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Strengthening cover crop seed value chains to scale agroecology in Cambodia: a Battambang case study

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Introduction: In Cambodia, cover crops (CC) are being explored as an agroecological practice to improve soil health, sustain crop productivity, and enhance land profitability over time. Since 2004, initiatives have introduced CC into rubber production systems during the immature period, later extending their use to annual rainfed crops and rice-based systems. In recent years, private companies, cooperatives, and non-profit organizations have become increasingly involved in developing the CC sector.

Method: This shift toward commercial operations prompted us to investigate the CC seed value chain and analyse the stakeholder network, aiming to identify key challenges, opportunities, and address the research gap. This case study in Battambang Province used a mixed-methods approach. Data collection included: (i) an agroeconomic assessment (2023–2024); (ii) a qualitative survey of 23 seed producers; (iii) four focus group discussions with rice farmers using CC; (iv) 26 key informant interviews; and (v) value chain analysis, including participatory elements such as a multi-stakeholder workshop.

Results: Findings indicate rapid expansion in CC seed production, from 2 ha in 2017 to 177 ha in 2023, mainly involving *Crotalaria ochroleuca* and *Crotalaria juncea*. Seed producers reported an additional mean net profit of $314.6/ha/year from CC seeds, compared to $438.5/ha/year from a single Maize production system. Fifty percent of seed producers cited soil fertility improvement and profitability as main incentives. In 2023, seed production was expected to reach 288.5 ha, but this target was not met due to lack of equipment and unfavourable climate. While 90% of rice farmers observed notable improvements in soil fertility, the same proportion identified economic and climatic constraints as barriers to scaling-up the use of cover crops.

Discussion: Stakeholder mapping revealed a diverse landscape with varying influence and interest. The study examines how stakeholder recommendations could support the scaling of CC, highlighting short-term economic incentives but also practice and results-based reward mechanisms as promising strategies.

KEYWORDS

conservation agriculture, farmers' perception, participatory process, regenerative agriculture, rice farming, stakeholder mapping

1 Introduction

The expansion of global food systems to meet increasing demand has resulted in significant environmental degradation, including an increase in greenhouse gas emissions, biodiversity loss, and disruptions to nutrient cycles (Jwaideh and Dalin, 2025). Ingalls et al. (2018) also highlight the environmental impact of agricultural development in Cambodia, particularly its contribution to land degradation and natural capital loss. Land degradation, defined as a long-term decline in ecosystem function and productivity, affects up to 44% of Cambodia's territory (Bai et al., 2008), primarily driven by agricultural expansion and forest cover decline (Sourn et al., 2023). Acknowledging the country's vulnerability, the Royal Government of Cambodia has adopted the "National Agricultural Development Policy 2022–2030", which promotes sustainable land, forest, and fishery resource management (Royal Government of Cambodia, 2022). Similarly, the Ministry of Agriculture, Forestry and Fisheries has set clear targets to combat land degradation (Vang, 2018). One such goal is to increase the soil organic carbon (SOC) stock in cropland by 1.2% per year by 2030, compared to 2015 levels. This initiative emphasizes sustainable agricultural practices and the development of policies such as payment for ecosystem services (PES) to incentivize biodiversity conservation and sustainable resource use (Dei Meas, 2025).

Among sustainable agriculture approaches, agroecology is widely recognized as a promising pathway (FAO, 2025). As a scientific discipline, a set of practices, and a social movement (Wezel et al., 2009), agroecology promotes diverse interventions. Wezel et al. (2014) identified 15 categories of agroecological practices, including the use of cover crops (CC) to enhance soil fertility and crop diversity while reducing fertilizer inputs. Quintarelli et al. (2022) define CC as "close-growing crops that provide soil protection, seedling protection, and soil improvement between periods of normal crop production". These crops are also effective climate adaptation and mitigation tools (San-Juan-Heras et al., 2024). When combined with no-till practices, CC have demonstrated considerable potential to improve soil fertility across various cropping systems and timeframes compared to conventional tillage systems (Séguy et al., 2006).

In Cambodia, measurable improvements have been observed due to these practices: increased labile carbon in topsoil after a cropping season (Koun et al., 2024), enhanced SOC and total nitrogen over extended periods (Hok et al., 2015, Hok et al., 2018, Hok et al., 2021), and improved soil profiles at deeper layers on the long term (Leng et al., 2024). Moreover, these techniques contribute to overall soil health (Pheap et al., 2019, Pheap et al., 2025), promoting self-regulatory pest control systems (Masson et al., 2022). Despite these benefits, adoption among farmers remains challenging (Men et al., 2025). In upland perennial systems, Marcon et al. (2024) note that pest management on CC is problematic, while Nickens et al. (2023) cite water scarcity as a critical constraint for both upland and lowland systems. In Southeast Asia, a recurring barrier is the necessity for short-term economic returns (Lienhard et al., 2014; Tuan et al., 2014). In addition, Atakoun et al. (2023) emphasize the importance of selecting species compatible with existing cropping systems and non-competitive for resources.

The development of cover crop systems in Cambodia has evolved steadily over the past two decades, beginning with public-sector initiatives and later expanding through private and cooperative engagement. In 2004, the General Directorate of Rubber (GDR) and the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) initiated a genetic bank for CC (Marquié and Reynaud, 2019). The focus at that time was primarily on integrating CC into the inter-rows of immature rubber plantations. Over subsequent years, both single and multi-species CC were tested across different agroecosystems, including annual and perennial cropping systems (Kong et al., 2016). Initially, cover crop seeds were imported; however, efforts gradually shifted toward domestic seed production. This transition was supported by the Department of Agricultural Land Resources Management (DALRM) and its specialized unit, the Cambodia Conservation Agriculture Research for Development Center (CARDEC), which facilitated seed production in provinces such as Kampong Cham, Kampong Thom, Preah Vihear, and Battambang. For several years, this production was mainly limited to research-for-development activities. In 2012, the first commercial-scale cover crop seed production began, focusing on *Stylosanthes guianensis* grown in the inter-rows of rubber plantations. For other species like *Crotalaria juncea* and *Crotalaria ochroleuca*, seed production remained marginal. A turning point came in 2017, when four producers in Rattanak Mondoul district (Battambang province) began cultivating five hectares for seed production. By 2021, this area expanded to 26 hectares and then grew rapidly to 110 hectares in 2022 and 177 hectares in 2023, primarily due to the involvement of the private company SmartAgro. The company began contracting local farmers to produce seeds and assumed responsibility for logistics, including transport, cleaning, processing, storage, and delivery to retailers and large-scale farmers.

In 2023, the Battambang Union of Agricultural Cooperatives (BUAC) also entered the sector. Their focus was on serving rice farmers in the Kanghot irrigation scheme in Sangkae District. BUAC worked closely with its cooperative members, such as the Agriculture Cooperative Kampong Prieng (ACKP), to expand production and supply not only within the district but also to private companies and farmers in Provinces across Cambodia. Other agricultural cooperatives and seed producer groups are today active in Cambodia across few provinces including Siem Reap, Kampong Thom and Preah Vihear.

Parallel to these developments, farmer-led experimentation played a key role in early adoption. In Battambang, efforts to introduce CC at the farm level began through on-farm experimentation led by the Department of Agricultural Land and Resource Management (DALRM) and CARDEC. These experiments initially took place in Rattanak Mondoul and Banan Districts, Battambang Province. Farmers were first introduced to CC by planting them before or after their main crop cycles (e.g., maize, rice), and to a lesser extent, in the inter-rows of perennial plantations such as mango and longan.

In 2011, CARDEC, in collaboration with a farmer from Sangha Village, initiated the first local production of *Crotalaria juncea* seeds for experimental use. This marked a significant step, as it enabled CARDEC to begin self-supplying seeds for research and demonstration activities in different villages, communes and districts of Battambang province. The introduction of CC into rice systems in the Kanghot irrigation scheme (Sangkae District) started later in 2020, under the AFD- and EU-funded program Water Resources Management and Agroecological Transition for Cambodia (WAT4CAM). Through its fourth component, focused on promoting innovative farming practices and supporting the rice value chain, WAT4CAM facilitated on-farm trials, provided technical assistance, and explored financial mechanisms to improve farmer access to affordable cover crop seeds. At the same period, Swisscontact, an independent foundation for international development cooperation, launched the METKASEKOR extension model: meaning "Farmer's Friend" (Swisscontact, 2026), which is embedded within the Provincial Department of Agriculture, Forestry and Fisheries (PDAFF). This initiative aimed to open the market to private sector investment in conservation agriculture and agroecology by supporting the delivery of knowledge and services to farmers. Further institutional reinforcement came with the establishment of the Dei Meas initiative (meaning "Golden Soil"), initially launched under the Agroecology and Safe Food System Transitions in Southeast Asia (ASSET) project. Dei Meas was led by DALRM and implemented in collaboration with SmartAgro, CIRAD, and Swisscontact. The initiative introduced a practice-based reward system to incentivize farmers who adopt specific agroecological practices, cover cropping is part of them. It supported farmers through access to seeds, technical training, and continuous follow-up. In parallel, several non-governmental organizations (NGOs) played a key role in promoting cover crop adoption by offering farmer training, financial support, and facilitating access to equipment and quality seeds.

Access to high-quality seeds is critical for the adoption of cover cropping practices (Rolston, 2015). While the United States leads in research about CC and their commercialization (Martins et al., 2021; Tyndall et al., 2021; San-Juan-Heras et al., 2024), other tropical countries have also studied seed markets. In India, *Medicago sativa* seed markets serve both domestic and international markets, especially Pakistan and Saudi Arabia (Biradar and Nagar, 2018), and production of *Stylosanthes hamata* seeds is reportedly in decline (Biradar et al., 2013). In Thailand and Laos, Ubon Forage Seeds has collaborated with over 1,000 smallholders for more than a decade to cultivate primarily fodder species such as hybrid of *Bracharia* (Mulato II, Cayman), *Panicum maximum* (Mombasa guinea, Tanzania guinea) and *Stylosanthes* (Ubon stylo, and Ubon paspalum). Their export-based model was more profitable than traditional cash crops for farmers (Hare, 2013, Hare, 2014). Rolston (2015) further highlighted the importance of quality and specificity in seed markets across Nepal, Thailand, New Zealand, and the US, arguing that market development should be based on these attributes rather than low prices.

In order to study commercial systems, Value chain analysis (VCA) is a recognized approach for understanding commercial systems. Introduced by Porter (1985), it initially evaluates the full range of firm-level activities that deliver a product or service. The concept has evolved into the global value chain (GVC) framework, encompassing both direct and indirect actors across all stages of production and distribution (Frederick, 2014). In tropical countries, VCAs of tomato (Tusiime et al., 2020), maize (Hoogendoorn et al., 2018), and forage seeds (Chakoma et al., 2016; Chakoma and Chummun, 2019) illustrate how such analyses can offer holistic insights. Llorente et al. (2022) proposed a six-block approach to VCA that includes: (i) input-output structure, (ii) geographic scope, (iii) governance, (iv) institutional context, (v) upgrading, and (vi) stakeholder analysis.

Despite strong evidence demonstrating the benefits of CC, and well-documented challenges and initiatives supporting their use, the dynamics of seed production, commercialization, application, and the roles of involved actors remain insufficiently understood. This study seeks to address this gap. Focusing on a case study in Battambang Province, the research examines the value chain of cover crop seeds and propose potential research and development opportunities to encourage broader adoption within an agroecological lens. We assessed (i) the agronomic practices regarding the production of seeds and their application in paddy rice fields, (ii) the market dynamics of seeds among actors within the commercial chain and (iii) the enabling environment including who influence the sector through programs, policies, and initiatives and how they can operate it effectively.

