows systemic inequities, including barriers to access and the exclusion of marginalized farms from service markets. Furthermore, methodological constraints further pose significant challenges to assessing the impact of ASS. Issues such as subjective interpretations of outcome, gaps in data validation, and the difficulty in quantifying intangible socio-institutional benefits, such as strengthened communal trust and enhanced bargaining power, contribute to an incomplete understanding of ASS effectiveness. Additionally, the studies reviewed highlight significant regional disparities in the distribution and development level of ASS, which can be largely attributed to various barriers, including financial constraints, digital divides, institutional drawbacks, and infrastructural disparities.

The interdisciplinary nature of ASS, which integrates aspects of agronomy, economics, and digital innovation, necessitates sophisticated methodologies to effectively analyze its complex socio-technical dynamics. Future research should prioritize mixed-methods frameworks that integrate sensor-based yield data with participatory assessments, as this will facilitate a comprehensive understanding of both biophysical and behavioral outcomes. Additionally, longitudinal studies, leveraging digital twins and blockchain-enabled service registries could elucidate deeper insights into the long-term impacts of ASS adoption, including effects on soil health regeneration and intergenerational knowledge transfer. Furthermore, contextually adaptive models co-designed with smallholders farms are critical for addressing geographic disparities and ensuring that interventions are tailored to local conditions and needs.

Policy initiatives must address the existing disconnect between research on ASS and their practical implementation in the field. Integrating ASS into China's Rural Revitalization Strategy requires the establishment of participatory governance mechanisms that align service provisioning with the needs and priorities of smallholder farmers, rather than relying solely on top-down technological innovations. By involving smallholders as co-designers of ASS ecosystems, stakeholders can transform these services from mere productivity-enhancing tools to foundational elements of inclusive and climate-resilient agricultural transformations. This paradigm shift, from fragmented impact assessments to a comprehensive framework of systemic innovation, offers a viable pathway for reconciling agricultural modernization with the socio-ecological realities faced by smallholder communities in China's rural heartlands.

While our systematic review has made significant contributions to the field, it is essential to acknowledge and address its limitations to enhance the robustness and comprehensiveness of the analysis. First, this systematic review is limited to articles sourced from Scopus and Web of Science (WOS), which restricts the inclusion of grey literature, such as conference proceedings and reports. This choice emphasizes peer-reviewed, indexed journal articles that are recognized for their scientific rigor. However, it may inadvertently neglect valuable insights available in non-indexed sources. Second, the focus on English-language articles introduces a potential bias by excluding valuable evidence published in other languages, such as Chinese. This exclusion may result in an incomplete understanding of the global research landscape. Finally, our review does not include a critical assessment of the methodologies employed in the studies examined. This represents a notable limitation, as evaluating the strengths and weaknesses of these methodologies is essential for accurately assessing the reliability and validity of the conclusions drawn in each study. It is important to acknowledge that review does not conduct an in-depth analysis of the theoretical or methodological approaches utilized in individual articles, which constraints our overall findings. Overcoming these limitations in future research can propel a more comprehensive understanding of ASS and support sustainable agricultural development in China.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

RZ: Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft. MA: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. CB: Data curation, Formal analysis, Investigation, Project administration, Supervision, Visualization, Writing – original draft. AKA: Formal analysis, Investigation, Supervision, Validation, Visualization, Writing – review & editing. XYY: Formal analysis, Validation, Visualization, Writing – review & editing. SJ: Formal analysis, Validation, Visualization, Writing – review & editing. XY: Formal analysis, Validation, Visualization, Writing – review & editing. BG: Formal analysis, Validation, Visualization, Writing – review & editing. ANA: Formal analysis, Validation, Visualization, Writing – review & editing.

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The author(s) declare that no Generative AI was used in the creation of this manuscript.

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Supplementary material

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