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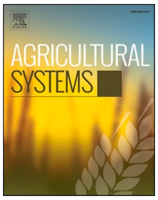

Economic outcomes from adopting cereal-legume intercropping practices in Sweden

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HIGHLIGHTS

- This study quantifies the consequences of intercropping adoption on farm economic outcomes for resilience.
- The economic outcomes and the resilience capacity of the intercropping systems are context specific.
- The high price of monocropping products and the low price of N fertilizer hinder intercropping systems' adaptability.
- Policies targeting markets, value chains, knowledge diffusion, innovations, standards and regulations are needed.

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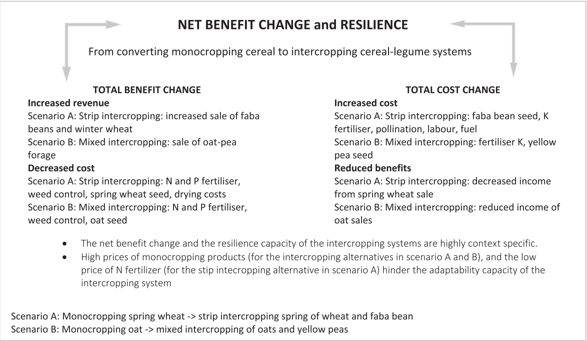
GRAPHICAL ABSTRACT



NET BENEFIT CHANGE and RESILIENCE

From converting monocropping cereal to intercropping cereal-legume systems

TOTAL BENEFIT CHANGE

Increased revenue
Scenario A: Strip intercropping: increased sale of faba beans and winter wheat
Scenario B: Mixed intercropping: sale of oat-pea forage

Decreased cost
Scenario A: Strip intercropping: N and P fertiliser, weed control, spring wheat seed, drying costs
Scenario B: Mixed intercropping: N and P fertiliser, weed control, oat seed

TOTAL COST CHANGE

Increased cost
Scenario A: Strip intercropping: faba bean seed, K fertiliser, pollination, labour, fuel
Scenario B: Mixed intercropping: fertiliser K, yellow pea seed

Reduced benefits
Scenario A: Strip intercropping: decreased income from spring wheat sale
Scenario B: Mixed intercropping: reduced income of oat sales

- The net benefit change and the resilience capacity of the intercropping systems are highly context specific.
- High prices of monocropping products (for the intercropping alternatives in scenario A and B), and the low price of N fertilizer (for the stip intecropping alternative in scenario A) hinder the adaptability capacity of the intercropping system

Scenario A: Monocropping spring wheat -> strip intercropping spring of wheat and faba bean
Scenario B: Monocropping oat -> mixed intercropping of oats and yellow peas

ABSTRACT

CONTEXT: The need for sustainable and resilient farming practices is clearly communicated by the scholars and the European Union policy strategies. The low interest in adopting the practice due to the uncertainties and the variability in the economic outcomes across various intercropping types calls for research attention. In this respect, research is needed to identifying specific intercropping practices that lead to improved farm-level economic outcomes and resilience.

OBJECTIVES: This study investigates consequences of intercropping adoption on the farm economic outcomes, in the context of achieving economic resilience. Specific objectives are to assess the effect of i) adopting intercropping on the economic outcomes; ii) production adjustments on the economic resilience of the intercropping practices, both in comparison to conventional mono-cropped agriculture.

METHODS: The analysis is conducted by using a stochastic partial budgeting model. We use Swedish agriculture as an empirical basis for our study and model two baseline cereal monocropping scenarios and two corresponding alternative (strip and mixed) cereal-legume intercropping scenarios. This is to examine net changes and risk characteristics resulting from the adaptation from monocropping to intercropping production practices.

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Estimates of net changes and the respective risk characteristics are integrated in an economic resilience assessment for the intercropping practices.