2 Materials and methods

This research focused on the cover crop (CC) seed in Battambang Province, Cambodia, assessing the full chain from seed production to end-user. The study presents a snapshot using data from 2023 and 2024, or the most recent data available. Both physical and monetary flows were examined, alongside support services, actor relationships, influence and interest dynamics, risk factors, and quality control mechanisms. In addition, the study investigates the characteristics of customers and producers, as well as the operational processes involved in CC seed production.

The methodological approach consisted to a value chain analysis composed of five main components: An economic assessment of cover crop seed production; a survey of seed producers; focus group discussions (FGDs) with paddy rice farmers using cover crops; key informant interviews (KIIs) with relevant stakeholders; and a multi-stakeholder dialogue event. Both qualitative and quantitative data were collected from primary and secondary sources.

To classify and present our research in a coherent and accessible way, we structured the study around three main dimensions: (i) Agronomic Practices, which encompass both the production of cover crop seeds and their application by farmers; (ii) Market Dynamics, which involve the flow of goods and interactions among actors within the commercial chain; and (iii) Enabling Environment, which includes categories of stakeholders who influence the sector through programs, policies, and initiatives.

This framework aligns with the multidimensional value chain analysis approach summarized by Llorente et al. (2022).

2.1 Site description

This study was conducted in Battambang and Phnom Penh Provinces in Cambodia. Within Battambang, the research focused mainly on two distinct areas: (i) Rattanak Mondoul District, location of the pioneer network of cover crop seed producers, among which some are located at the border with Banan District and (ii) Sangkae District in the irrigation scheme of Kanghot, where rice farmers apply cover cropping practices (Figure 1) since few cropping seasons. Stakeholders involved in the study were either active locally within Battambang, regionally in Phnom Penh, or operated nationally with influence on agricultural development in Battambang Province.

Battambang region is classified as Tropical Savanna (Aw) according to the Köppen–Geiger climate classification system. The average annual temperature is approximately 27.7 °C, with observed seasonal variations. Rainfall is highly seasonal, predominantly falling between May and November. Historical meteorological data for the period 1982–2021 indicate an average annual precipitation of 1,366 mm (Pheap et al., 2025). In Rattanak Mondoul District, soil Type is classified as Phaeozem (WRB) (IUSS Working Group WRB, 2022). In Sangkae District, soil type is classified as Acrisols (Sourn et al., 2022). Sangkae district is located approximately 15 km from Battambang city and 60 km from Rattanak Mondoul. Kanghot irrigation scheme is shaped by an extensive irrigation infrastructure. Originally constructed in 1976 during the Khmer Rouge regime, the system was abandoned during the civil conflict and subsequently rehabilitated in two phases between 2009–2013 and 2014–2015. The combined irrigated area spans 64,500 hectares, comprising seven main canals, further subdivided into smaller distribution networks (Diepart and Thuon, 2022). Since 2020, the district has seen increased intervention from the Royal Government of Cambodia and international development organizations, with the aim of rehabilitating the infrastructure and promoting sustainable agricultural initiatives.

2.2 Data collection

For clarity and consistency throughout the paper, we also refer to "producers" as cover crop seed producers, and "farmers" as paddy rice farmers who apply CC. Although cover crops are used in several villages, communes and districts in Battambang, our analysis focuses on their use in the Kanghot irrigation scheme by rice farmers.

2.2.1 Economic assessment

Since 2017, DALRM/CARDEC has collected quantitative data to evaluate the economic performance of cover crop seed production systems. In 2023, this assessment was expanded to include the main cash crop, maize, which is cultivated prior to the production of cover crop seeds, in order to provide a comprehensive agro-economic evaluation of cropping patterns incorporating cover crop seed production. The study focused on seed producers who had cultivated *Crotalaria juncea* and *Crotalaria ochroleuca* seeds for at least two consecutive years (2023 and 2024),

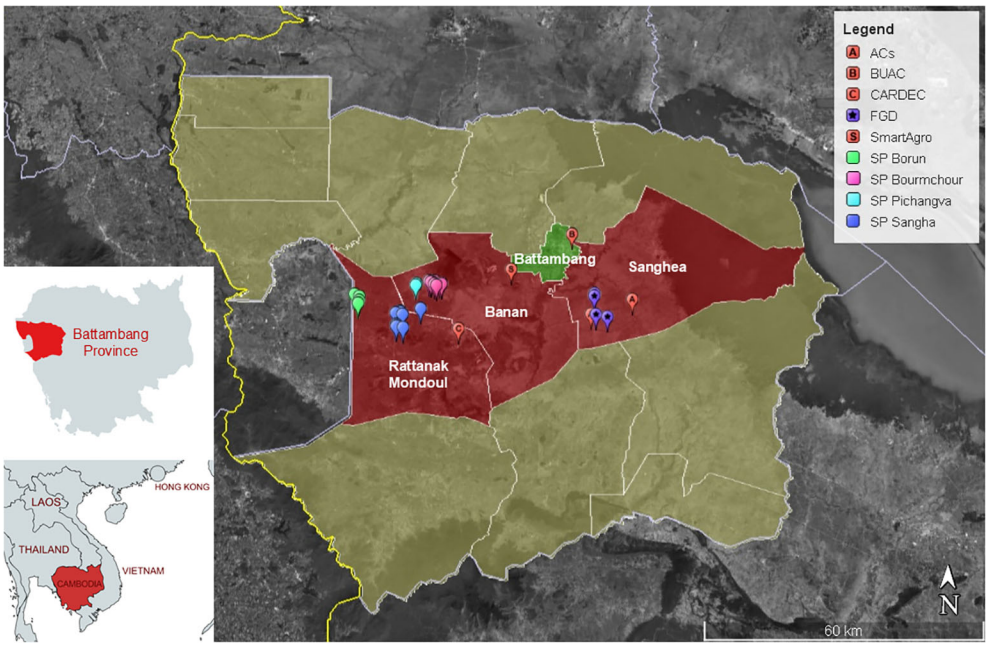


FIGURE 1
Administrative layers include the Battambang Province district boundaries, and the study area encompassing the target districts of Rattanak Mondoul, Banan, and Sangkae (in red). Respondent locations are indicated by distinct symbols: cover crop seed producers (SP) are shown as colored pins identifying individual producers according to their villages; focus group discussions (FGDs) with paddy rice farmers using cover crops; key informant interview locations are indicated for agricultural cooperatives (ACs), BUAC (B), CARDEC (C), and SmartAgro (S).

representing the total known population of consistent producers. The number surveyed per year varied: 4 (2017), 9 (2018), 10 (2019), 9 (2020), 6 (2021), 31 (2022), 22 (2023), and 19 (2024). All field operations and related expenses were recorded in collaboration with the farmers on each plot and for each treatment.

2.2.2 Survey

A survey combining closed questions with semi-structured interviews was administered to the same group of 23 seed producers. The survey was designed to collect both quantitative and qualitative data on species cultivated and cultivated area, contractor agreements and contractual terms, seed retention and informal distribution, access to services and technical support, and producers' perceptions; including perceived difficulty of production and seed quality, interests and uses, perceived benefits, constraints, and recommendations. The questionnaire was pre-tested with interpreters to ensure clarity, accuracy in translation, and appropriateness of language. Responses were analyzed to complement the economic data and enrich the understanding of producers' operational contexts and motivations. The consent of respondents was asked before each interview,

2.2.3 Focus group discussions

Four Focus Group Discussions (FGDs) were held with a total of 23 rice farmers who have adopted cover cropping practices in Sangkae District, in the Kanghot irrigation scheme.

Farmers were selected through purposive sampling, targeting early adopters who had received subsidized seed support. DALRM/CARDEC facilitated participant identification. Each FGD followed a consistent structure, starting with an introduction to the project, followed by an explanation of the research objectives and session goals, participatory ranking exercises in which farmers voted on (i) the main purposes of using cover crops, (ii) primary constraints, and (iii) key recommendations, and concluding with an open discussion on the species used, technical support received, and seed access.

Farmers used stickers to indicate all species they applied (e.g. *Vigna radiata*, *Crotalaria juncea Crotalaria ochroleuca*, *Sesbania sesban*, *Vigna unguiculata*, *Centrosema pascuorum*, *Sorghum bicolor*). Sessions were documented with notes capturing both participant responses and qualitative impressions (e.g., level of engagement). A feedback session was conducted with CARDEC staff to clarify ambiguous responses. Both quantitative rankings and qualitative narratives were collected.

2.2.4 Key informant interviews

Twenty-seven Key Informant Interviews (KIIs) were conducted with a diverse set of stakeholders across the value chain. The selection process combined purposive and snowball sampling strategies. Interviews were guided by a semi-structured questionnaire. The first part captured the respondent's activities and roles within the cover crop sector. The second focused on stakeholder analysis, drawing on the influence–interest mapping approach inspired by Bendtsen et al. (2021). We applied the second part only to 11 interviews, targeting stakeholders who contribute to the enabling environment. Interviewees were asked to assess their own position in the value chain and to provide strategic documents, reports, or datasets where applicable.

2.2.5 Multi-stakeholder event

The Participatory Market Chain Approach (PMCA) is a methodology designed to stimulate innovation within market chains and deliver tangible benefits for all stakeholders (Bernet et al., 2012). One tool recommended by PMCA is the organization of multi-stakeholder events to present research findings and explore opportunities for market innovation, typically focused on a topic identified by the research team. In this study, such an event was held to pursue three main objectives: (i) facilitate discussion among Cambodian organizations on cover crop activities, (ii) examine key pricing challenges in the cover crop seed sector, and (iii) gather participants' perspectives on constraints and recommendations for improvement. Participants were selected through purposive sampling, coordinated by the Swisscontact team. Most were representatives of organizations previously involved in KIIs. The event took place at the Swisscontact office in Phnom Penh, with invitations extended to those directly involved in the cover crop sector.

2.3 Data management and analysis

Data were collected using paper-based questionnaires for interviews with farmers and direct value chain actors. Responses were digitized using Microsoft Excel and Microsoft Word for initial data entry and organization. Qualitative data were analyzed using MAXQDA, while quantitative analysis and descriptive statistics were conducted in RStudio. We conducted an Analysis of Variance (ANOVA) followed by a Tukey's Honest Significant Difference (HSD) *post-hoc* test to assess whether there were statistically significant differences in the average net profit of seed producers between the production of maize and cover crop seed. Field interviews and FGDs were conducted in Khmer, with real-time translation into English provided by DALRM/CARDEC-employed translators with backgrounds in agronomy. Informed consent was obtained prior to recording interviews and taking photographs. During transcription and cleaning, irrelevant or off-topic responses were excluded from the dataset. Missing data were excluded in the economic assessment analysis. Responses related to constraints and recommendations were cross-verified and triangulated across stakeholder groups to enhance consistency and reliability of the findings.

2.4 Typology of respondents

2.4.1 Producers

The age of household heads ranged from 33 to 67 years, with a median age of 44. Of these, 16 were male and 7 female. Producers are located across four villages in Rattanak Mondoul District and Banan District: Boeng-Prey (n=9), Sangha (n=8), Borun (n=4), Pichangva (n=2) and are involved in other cropping activities (Figure 2). All,

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except one respondent, rely on agriculture as their main source of income; one respondent is a teacher and estimates working 30% in agriculture. However, 15 producers also engage in off-farm economic activities. These include: 10 acting as service providers, offering ploughing, harvesting (with combine harvesters), and transportation, 3 operating small retail shops, and 1 working as an extension officer. On average, these seed producers owned 12.3 hectares, and the main cash crop was maize, followed by cassava (Figure 2). It should be noted that, while these producers are representative of cover crop seed producers, they are not representative of farmers in this region, where several types of farm coexist (Kong et al., 2019), including those with a predominance of perennial plantations (e.g. mango and longan). This group distinguishes itself by cultivating a larger area of annual upland crops than other groups, which allows them to engage in the production of cover crop seeds after the maize cycle.

2.4.2 Support actors in seed production

We investigated the roles of four main actors in 2023: DALRM/CARDEC, SmartAgro, local service providers, and the seed producers themselves. Two forms of assistance were distinguished: technical support and service provision. When seed producers explicitly mentioned carrying out a task themselves, we attributed the activity accordingly. In cases where no external actor was identified, we assumed that the seed producers conducted the operation independently.

2.4.3 Farmers

Rice farmers originated from the following villages: Wat Kandal (n=11), Reang Kessei (n=8), Domnak Dangkor (n=3), Svay Chet (n=1). Among participants, 7 were women and 16 were men. All farmers had at least two seasons of experience using CC, with adoption years ranging from 2020 to 2022. They cultivated rice on plots ranging from 3 to 10 hectares, with a median area of 5 hectares.

2.4.4 Key informant

The stakeholder groups (Table 1) included: (1) farmers using cover crops (CC), to complement FGD results; (2) agricultural cooperatives and a private company; (3) middlemen, identified through referrals by cooperatives; and (4) stakeholders contributing to the value chain and/or its enabling environment, including five categories: (i) higher education and research, (ii) NGOs and consultancy, (iii) platforms, (iv) programs and projects, and (v) research and technical institutes.

3 Results

3.1 Agronomic practices

3.1.1 Production

3.1.1.1 Economics

Seed producers of cover crops follow several agronomic steps, with practices evolving over the years. In land preparation, costs were higher in the initial years, rising from $31/ha in 2017 to a peak of $43/ha in 2019, then decreased to $10/ha in 2024 due to seed broadcasting of cover crops caused by heavy rainfall (Table 2); during periods of heavy rainfall, a no-till seed drill cannot be used. The proportion of total production costs attributed to land preparation declined from 15.3% to 3.6%, indicating improved operational efficiency. For *Crotalaria ochroleuca* and maize, land preparation costs remained relatively stable, ranging from 10%–12.6% and 10.4%–14%, respectively.

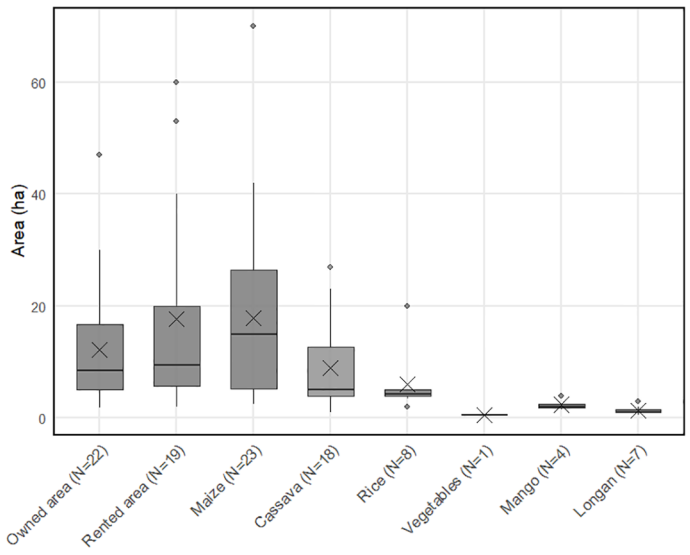


FIGURE 2
Repartition of the land areas owned, rented and cultivated by seed producers, Rattanak Mondoul district, Battambang.

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TABLE 1 Summary of stakeholders interviewed and tools applied. Stakeholders are classified by categories.

Categories of stakeholder	Tools applied	Number of respondents
Seed producers	Economic assessment & Survey	23
Rice Farmers	Focus Group Discussion	23
Rice Farmers	Key Informant Interview	4
Middlemen	Key Informant Interview	4
Programs & projects	Key Informant Interview	4
Higher education & Research	Key Informant Interview	3
NGOs & Consultancy	Key Informant Interview	3
Research and Technical Institutes	Key Informant Interview	3
Agricultural Cooperative	Key Informant Interview	2
Union of Agricultural Cooperatives	Key Informant Interview	1
CASIC platform for policy dialogue and coordination in Agroecology	Key Informant Interview	1
Private Company	Key Informant Interview	1

In sowing, costs varied by crop and sowing method. *Crotalaria juncea* ranged from 13.7% to 26.2%, *Crotalaria ochroleuca* from 17.5% to 29.6%, and maize remained relatively constant at 28%. The method of sowing influenced cost, broadcasting ranged from $5–20/ha, while no-till sowing cost around $40/ha. Despite the higher cost, producers favored no-till sowing due to improved seed placement and homogeneity of the crop. However, heavy rains during the sowing window (August–September) often forced a reversion to manual broadcasting.

In Fertilization, Weeding, and Pest management, initially absent from operations, these practices became increasingly necessary. For *Crotalaria juncea*, input costs rose to 17.5% of total costs by 2024, largely due to pest pressure from *Utetheisa lotrix*, which led to up to four pesticide applications per season for some producers. *Crotalaria ochroleuca* followed a similar trend from 2022 onwards.

Manual harvesting in 2017 cost an average of $45/ha (23.3%). Mechanization using combine harvesters brought the cost of harvesting and (pre) threshing to $144/ha (52.9%), but as equipment became more available, costs declined to $87–93/ha by 2024. Some producers not harvesting in 2022 skewed the average cost downward.

Post-harvest processing was initially expensive due to thresher use ($84–115/ha), costs declined substantially as producers hired the service of combine harvester and adopted on-farm pre-cleaning using simple tools like fans, reducing post-harvest costs from 25.9% to 2.3% by 2022.

For *Crotalaria juncea*, total production costs ranged from $193–$299/ha across years, while gross income varied from $506/ha to $803/ha, depending on yield and farm gate price (Table 3). The 2017 and 2024 cohort showed particularly high returns compared to other years. *Crotalaria ochroleuca* maintained stable production costs ($223–273/ha) with income between $399–523/ha, despite a higher seed price ($1.15/kg vs. $0.80/kg for *Crotalaria juncea*). The lower yield of *Crotalaria ochroleuca* (attributed to seed size) may explain this discrepancy. In 2024, bad weather conditions particularly influenced yield, compared to 2023.

Results of the net profit distribution per hectare indicate a statistically significant difference in average net profit between *C. ochroleuca* and maize production (p = 0.0006), with maize generating higher mean profits per hectare (Figure 3). The difference between maize and *C. juncea* was marginally non-significant (p = 0.0595), while the comparison between *C. ochroleuca* and *C. juncea* was not statistically significant (p = 0.1794). Mean net profits further illustrate these patterns, with maize achieving $427.1/ha, *C. juncea* $314.6/ha, and *C. ochroleuca* $224.7/ha. Standard deviations suggest that maize profitability is more variable ($275.3/ha) compared to *C. juncea* ($210/ha) and *C. ochroleuca* ($217.1/ha), possibly reflecting higher risk and return potential for maize. These findings highlight the economic importance of producing cover crop (CC) seeds as a valuable source of additional income, particularly given that these crops are cultivated after maize in an annual cropping sequence and utilise the marginal rainfall at the end of the wet season.

3.1.1.2 Seed production and management

In 2023, the seed production network produced five different cover crop species. *Crotalaria ochroleuca* was by far the most cultivated, yielding 49,842 kg of seeds, followed by *Crotalaria juncea* (9,700 kg), *Sesbania sesban* (4,350 kg), *Cajanus cajan* (950 kg), and *Pennisetum glaucum* (870 kg). Ten seed producers reported retaining part of their harvest for sowing in the subsequent season or for personal use (short cycle cover crop before Maize). However, retained quantities were relatively low: 597 kg of *Sesbania sesban*, 560 kg of *C. juncea*, and 140 kg of *C. ochroleuca*. Four producers noted that uncertainty regarding contractors' future seed demands discouraged them from saving larger quantities, as they often depend on contractors to provide new seeds for each production cycle.

In terms of informal distribution, four of the ten producers either sold or gave away small volumes of seeds, typically to other farmers or family members. The total distributed included 150 kg of *Sesbania sesban*, 130 kg of *C. juncea*, and 30 kg of *C. ochroleuca*.

Regarding formal sales, twenty-two seed producers sold their seeds to SmartAgro, six to CARDEC to sustain research activities, three to other farmers, and one to the Battambang Union of Agricultural Cooperatives (BUAC). Contractual relationships followed similar patterns: 21 producers had contracts with SmartAgro, five with CARDEC, and one with BUAC.

We also investigated the presence of subsidies or in-kind support to seed producers. While no direct subsidies were reported since 2017, some forms of material support were identified. SmartAgro and CARDEC loaned seeds to four producers under an arrangement

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TABLE 2 Average absolute and relative costs of field operations of *Crotalaria juncea*, *Crotalaria ochroleuca* and maize.

Crops / Species	Year	Land preparation		Sowing		Fertilizer		Weeding		Pest protection		Harvest		Post-Harvest	
Name	Date	($/ha)	%	($/ha)	%	($/ha)	%	($/ha)	%	($/ha)	%	($/ha)	%	($/ha)	%
Crotalaria juncea	2017	31	15,9	50	26,0	0	0,0	0	0,0	17	9,0	45	23,4	50	25,8
	2018	38	14,1	46	23,6	0	0,0	0	0,0	24	8,8	144	52,8	21	7,6
	2019	43	14,3	65	33,7	11	3,7	0	0,0	17	5,8	138	45,9	26	8,6
	2020	40	15,3	64	33,2	0	0,0	0	0,0	21	7,9	111	42,7	25	9,6
	2021	20	6,9	39	20,4	25	8,8	32	11,3	36	12,5	118	41,3	15	5,4
	2022	16	6,0	68	35,1	16	6,3	39	14,8	28	10,8	87	33,6	6	2,4
	2024	10	3,6	64	33,1	16	5,6	33	11,7	49	17,6	93	33,0	16	5,8
Crotalaria ochroleuca	2022	25	10,0	74	38,3	0	0,0	45	18,1	0	0,0	106	42,4	0	0,0
	2023	35	12,8	55	28,5	16	5,8	24	8,9	29	10,7	95	34,8	19	6,9
	2024	28	12,3	39	20,4	3	1,4	23	10,1	29	12,8	94	41,9	9	3,8
Maize	2023	48	10,5	129	67,2	90	19,5	36	7,8	41	9,0	116	25,2	0	0,0
	2024	68	14,0	137	70,9	74	15,2	38	7,8	33	6,7	114	23,4	24	4,8

The values in brackets denote the number of repetitions per year.

where the quantity was repaid post-harvest. In two cases, SmartAgro covered the replanting costs when initial germination rates were poor. Additionally, four producers received seeds free of charge from SmartAgro and CARDEC as part of varietal trials. CARDEC lent sowing machinery (no-till seeder) to one producer without charge. Finally, in 2022, the Dei Meas initiative subsidized the cost of cover crop seeds for one farmer.

3.1.1.3 Support actors in seed production

CARDEC exhibited significant involvement at the sowing stage, primarily due to the provision of a specialized no-till seeder equipped to sow small seeds (Figure 4). Beyond this, the data show high engagement of local service providers in fertilizer application, pesticide spraying, and harvesting. For harvesting, most producers contracted local service providers equipped with combine harvesters. Post-harvest operations were almost exclusively managed by seed producers using their own equipment and labor. Similarly, land preparation was partially outsourced while the remainder was managed directly by the producers.

Technical support services were not reported for sowing, harvesting, or post-harvest stages, as these operations were fully handled by service providers or by the seed producers themselves.

In contrast, CARDEC played a dominant role across the remaining field operations, offering technical assistance in approximately 25-50% of cases. Seed producers also relied on their own knowledge, especially during land preparation (90% of cases), and for other operations. SmartAgro provided targeted

TABLE 3 Average economic outcome of *Crotalaria juncea*, *Crotalaria ochroleuca and* maize.

Crops/Species Name	Year Date	Total costs ($/ha)	Labor (man/day)	Selling Price ($/kg)	Yield (kg/ha)	Income ($/ha)	Net profit ($/ha)
Crotalaria juncea	2017	193	5,25	1,0	803	803	576
	2018	272	3,00	1,0	514	514	244
	2019	299	NA	0,8	850	680	381
	2020	261	NA	0,8	644	515	254
	2021	284	3,50	0,8	691	579	294
	2022	260	3,69	0,8	636	506	246
	2024	280	3,23	0,8	900	720	440
Crotalaria ochroleuca	2022	250	4,50	1,25	365	456	206
	2023	273	3,44	1,0	516	523	250
	2024	223	2,91	1,2	347	399	175
Maize	2023	461	2,16	0,2	4777	845	384
	2024	486	3,29	0,2	6130	963	477

The values in brackets denote the number of repetitions per year.

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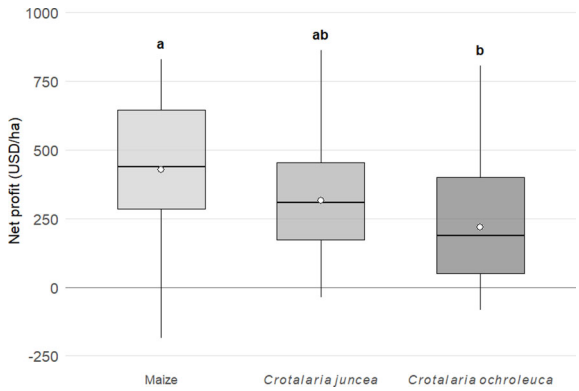


FIGURE 3
Net profit of maize (n=41) cultivated prior the cover crops in an annual crop sequence, *Crotalaria juncea* (n=53) and *Crotalaria ochroleuca* (n=36). Small letters refer to mean comparison (ANOVA + Tukey).

technical guidance, particularly for weeding, fertilization, and pesticide application, with involvement ranging from 25% to 45% depending on the activity.

3.1.1.4 Cover crop seed producers' perception

Perceptions of production difficulty varied (Figure 5a). Eleven producers rated CC seed production as very easy, seven as easy, and five as neutral. Those who rated it favorably cited simplified sowing, maintenance, and harvesting compared to crops such as maize or mung bean.

The predictability and assurance offered by contract farming were also highlighted as contributing to ease of production. In contrast, producers with neutral perceptions pointed to labor-intensive post-harvest tasks, including extended sun-drying and residue cleaning. Manual weeding was also reported as burdensome by producers who do not employ service providers, with some experiencing skin irritation from contact with plant material.

Market prospects were largely viewed positively (Figure 5b). Thirteen producers assessed market growth as very fast, eight as fast, and two as neutral. Respondents emphasized the inability of current supply to meet contractor demand and increasing interest from new producers. Several noted that CC seed production can be more profitable than a second maize cycle. Nonetheless, a few producers expressed concerns regarding future demand due to climatic risks and growing market entry by actors with limited commitment to long-term quality standards.

Fourteen producers perceived the seed quality produced as very favorable, five as favorable, and one as neutral (Figure 5c). Those rating quality highly frequently referenced receiving first-grade classification from contractors, translating into higher remuneration (e.g., $1.15/kg for first grade vs. $1.05/kg for second grade). These producers also reported post-harvest vigilance, including removal of broken or impure seed. In contrast, lower-rated responses were associated with the receipt of second-grade assessments, often attributed to visible seed damage.

The most frequently cited challenge was pest pressure, notably from *Utetheisa lotrix* on *Crotalaria*, reported by 13 producers, eight ranked it as their primary challenge (Figure 5d). Infestation led to increased reliance on chemical control (e.g., emamectin benzoate), with application frequency rising to four sprays per season in some cases. Another major concern, identified by 11 producers, was climate variability, particularly during the narrow sowing window for *Crotalaria ochroleuca* in August and September. When rainfall prevents the use of no-till planters, producers must revert to hand-broadcasting, often reducing seed quality produced due to a higher density of weeds growing. Additionally, limited access to mechanized sowing equipment, exacerbated by dependence on a single no-till planter managed by CARDEC, was cited. Isolated mentions included insufficient technical support and low germination rates attributed to seed quality.

The primary motivation cited by producers was soil fertility improvement: 20 respondents identified it as a key factor, 13 of whom ranked it as their primary reason for producing CC seeds (Figure 5e). Soil structural enhancement, erosion control, nutrient cycling, and maintenance of ground cover during otherwise fallow periods were among the stated benefits. Income generation was the second most commonly mentioned incentive (n = 17), with producers appreciating the predictability and profitability offered by contract-based CC seed sales. Other reported benefits included weed suppression, reduced mineral fertilizer use, and overall soil conservation.

Most seed producers (n = 14) reported using CCs in their own fields (Figure 5f). The primary reason was soil fertility enhancement. Producers often planted short-cycle species (40–45 days) between March and May before maize planting. Some also benefited from spontaneous regrowth after harvesting *Sesbania sesban*, incorporating the biomass into the soil. Others characterized CCs as "organic fertilizers" due to their ability to substitute for synthetic inputs. Additional advantages included weed control and enhanced biodiversity.

Eight categories of recommendations were identified and ranked by frequency. The most common suggestions (each cited by four producers) included adjusting seed prices to better reflect production costs, improving seed quality and varietal purity from suppliers, and promoting diversification of the cover crop seed species produced. Three producers advocated for increased technical training and expressed willingness to contribute as local extension agents. Additional proposals included earlier communication of contract terms, immediate payment post-

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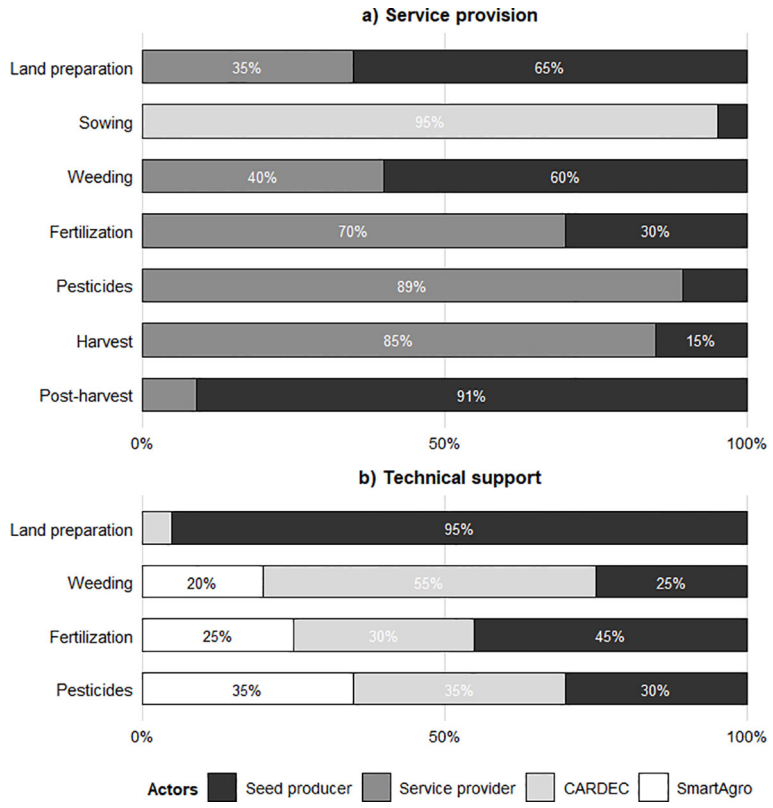


FIGURE 4
Actors involved along the production of cover crops seeds.

harvest, and interest in expanding production under guaranteed market conditions.

3.1.2 Application by rice farmers, Kanghot irrigation scheme

Farmers identified *Vigna radiata* (16 votes, common specie used first for grain production), *Crotalaria juncea* (15), *Crotalaria ochroleuca* (7), *Sesbania sesban* (5), *Vigna unguiculata* (5), *Centrosema pascuorum* (1), and *Sorghum bicolor* (mentioned but not voted for) as species used. *Vigna radiata*, though not produced by the seed network, is popular due to its capacity for seed harvest and additional income, sold for human consumption. Its seeds are sourced from local grain producers mainly located in Bavel district (Battambang Province). While *Centrosema pascuorum* has been promoted by Programs & projects partners, its limited market availability was noted. Farmers rarely apply a single species; mixing strategies are commonly used to diversify growth patterns and mitigate pest pressure. For example, *Crotalaria juncea* is often mixed with *Sesbania sesban* and *Crotalaria ochroleuca* post-second rice cycle, and with *Sesbania sesban* alone before the first rice cycle. Although *Crotalaria ochroleuca* has a longer growth cycle than *Crotalaria juncea*, it remains widely used.

Improvement of soil fertility emerged as the dominant motivation (14 first-, 2 second-choice votes), followed by enhancement of soil biodiversity (3 first-, 6 second-choice votes) (Figure 6). Other priorities included reducing mineral fertilizer use, weed management, and improving soil moisture. Other purposes such as improving root systems of rice, increasing soil porosity, or reducing pesticide use were cited less frequently. GHG mitigation and income generation were mentioned only as second- or third-tier priorities, typically tied to grain-producing species like *Vigna radiata*.

Initial access to CC seeds came via the WAT4CAM program phase 1 (2020–2022), followed by DEI MEAS initiative, BUAC, and occasionally CARDEC's Research Station Bos Khnor (e.g., for trialling *Vigna unguiculata*). Seeds are distributed through agricultural cooperatives (e.g., AC Reang Kessei, ACKP), local farmer houses, or project teams, within a 1–10 km radius. Seed prices ranged from $0.75–$1/kg due to 50% subsidies. Technical support initially came from the research for development component of WAT4CAM, and since 2021, the PDAFF through METKASEKOR field demonstrations. DEI MEAS and Larano (a private company involved on agricultural machinery manufacturing and importing) contributed demonstrations and mechanization services. Farmers mentioned relying on peer-to-peer learning for knowledge dissemination and troubleshooting.

Drought emerged as the primary constraint (11 first-choice, 10 second-choice votes). Inadequate rainfall hampers sowing in March and affects germination and biomass production. Pest pressure, particularly from *Utetheisa lotrix* (affecting *Crotalaria juncea*), followed closely (8 first-choice votes). Pest invasions can devastate fields within days, especially in April. One farmer reported issues with mole crickets. Seed costs were also noted, cited by six farmers as a third-choice constraint. As subsidies decrease, the price is expected to increase to approx. $51/ha, considered unaffordable by several. Other constraints include cattle roaming (mainly in

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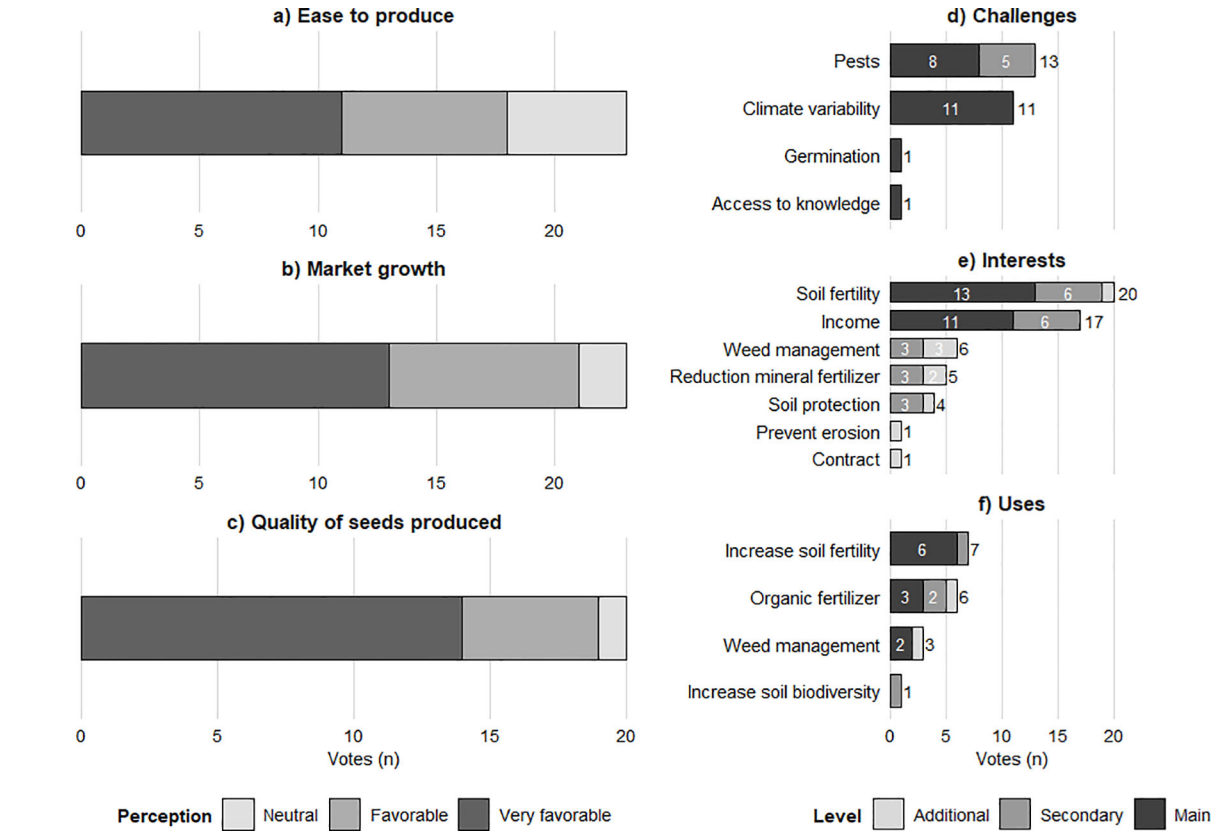


FIGURE 5
Perception of 23 seed producers investigated on the ease to produce cover crops seeds, market growth, quality of seeds produced, challenges faced, interests to produce, and personal use. On the left-hand side, respondents rated each aspect on a scale from 1 to 5, where 1 indicates a very favorable perception, 3 is neutral, and 5 is very unfavorable. On the right-hand side, participants were invited to name and rank up to three categories relevant to each topic based on their own experience. When multiple categories were mentioned, they were ranked in order of perceived importance, from most to least important.

clustered plots, affecting *Crotalaria ochroleuca*), heavy rainfall (particularly in April or December) and accidental fire from nearby field- rice straw burning practices.

The most prominent recommendation was a reduction in seed prices (9 first-choice votes). Farmers argued that a range of $10–25/ha is more appropriate. Withdrawal of subsidies poses a significant economic burden, especially when biomass production is uncertain. Farmers favor reward mechanisms, such as those piloted by Dei Meas, as more sustainable. Improving irrigation access was the second most cited recommendation, particularly through canal opening during critical growth stages. Other recommendations included promoting short-cycle species better adapted to late dry-season planting, and contract-based seed production by rice farmers (though not unanimously supported). Less frequently mentioned suggestions included:

- Development and testing of new species (e.g., non-palatable for cattle and/or harvestable for additional income sources. e.g., *Vigna unguiculata*, which could be sold for human consumption)
- Insurance mechanisms to cover land preparation and seed costs
- Fencing to prevent cattle intrusion
- Expanding training programs on all CC species
- Leveraging CC application to meet export requirements and practice-based incentives (e.g., via Sustainable Rice Platform certification)

3.2 Market dynamics

3.2.1 Market status and value chain

At the core of the chain is the network of seed producers, who collaborate with input suppliers, providing fertilizers, herbicides, and pesticides, and service providers, contracted for land preparation, sowing, weeding, chemical application, harvesting, and transportation (Figure 7). Upon completion of production, the seed producers supply CC seeds to five main stakeholders: SmartAgro, BUAC, DALRM/CARDEC, other farmers and themselves, for reuse. In 2023, SmartAgro held contracts for 179.4 ha (96% of the total area), while CARDEC managed 6.5 ha (4%). By 2024, SmartAgro's share had dropped to 79% (142 ha), with BUAC and the research institute managing 7% (12.5 ha) and 14% (24 ha), respectively. The main species cultivated were: *Crotalaria ochroleuca* (123 ha), *Crotalaria juncea* (20.5 ha), *Sesbania sesban* (26 ha), *Sorghum bicolor* (3 ha), *Pennisetum glaucum* (6 ha).

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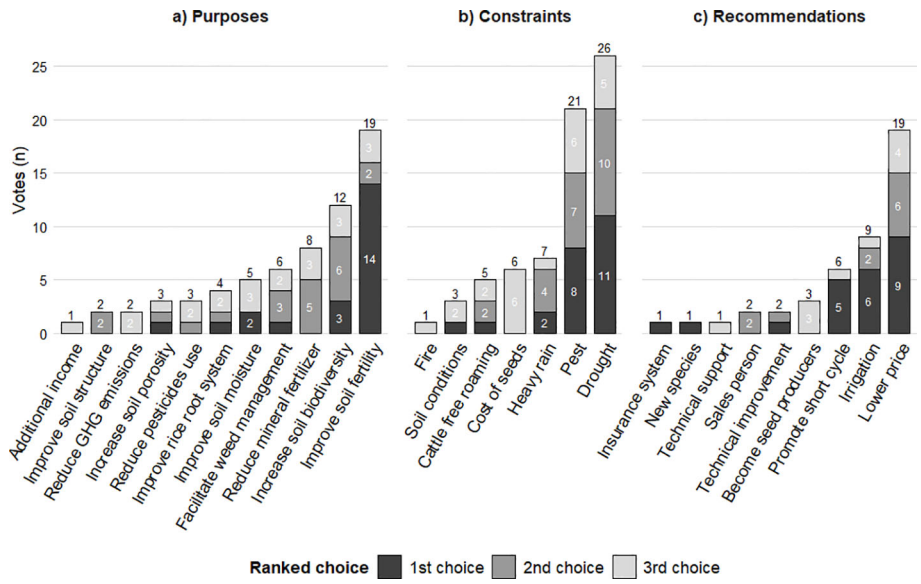


FIGURE 6
Purpose, constraint, recommendation for application of cover crops in rice fields in Kanghut District. Results are a combination of 4 Focus Group Discussion with 23 farmers in total. Each category was first cited by farmers and then voted according to the relevance of the statement. Defined by 1st, 2nd and 3rd choice. Purpose, n=22, 21, 22, Constraints, n=23, 21, 22 and Recommendations n=23, n=11, n=10, for the 1st, 2nd and 3rd choice, respectively.

SmartAgro is a private contractor in the CC seed sector and principal supplier, working with 47 producers and collecting approximately 80 tons of seed in 2023. The company manages village-level collection points and oversees all post-harvest operations, including cleaning, sorting, packaging, and storage. Seed quality is assessed through outsourced laboratory analysis in Thailand, where parameters such as moisture content, impurity rates, mechanical and disease-related damage, and germination rates are examined. Final purchase prices depend on species-specific thresholds for these indicators. However, the delayed availability of laboratory results, often taking several weeks, postpones payments to producers. SmartAgro exports roughly 70% of its seeds (mainly *Crotalaria ochroleuca*), with the remaining 30% sold domestically to all types of actors: large-scale and smaller-scale farmers, development partners (Programs, Projects, NGOs), private companies and agricultural cooperatives.

BUAC (Battambang Union of Agricultural Cooperatives) represents over 2,500 farmers and 10,000 hectares of farmland through 10 affiliated cooperatives. Since 2021, BUAC has distributed CC seeds to rice farmers at subsidized prices, enabled by a $10,000 grant from a development partner. By 2024, a 13-ton seed stock had been fully sold at prices ranging from $0.875/kg (*Crotalaria juncea*) to $1.25/kg (*Crotalaria ochroleuca*). Concurrently, BUAC initiated contractual arrangements with seed producers in Rattanak Mondoul, similar to SmartAgro's model. In 2024, BUAC marketed 4,000 kg of *C. juncea*, 2,000 kg of *Sesbania sesban*, and 2,000 kg of *C. ochroleuca*, at prices of $1.75/kg, $2.00/kg, and $2.50/kg respectively. BUAC handled logistics, including transportation ($20/t), cleaning and packaging ($25/t), and seed treatment ($6/t), ultimately distributing seeds to 125 farmers.

In coordination with BUAC, Agricultural Cooperative Kampong Prieng (ACKP), a cooperative comprising 226 members, plays a significant role in the dissemination of CC seeds at preferential rates to BUAC-affiliated members. Its clientele includes middlemen (50%), farmers (25%), and other cooperatives (25%). Sales prices are differentiated: $1.50/kg for middlemen and $1.00/kg for farmer members and cooperatives. ACKP primarily focuses on *C. juncea* and works with the same group of seed producers as BUAC. Since 2023, the ACKP–BUAC partnership has supported five producers over 11 hectares, producing a total of nine tons of seeds. ACKP is also active in community outreach and promotional events, supported by Swisscontact.

Two distinct types of middlemen were identified. The first group acts as local distributors, typically cooperative members who manage physical access to stored seeds for rice farmers. Their roles are unpaid and informal, aim at supporting their cooperative. Some also import seeds, such as *Vigna radiata*, from outside the network, reflecting additional value chain pathways. The second group consists of intermediaries working with ACKP to distribute seeds to markets in and outside Battambang Province (Kampong Cham, Preah Vihear, Kampong Thom, Kampong Speu, Battambang, Phnom Penh, and Kandal). ACKP organize transportation and benefits are paid back to the cooperative. These actors manage sales to other middlemen, rice farmers, orchard owners, home gardeners, cooperatives, and development projects (Programs, Projects, NGOs). Prices vary from $1.25 to $2.00/kg, depending on volume and client type. They reported that some large-scale rice farmers paying up to $2.00/kg. Sales are often facilitated through social media platforms (e.g., Facebook), with reported sales volumes of 1.2 and 7 tons of *C. juncea* by two interviewed intermediaries.

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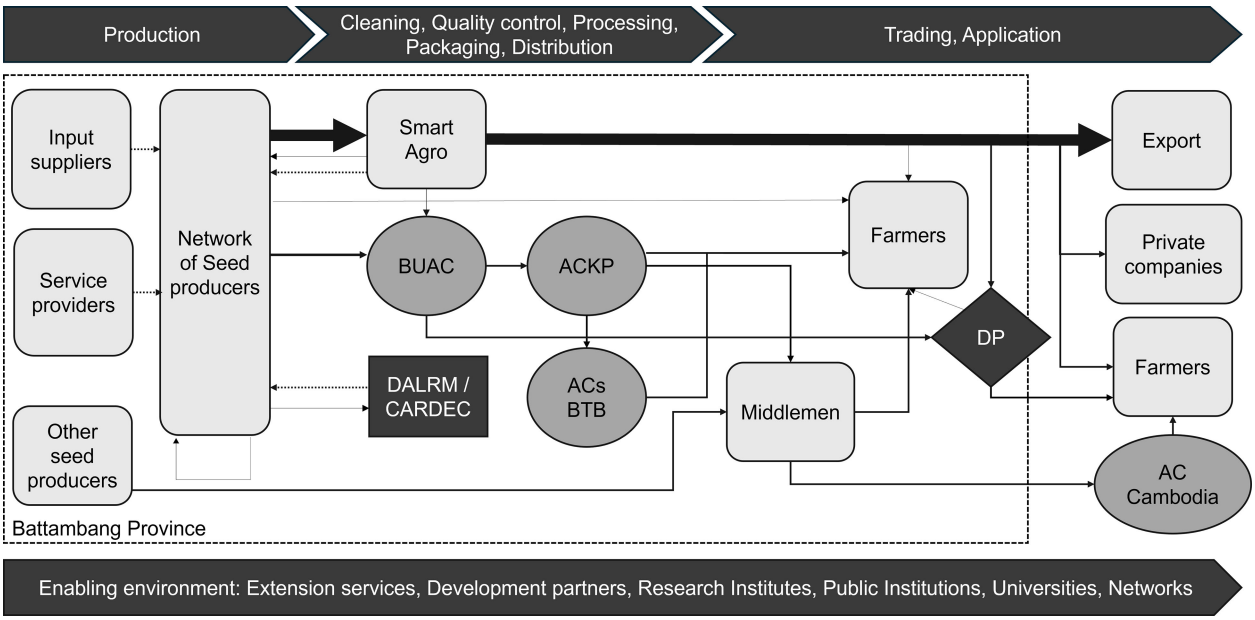


FIGURE 7
Value chain of cover crop seeds in the Case Study in Battambang, in 2023. The value chain is summarized in 3 main stages; (i) Production, (ii) Cleaning, Processing, Packaging, Distribution, (iii) Trading and Application, while these processes are supported by the enabling environment. The value chain landscape is composed of five main categories of actors. (i) In light grey squares are private actors: Input suppliers, Service providers, Network of Seed Producers, SmartAgro, Middlemen, Farmers, Farmers Cambodia and Export. (ii) In grey oval shapes are agricultural cooperatives (ACs). BUAC, ACKP, ACs in Battambang, ACs in Cambodia. (iii) In dark grey square is DALRM/CARDEC. (iv) In dark diamond shapes developement partners (DP). (v) actors presented in the enabling environment; Extension services, Higher education & Research, NGOs & Consultancy, Programs & projects, Platform, Research and Technical Institutes. The arrows between actors displays the type of interaction. Dots displays support to production, with service or inputs. Full arrows display exchanges of seeds. The width is related to the quantity exchanged.

Development partners (Programs, Projects, NGOs) source seeds from SmartAgro, Agricultural Cooperatives and may also import seeds. They are active in Battambang and other regions. They mainly work with small-scale farmers, providing technical and financial support.

DALRM/CARDEC, also acts as a coordination body among seed producers, SmartAgro, and BUAC, organizing planning and communication around field interventions. Historically, CARDEC introduced CCs in the region and promoted agroecological practices. Although it contracts only small seed volumes, mainly for reproduction, it remains until now instrumental in maintaining the technical integrity of the value chain.

3.3 Enabling environment and stakeholders analysis

3.3.1 Higher education and research

The National University of Battambang (NUBB) has recently integrated agroecology into its academic curriculum (Bsc), alongside existing programs in horticulture. The agroecology curriculum is contextually tailored to Cambodian farming conditions and includes a practical component on cover cropping. Students participate in field visits and internships in areas such as Rattanak Mondoul and Kanghot District, gaining direct exposure to agroecological practices increasingly sought after by development organizations. NUBB also leads several research initiatives in collaboration with international partners, with a particular focus on improving soil organic matter, a critical deficiency in Cambodia's soils. NUBB rated its interest in CC at *8* and its influence at *10*, emphasizing its strategic outreach potential given that over 50% of its students originate from farming households (Figure 8).

At the Royal University of Agriculture (RUA), the Faculty of Agricultural Biosystems Engineering (FABE)provides training on conservation agriculture machinery, including no-till planters for rice and maize. However, the department has ceased its research and development activities. While past efforts have contributed significantly, alumnis are now employed at companies such as SmartAgro, RUA currently offers no demonstrations nor training on CC-specific technologies. RUA rated its interest in CC at 4 and influence at 3, indicating a supportive but non-active role to cover crop technologies.

The Center of Excellence on Sustainable Agricultural Intensification and Nutrition (CE SAIN), one of the research center of RUA, provides training for future extension workers and researchers. Its focus areas include diversified cropping systems, composting, and irrigation technologies. CE SAIN is actively engaged in developing local machinery, such as no-till planters for upland vegetable systems in Battambang Province. Several researchers have been directly involved in projects where CC were the primary focus, including two PhD theses in Rattanak Mondoul and one in Bos Khnor. Additionally, the Center has supported initiatives in partnership with CIRAD and Swisscontact to scale up cover crop (CC) practices. CE SAIN rated its level of interest and influence as 8.

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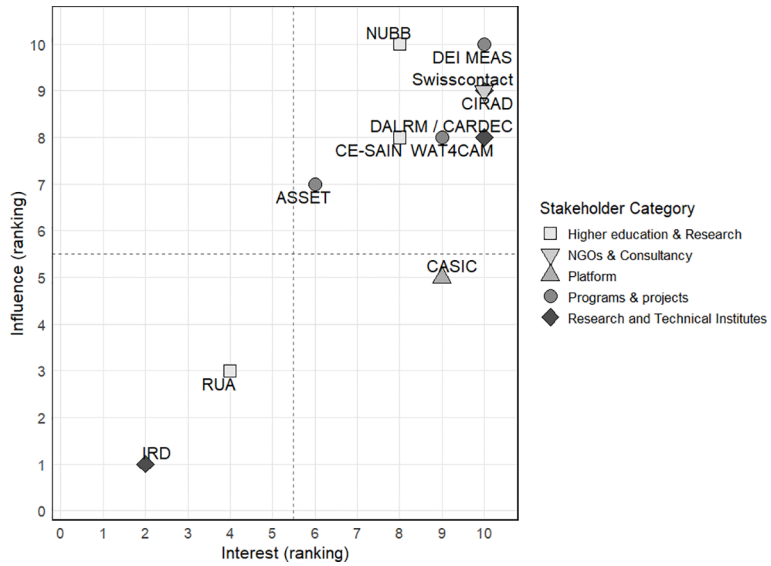


FIGURE 8
Interest and influence matrix of enablers on CC in Battambang province. This group of stakeholders is composed of five categories: Higher education & Research, NGOs & Consultancy, Programs & projects, Platform, Research and Technical Institutes. Their Influence and Interest is displayed on a scale of 1 to 10 on the left, and right side of the diagram, respectively.

3.3.2 Research and technical institutes

The French Agricultural Research Centre for International Development (CIRAD) has a long history of working with CC worldwide (Séguy et al., 2006). In Cambodia, a team of CIRAD called AIDA (Agroecology and Sustainable Intensification for annual crops) has played a key role in the development of these practices since 2004. CC are considered as the foundation of agroecological systems, an essential element that promotes multifunctional biodiversity by integrating diverse mixes into cropping systems. This approach leads to long-term improvements in soil and water resources as well as overall biodiversity. The research institute has extensive experience both in conducting field experiments and in scaling up these practices. Compared to other Cambodian stakeholders, the team of CIRAD involved on this initiative rates its level of interest at 10 and its influence at 9.

The Department of Agricultural Land Resources Management (DALRM) and its specialized unit, the Cambodia Conservation Agriculture Research for Development Center (CARDEC), have facilitated seed production in Kampong Cham, Kampong Thom, Preah Vihear, and Battambang. Their work centers on conservation agriculture, with CC as a key component. CARDEC leads the development, technical support, and coordination of the seed producer network, working closely with hundreds of farmers to integrate these practices in Rattanak Mondoul District and beyond. They rate their interest at 10 and their influence at 8, noting that reliance on public funding limits their influence compared to private sector actors.

The French National Research Institute for Sustainable Development (IRD), also located at RUA, primarily engages in fundamental research with limited emphasis on CCs. It focuses on traditional and locally relevant species within participatory research frameworks. Though supportive of CC benefits, IRD's contribution remains marginal. It rated both interest and influence in CC at 2 and 1, respectively, citing limited resources and thematic prioritization.

3.3.3 Programs and projects

WAT4CAM (Water Resources Management and Agroecological Transition for Cambodia) program phase 1 is a large-scale development initiative operating across five provinces. Funded by the Royal Government of Cambodia, French Development Agency (AFD) and the European Commission, the program includes dedicated components on research for development in agroecology (Subcomponent 4.2, led by CIRAD) and Extension (subcomponent 4.3, led by TA-AGRI - NIRAS). Since 2020, WAT4CAM has supported field demonstrations, technical support and under its Extension subcomponent, a seed subsidy schemes, targeting 2,000 ha of CC application by 2026. In Kanghot irrigation scheme, it implemented a degressive subsidy strategy, 50% in 2023, 20% in 2024, and 0% by 2025. WAT4CAM TA-AGRI (NIRAS) rated its interest at 9 and influence at 8, citing motivations such as improving rice export standards and reducing farmer input costs, while acknowledging that actors like SmartAgro and DARLM/CARDEC have more central operational roles.

Dei Meas (Golden Soils, ASSET) was created through a consortium including DALRM/CARDEC, CIRAD, Swisscontact, and SmartAgro to explore a range of a financial mechanism called to address the funding gap for farmers transitioning from conventional to agroecological practices. Since 2022, Dei Meas indirectly promotes the adoption of CC by supporting agroecological transitions. Thanks to the Sustainable Rice Platform (SRP) and the top-up provided by rice millers, farmers can earn extra income by changing their agricultural practices or through impact-based certification tied to increased soil organic carbon, achieved through agroecology and no-till systems that include CC was also explored. The initiative rates both its interest

and influence in scaling up cover cropping at 10, as the practice is central to its strategy.

The Agroecology and Safe Food Transition (ASSET) project promotes CC adoption in Battambang and Preah Vihear Province, emphasizing soil health, economic viability, and the dissemination of agroecological methods. ASSET, along with DALRM/CARDEC and Swisscontact, played a key role in registering the 15 CC species by the General Directorate of Agriculture. ASSET rated its interest in CC at 5 and influence at 7, noting that while CCs are a relevant component, they do not form the program's core focus.

3.3.4 NGOs and consultancy

Swisscontact Cambodia (SC), through its Innovation for Sustainable Agriculture (ISA) project, has led and leads numerous initiatives to develop and implement agroecology and CC. Their efforts span research for development, extension, education, development of technology and equipment, with a strong emphasis on partner coordination and financing the transition to agroecology. Swisscontact focuses on increasing demand for CC among farmers and improving their accessibility and affordability. Their primary motivation is to support smallholder farmers and enhance soil fertility through a systemic change approach. They rated their interest at 10 and their influence at 9.

3.3.5 Platform

The Cambodia Conservation Agriculture and Sustainable Intensification Consortium (CASIC, Ministry of Agriculture, Forestry and Fisheries) serves as a coordination platform between public and private actors promoting conservation agriculture. Although its direct involvement with CC is not specified, CASIC helps align research, policy, and field activities. The consortium views CC as a key driver of change for farmers traditionally practicing conventional tillage and sees them as an entry point for encouraging agroecological adoption. CASIC's primary role is to facilitate collaboration and build connections among stakeholders interested in CC. While it aspires to reach an influence level of 8 or 9, its current influence is about 5. Its interest level is rated at 9.

3.3.6 Constraints and recommendations by stakeholders

Constraints and recommendations are classified by the same structure as this study: (i) Agronomic Practices, (ii) Market Dynamic and Value Chain, (iii) Enabling Environment and Stakeholders analysis in Tables 4–6.

4 Discussion

The case study reveals a complex and dynamic landscape shaped by a diverse array of actors and interrelated layers of actions, interests, and influences. To facilitate a comprehensive understanding, the discussion is organized into the same sub-sections as the study's structure: (i) Agronomic Practices, (ii) Market Dynamics, and (iii) the Enabling Environment

4.1 Agronomic practices

4.1.1 Production

4.1.1.1 Economics

Seed producers reported profitable results. The average net profit per hectare was $308 for *Crotalaria juncea*, $186 for *Crotalaria ochroleuca*, and $438 for maize. In Northern Thailand, Hare (2014) found net incomes of $420/ha and $895/ha for rice and cassava, respectively, while farmers earned $1,105/ha, $1,870/ha, $1,459/ha, and $1,085/ha for producing of fodder species such as Ubon paspalum, Mulato II, Ubon stylo, and Mombasa, respectively. However, seed production often competed with main crops, requiring farmers to forgo cash crops, especially when market prices rose (Hare, 2013, Hare, 2014). In contrast, in Rattanak Mondoul, producers can grow both cash crops and cover crops seeds in the same sequence. Additionally, seed production offers a valuable supplementary income for farmers with limited alternatives. Furthermore, these crops contribute to soil erosion control, carbon sequestration, nitrogen fixation, among other co-benefits compared to typical cash crops in the region (Hare, 2014).

Seed producers reported increasing pest pressure linked to the emergence of *Utetheisa lotrix*, which has become a significant concern over recent years. The relative costs for pest control were 8.8% in 2017, 0% in 2022, of total production costs, and rose to 17.5% and 13% for *Crotalaria juncea* and *Crotalaria ochroleuca*, respectively. Costa et al. (2012) reported *Crotalaria juncea* as a suitable host plant for *Utetheisa ornatrix*, a closely related species. The observed outbreak may be partially attributed to the geographic and quantitative expansion of *Crotalaria* production.

4.1.1.2 Seed production and management

The other key challenge reported by seed producers is the limited availability of appropriate equipment, most notably, no-till planters. The sowing window for *Crotalaria ochroleuca* spans from mid-August to early September, and for *Crotalaria juncea*, it falls in September to mid-October. This period coincides with heavy rainfall, during which field access for mechanized and even no-till sowing can be limited. As of 2024, only one no-till planter suitable for these species is available in Rattanak Mondoul, covering over 170 hectares. Due to this constraint, many producers were forced to sow manually in 2024, resulting in uneven seedling emergence and increased weed pressure. These conditions significantly compromised seed quality and hindered the network's ability to meet export standards. This disruption contributed to a notable decrease in profitability: average net profits dropped by 30% in 2024 ($175/ha) compared to 2023 ($250/ha) for *Crotalaria ochroleuca*, when no-till planting was more widely accessible along with better soil conditions for a mechanized sowing. These findings align with

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TABLE 4 Constraints and recommendations for agronomic practices from stakeholders consultation.

Categories	Constraints	Recommendations	Mentioned by
Production	Lack of specific machinery	Increase the number of specific machineries (e.g. no-till planters and seed cleaning machines)	Agricultural Cooperatives, Higher education & Research (2), NGOs & Consultancy, Multistakeholders event
	Risk of low quality of seeds when produced by agricultural cooperatives		Research and Technical Institutes
	Lack of specialized service provision	NA	Multistakeholders event
	Lack of planning in the production induce issues with seed producers		Research and Technical Institutes
	Payment terms for seed producers		Research and Technical Institutes
Application	New practice is hard to implement for farmers. It requires time, knowledge, good experiences.	Target partnerships with Champion farmers to showcase and share good practices	NGOs & Consultancy, Multistakeholders event
	Lack of extension services and knowledge on benefits	Organize massive promotion campaigns and raise awareness among farmers	Agricultural Cooperatives, Platform, Multistakeholders event, NGOs & Consultancy
	Seeds are not available everywhere in Cambodia	NA	Academia
	Cattle free roaming in the dry season		NGOs & Consultancy, Research and Technical Institutes, Private sector
	Agronomic constraints in lowlands: compacted soil, water shortages	Implement interventions on a territorial scale rather than on a parcel-by-parcel basis	NGOs & Consultancy, Higher education & Research, Research and Technical Institutes
	Little short term return on investment	Find short term profitability strategies for small scale farmers	Research and Technical Institutes

TABLE 5 Constraints and recommendation upon market dynamic and value chain from stakeholders consultation.

Categories	Constraints	Recommendations	Mentioned by
Subsidies	Reliance on subsidies makes farmers reluctant to pay the full price	Understand value proposition from farmer viewpoint, not donor	NGOs & Consultancy (2), Agricultural cooperatives, Private sector
		Stakeholders agreement upon pricing point	Multistakeholders event
		Withdraw of subsidies from development partners to cover crop seeds	Research and Technical Institutes, Private sector
Practice- and result- based incentives	Cost of seeds hinders a wider adoption	Outcome & Result Based Payments (Carbon Credits, Payment Ecosystem Services, Regenari Certification)	Platform, Programs & projects
Market Structure and Seed Quality		Franchise model; private sector-branded seeds and collaborate with ACs for contract farming and seed distribution	NGOs & Consultancy
		Partnership with Rice Miller to sustain technical support through prices for certified production	NGOs & Consultancy, Platform
Cost Efficiency		Keep low price (Price of 20 to 25$/ha)	Agricultural Cooperatives, Programs & projects
		Offer diversification with specie/varieties which can produce additional income sources	Higher education & Research
		Economy of scale to reduce costs and increase profitability	NGOs & Consultancy (2), Research and Technical Institutes, Agricultural cooperatives
		Import seeds from India (approximately 1$/kg)	NGOs & Consultancy
		Ensure high-quality seeds for export and lower-grade for domestic use	NGOs & Consultancy
		Funding Needs: Seek project financing to scale up seed production	Agricultural Cooperatives

TABLE 6 Constraints and recommendations for the enabling environment from stakeholders consultation.

Categories	Constraints	Recommendations	Mentioned by
Policy, Advocacy, Regulation	Lack of awareness of politicians makes it difficult to draft policies	Convince policymakers with evidence on return on investment for farmers	NGOs & Consultancy, Multistakeholders event, Platform
	Lack of evidence on profitability to convince stakeholders (donors, policymakers, etc.)		Research and Technical Institutes
	Low engagement of public sector in supporting policies or strategic investment	Set national targets for agroecology/conservation agriculture.	Private sector, Platform Research and Technical Institutes, Multistakeholders event
	Lack of regulation on quality standards	NA	Multistakeholders event
Strategic planning	Lack of coordination and long term strategies, overlapping activities	Plan withdraw of development aid through local market demand creation	NGOs & Consultancy (2) Programs & projects, Public Institution
	Lack of coordination to convince large donors (ADB, World Bank,…)	NA	NGOs & Consultancy, Platform
	Low competition in the sector; constraints for donors engagement, innovation, selling price, instable market if development partners withdraw.	Estimate market size to attract investment and offer grants to seed production companies to launch	NGOs & Consultancy
		Support a diversified landscape of business models (e.g. AC, Private Companies) to reach farmers accordingly	Agricultural Cooperatives, NGOs & Consultancy
	Lower supply than demand in 2024	Large-Scale Planning: Target additionally 180 hectares for cover crop seed production	Programs & projects, Agricultural cooperatives
	Farmer producers; risk to lower the seed quality	NA	Programs & projects, Research and Technical Institutes, Private sector
Threat and Opportunities	The 3 rice cycle per year: leaves no time for cover crop (currently not applied in Kanghot)	Farmers need to meet international requirements in terms of exportation standards due to EU restriction	Platform

Hare (2014), which emphasized the importance of access to appropriate equipment for seed production.

Climate variability further compounds these difficulties. Excessive rainfall during sowing impairs germination, while insufficient rainfall in December weakens seed development and reduces seed quality. Although the climatic context in Cambodia differs markedly from that in Indiana, similar challenges related to climate variability were also reported by Tyndall et al. (2021), underscoring the broader relevance of this issue in cover crop seed systems.

4.1.1.3 Supporting actors in seed production

In contrast to much of the literature, which often highlights insufficient production-level support as a key constraint in seed systems, this challenge appears less pronounced within the investigated network (Biradar et al., 2013; Chakoma and Chummun, 2019; Florez et al., 2024). For example, in the case of *Stylosanthes hamata*, Biradar et al. (2013) identified insufficient technical support as one of the factor contributing to the decline of seed production. In contrast, within our study, only two producers reported a lack of technical assistance, both of whom were in their second year of seed production. Notably, these individuals were able to compensate for this gap by seeking guidance from more experienced producers within the network. This suggests a strong and functional peer-support system, reflecting the maturation and resilience of the seed producer network. We hypothesize that this outcome is attributable to a sustained history of interventions and consistent technical support provided by CARDEC/DALRM, implemented in collaboration with SmartAgro.

On the contrary, a further challenge lies in the strong reliance on CARDEC/DALRM for both service provision and, to a lesser extent, technical support. CARDEC currently provides the only available no-till planter suitable for sowing of CC (small seeds and low seed rate per ha). Although other no-till planters are present in upland areas, they are not compatible with the optimal row spacing and seed density required for these species. Stakeholders reported that a specialized company has recently begun manufacturing appropriate equipment; however, the retail price remains prohibitively high for most local service providers, and the overall demand from seed producers is still insufficient to justify large-scale adoption.

4.1.1.4 Perceptions

Overall, producers reported a positive collaboration with their main contractor, SmartAgro, as well as reliable technical support from CARDEC and consistent additional income from cover crop seed production. Their interest in expanding operations, along with growing interest among neighbouring farmers to engage in seed production, further reinforces the perceived benefits of this activity. Notably, a majority of producers indicated that their primary motivation for cultivating CC was to improve soil fertility, with income generation cited as a secondary interest, despite the fact that earnings from seed production were comparable to those from their primary cash crop, maize. This suggests a dual value in cover crop production, serving both agronomic and economic purposes. Moreover, 14 out of 23 producers reported applying CC on their own fields to improve

the yield of cash crops, demonstrating their recognition of the agronomic value of the practice. These findings are consistent with Daryanto et al. (2018), who highlighted that cover cropping generally led to higher yields in main cash crops.

4.1.2 Application

Rice farmers operate in a landscape supported by several research and development organizations that provide technical assistance and subsidies. Between 2021 and 2024, over 300 hectares of CC were established in the area, according to monitoring reports from WAT4CAM – TA-AGRI. This figure likely underestimates actual adoption, as it does not include independent farmers operating outside the scope of programs. Findings on reasons to use CC, such as improvement of soil health, align with those of Marcon et al. (2024), who reported similar drivers for cover crop adoption in perennial systems in the uplands.

Vigna radiata is particularly appreciated due to its dual-purpose function, farmers can harvest grains once, providing additional income. Similar farmer interest was reported for *Vigna angularis* in Vietnam (Tuan et al., 2014). Likewise, Lienhard et al. (2014) emphasized the importance of creating market opportunities for cover crop materials in Laos. It should be noted, however, that *Vigna radiata* seeds in Kanghot are supplied by a separate group of producers not captured in this study. While *Crotalaria juncea* was one of the most commonly selected cover crops in FGDs, farmers reported a preference for mixing species of CC to improve resilience against climate variability and pest outbreaks.

Several agronomic constraints were highlighted. These include limited access to irrigation and increasing pest pressure from *Utetheisa lotrix*. Additionally, free-roaming cattle, though only briefly mentioned by farmers, were frequently cited as a barrier by key informants. This issue appears to vary with cropping cycles, as cattle typically roam during the dry season, posing greater risks for long-cycle crops than for short-cycle sown in April before the 1st rice cycle.

Although most of the discussion focused on agronomic challenges, farmers then emphasized the importance of maintaining low seed prices. This concern is particularly relevant as a key subsidy program is expected to end by 2025. While Nickens et al. (2023) reported that farmers in Battambang Province appreciated the fairness of seed prices, but the study did not specify actual cost values. In the FGDs, farmers expressed apprehension about paying the full market price of $50–$60/ha, currently covered in part by subsidies. This aligns with findings from Tyndall et al. (2021), who noted a similar seed cost of $50/ha in the U.S, although socio-economic capacities of farmers are very different.

The second most frequently recommended intervention was to improve access to irrigation. Discussions with key informants explored the possibility of opening existing canals; however, this was deemed unfeasible in the dry season due to water shortages in the dam. As a coping strategy, farmers proposed prioritizing short-cycle CC, which are more compatible with available water resources at the onset of the rainy season and less vulnerable to drought stress.

4.2 Market dynamics

This subsection examines the current status and emerging strategies related to the commercialization of cover crop seeds. It is organized into four thematic areas:

(i) Market status and value creation, (ii) Practice and result-based incentives, (iii) Market structure and seed quality, and (iv) Cost efficiency. The first area explores the overview of the seed market, while the following sections outline strategic responses to the identified challenges.

4.2.1 Market status and value creation

As of the field study, the seed producer network in Rattanak Mondoul was predominantly contracted by a single private company, SmartAgro, with one emerging player: the Battambang Union of Agricultural Cooperatives (BUAC) collaborating with the Agricultural Cooperative Kampong Prieng (ACKP). DALRM/CARDEC contracted a small share of seed producers, both in 2023 and 2024. Cover crop market segmentation revealed three major channels:

1. Export market (accounting for 70% of total output), primarily *Crotalaria ochroleuca*.
2. Domestic market (large-scale companies, commercial farms, NGOs, Programs and Projects).
3. Smallholder market (e.g., Kanghot irrigation scheme).

Value chain analysis showed that international and national markets represented the largest demand. Smallholder farmers remain a minor target, prompting ongoing debate over how best to stimulate market access to lower-demand segments.

Subsidies have been employed since 2021 to stimulate demand. While effective in short-term adoption, they are viewed by private companies and some development partners as undermining long-term sustainability. Echoing Rolston (2015), subsidized seed markets risk weakening the perceived value of CC, leading to reluctance among farmers to pay full market prices.

Focus group discussions confirmed this: although farmers cited agronomic barriers, they prioritized reducing seed prices. Similar insights were documented by Rolston (2015), who found price sensitivity to outweigh considerations of quality or suitability. Stakeholders recommend shifting from blanket subsidies to demand-creation strategies such as on-farm demonstrations and peer learning with influential “champion farmers” (Tyndall et al., 2021). Moreover, different strategies are explored to open and sustain the seed market. They were proposed by key informants and discussed in the following sub-sections.

4.2.2 Practice and result-based incentives

Evidence from more than 18,000 studies reviewed by Piñeiro et al. (2020) underscores that direct economic returns are the primary motivator for farmer adoption of sustainable practices. Key informants echoed this, noting that many farmers lack both

short-term financial incentives and understanding of the long-term value proposition of cover cropping.

To address this, the Dei Meas initiative (2023–2025) is exploring: (i) financial gaps related to agroecological transitions, (ii) methods to quantify environmental impact, and (iii) global financing models such as carbon credits, certification premiums, and payment for co-benefits (Dei Meas, 2025). A key informant underscored the importance of multiple options instead of focusing one solution.

In parallel, BUAC, with support from development partners, is planning to double seed production (+183 ha by 2025) in alignment with the expected implementation of the Regenagri rice certification. This certification mandates cover crop use and offers financial incentives. The approach aims to align production incentives with agroecological goals, by covering establishment costs of farmers, technical support and administrative expenses. Thereafter, specific equipment, such as no-till planter and professional seed cleaner plans to be acquired.

4.2.3 Market structure and seed quality

SmartAgro follows a contract farming model, overseeing post-harvest processes and seed cleaning for international markets, similar to models described by Hare (2014). Meanwhile, BUAC is emerging as a potential major actor but lacks the infrastructure, technical capacity, and experience to ensure quality control at scale. This raises a key question: *Should agricultural cooperatives become large-scale seed contractors?* On the one hand, BUAC is among the main aggregator covering 10 ACs, benefiting from proximity to farmers, and potentially able to increase affordability trough certifications, which is likely to increase adoption. On the other hand, ACs tend to have a weak internal system, potential quality risks and misalignment with their rice-focused mission. One proposed solution from a KI is a "franchise model", wherein cooperatives produce seeds under private sector supervision. The private company would ensure varietal purity, quality control and marketing while the cooperative handles contracting, logistics, and farmer engagement. This division of labor could optimize market efficiency, transfer capacities to longstanding actors and reduce dependence on donors' funding. At same time, the development of Quality Declared Seeds (QDS) by the Department of Crop Seeds, under the General Directorate of Agriculture will support the availability of quality seeds.

4.2.4 Cost efficiency

Tyndall et al. (2021) recognized seed cost as the primary barrier to adoption in the US. Although a Cambodian study present contradictory results (Nickens et al., 2023), the topic was frequently mentioned by stakeholders. Several strategies to improve cost-efficiency were recommended:

- Economies of scale: Large-scale, mechanized production could reduce costs per kilogram. However, initial investment remains high, and private-sector investment is seen as risky without co-financing (Martins et al., 2021). In addition, and even if the seed producers have relatively large area of land, the seed contractor needs to deal with a large number of seed producers and thus a diversity of practices and conditions to be 'standardized' to match with seed quality system.
- Imports: A development partner is investigating sourcing seeds from India at ~$1/kg. While potentially cost-effective, very high concerns subsist over quality, impact on local markets and loss of sovereignty.
- Competition stimulation: Expanding the number of national seed suppliers (including ACs) could improve quality and pricing through competitive pressure. Grants, licenses and technical assistance for new entrants have been suggested.

Some stakeholders proposed a dual-market model: exporting high-quality seeds while making lower-grade seeds available to domestic farmers at affordable rates. However, any decline in quality could jeopardize farmers' trust, particularly if there is inconsistency in seed performance and weed seed contamination.

4.3 Enabling environment

This section explores the institutional, strategic, and policy dimensions supporting the cover crop seed sector assessing: (i) Stakeholder Landscape, (ii) Strategic Planning, (iii) Policy and Regulation, and (iv) Threats and Opportunities. The first area explores the overview, while the following sections outline strategic responses from key informants to the identified challenges.

4.3.1 Stakeholder landscape

The results reveal a diverse and multilayered landscape composed of both direct value chain actors and institutional stakeholders. During key informant interviews (KIIs), stakeholders were asked to self-assess their level of interest and influence in the sector. The responses suggest a dense ecosystem of highly engaged and influential actors. This could be attributed to two factors:

i. High intervention density, as multiple respondents acknowledged the growing number of development activities in the sector;
ii. Methodological bias, as purposive sampling by field experts may have skewed the selection towards more active stakeholders.

While Biradar and Nagar (2018) emphasized the role of middlemen in value chain development, the present study highlights the dominant position of development partners. Although several middlemen were interviewed, a better understanding of their network is required for scaling the practice.

4.3.2 Strategic planning

In response to overlapping mandates and fragmented efforts, development actors have emphasized the need for improved inter-organizational coordination. A key issue that emerged during the multi-stakeholder event was the need to establish a harmonized

seed pricing strategy. Current subsidy schemes have generated tensions between cooperatives, private companies, and NGOs, due to differing objectives and interpretations of market fairness. Better coordination could also help avoid duplication of effort and enhance knowledge sharing across programs. Development partners stressed the importance of maintaining a shared strategic vision and a "big picture" perspective among collaborating actors.

A Platform representative highlighted the need to plan for the progressive withdrawal of development partners. As illustrated by the findings, international organizations currently play a central operational and financial role. Therefore, an exit strategy is deemed essential. One proposal is to strengthen public–private partnerships, such as linking agricultural cooperatives with rice millers with strong negotiation leverage and access to rice farmer networks. Through practice- and result-based incentives, additional income streams from certified rice paddy production could be leveraged to fund technical support, compliance auditing, and administrative systems. Over time, private sector actors could assume a more central role in sustaining and expanding operations.

4.3.3 Policy and regulation

Despite growing adoption, CC remain weakly embedded in national agricultural policy. A public-sector respondent emphasized that CC are not explicitly mentioned in major strategic frameworks, despite the inclusion of sustainable agriculture and agroecology in national policies (Royal Government of Cambodia, 2022). To scale adoption, respondents recommended the introduction of quantifiable national targets, such as setting specific hectare goals under agroecological or cover crop practices (e.g., 500,000 ha).

From a regulatory standpoint, 2024 marked an important milestone with the registration of 15 cover crop species at the Department of Crop Seeds (ASSET, 2025). This makes them legally eligible for certified seed production. Moving forward, licensed contractors should be required to adhere to varietal and quality standards (Qualified Declared System) to ensure the performance of the sector. NDC 3.0.

4.3.4 Threats and opportunities

Key informants identified several external factors that may enable or constrain the development of the cover crop seed market in Cambodia. One prominent threat is the introduction of a third annual rice cycle, enabled by expanded irrigation systems and improved input use (Diepart and Thuon, 2022). Stakeholders emphasized that this practice leaves no temporal window for cover crop integration, directly competing with the agronomic calendar of seed production but also for any holistic approach aiming at improving the resilience of the rice cropping and farming systems under an irrigated lens. Concerns were also raised about Cambodia's competitiveness in the international seed market. High energy and production costs, combined with tariff uncertainties, particularly with U.S. trade policies, could hinder export prospects. Conversely, international market pressures may present opportunities. A public-sector respondent noted that stricter European Union import regulations are pushing Cambodian rice farmers toward sustainable production models. This compliance pressure may serve as a catalyst for mainstreaming CC as part of broader sustainable certification systems.

5 Conclusion

This study sheds light on the value chain of cover crop (CC) seed in Battambang Province, Northwest Cambodia. It provides empirical evidence on the costs of production, income, and net profit associated with *Crotalaria juncea* and *Crotalaria ochroleuca* seed production, with direct comparison to maize. By quantifying economic returns and capturing producer perceptions, the study offers critical insights into the financial viability of CC seed production as a livelihood strategy for smallholder farmers.

Our findings confirm that cover crop seed production is profitable and positively perceived by producers. Seed producers reported satisfaction with income levels and expressed willingness to scale up production if appropriate contracts and support are provided. The recent expansion of seed-producing areas in Battambang Province underscores the economic potential of this emerging sector. Nevertheless, this expansion is challenged by the lack of appropriate machinery.

The adoption of CC under irrigated rice systems is still limited by agronomic challenges, such as water management and pest control, and by the lack of short-term economic returns. Despite these constraints, demand for cover crop seeds is growing, as evidenced by farmers in other regions being willing to pay the full price, which highlights the perceived value of CC. The introduction of double use species, which can be harvested for grains, was requested by farmers.

While the structure and dynamics of cover crop seed markets have been examined in countries such as the United States and India, there is little research on these topics in tropical countries and in Southeast Asia. The limited literature on CC seed markets and value chains in this region highlights the need for further research to understand factors limiting uptake.

This research contributes original empirical data and valuable market insights. However, a more precise understanding of the market potential in the cover crop sector would support entrepreneurs considering investment. This must be strengthened by the enforcement of a seed quality control system. In addition, there remains a gap in the understanding of networks of middlemen supplying CC seeds, and improving it, the capacity and the knowledge of this group is essential to deliver high-quality seeds at affordable prices. We encourage researchers to engage further on these topics.

The study also demonstrates that the enabling environment is complex but influential. Numerous actors have launched initiatives to promote CC, and among the most promising strategies are short-term economic incentives and practice- or result-based rewards, such as those piloted by the Dei Meas initiative. Better coordination among stakeholders will be crucial to align strategies and increase effectiveness. In the long run, a transition towards private sector-led

businesses should be planned to ensure the eventual exit of development organizations and projects.

By documenting economic outcomes, farmer perceptions, adoption constraints, and the roles and strategies of stakeholders, this research supports the scaling of cover crops and therefore agroecological practices in Cambodia. It brings together feedback and recommendations from producers, practitioners, researchers, and policymakers, offering a comprehensive, multi-perspective understanding of pathways to advance agroecology.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

QàH: Writing – review & editing, Writing – original draft. AG: Writing – review & editing. VS: Project administration, Supervision, Writing – review & editing. SK: Writing – review & editing. SS: Investigation, Project administration, Supervision, Writing – review & editing. VL: Investigation, Project administration, Supervision, Writing – review & editing. SR: Funding acquisition, Project administration, Resources, Writing – review & editing. FT: Writing – review & editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. To reformulate language.

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