RESULTS: Results reveal that the net economic benefit change from adopting differs across the intercropping alternatives. Prices of the monocropped and the intercropped products of both intercropping alternatives and the use of N fertilizer for the strip intercropping alternative are the most influential factors in determining the adaptability capacity.

CONTRIBUTION: This study provides a novel approach that contributes to the literature via quantifying economic resilience capacities of hypothetical technology adoption. The paper presents unique results on the economic resilience of adopting cereal-legume intercropping practices in a Nordic context, giving agriculture in Nordic regions shares common challenges such as short growing season and cold temperature. The results offer valuable insights for extension services in guiding farmers to choose appropriate intercropping practices based on the production possibilities and market needs. Policy implications targeting the adoption of cereal-legume intercropping adoption are discussed.

1. Introduction

The monocropping systems in which only one crop species is grown at one time on a specific field (Power and Follett, 1987) represent the predominant method for conventionally grown crops in the world (FAO, 2022). Technology changes enabling easy plant management, infrastructure, marketing, and subsidies supporting monocropping systems has reinforced this trend (Jensen et al., 2020; Lin, 2011; Power and Follett, 1987). Despite the largest contribution to the world's food production, monocropping is among the most debated production systems in modern agriculture due to their notable negative impact on soil, water quality, eutrophication, and climate change (Brooker et al., 2015). Consequently, these systems undermine the continuity of the farming activities and the delivery of food system outcomes including heathy and stable food supply, farm incomes, and secured biodiversity (Brooker et al., 2015). The adverse impacts of monocropping on the environment and farming activities urges for application of alternative systems that integrate ecological and economic benefits for sustainable and resilient agriculture (Martin-Guay et al., 2018; Rosa-Schleich et al., 2019).

Intercropping is the practice of mixing two or more crop species in space and at least some of their growing periods (Wang et al., 2023). The practice is gaining increased attention both in the European research (Brannan et al., 2023; Jensen et al., 2020) and the European Union (EU) policy strategies (European Commission, 2022) for enhancing the sustainability and the resilience of the current food system. Intercropping adoption increases crop diversity, which enables the complementary use of resources such as soil nutrients, water, and sunlight (Francis and Francis, 1986; Huss et al., 2022). Moreover, intercropping is widely recognized as a potentially cost-effective method for achieving plausible environmental and climate resilience via lower chemical use (Huss et al., 2022; Lin, 2011; Martin-Guay et al., 2018; McAlvay et al., 2022). However, compared to worldwide figures, the adoption of intercropping in Europe is low. For instance, cereal-legume mixtures, which are the most common intercropped system, covered only 1.5% of arable land in Europe in 2014, compared to 15% coverage of arable land globally (Watson et al., 2017). In Sweden, the empirical focus of this study, the adoption of intercropping is limited and species-poor, primarily involving grassland-leys mixtures with farmers' hesitation to intercrop commercial crops (Jensen et al., 2020). As elsewhere in Europe, cereal-legume mixtures are grown on only 1.7% of the total arable land in Sweden (SCB, 2020).

The supply of potential environmental and climate benefits together with economic viability remains key prerequisites for building sustainable and resilient farming (Meuwissen et al., 2020; Meuwissen et al., 2022). Despite this, scientific knowledge about changes in farms' economic outcomes due to intercropping adoption in EU is limited (Bonke et al., 2021; Huss et al., 2022). Moreover, there is a lack of studies that assess economic resilience resulting from the inclusion and exclusion of new systems including intercropping practices (van der Lee et al., 2022; Zabala et al., 2023; Alcon et al., 2020). To report economic resilience, the existing literature uses some common indicators including i) capital accumulation (Serfilippi and Ramnath, 2018; Volkov et al., 2021; Schipper and Langston, 2015), ii) profitability (Slijper et al., 2022, Volkov et al., 2021, Schipper and Langston, 2015), income (Serfilippi and Ramnath, 2018; Volkov et al., 2021), and income stability (Benoit et al., 2020). However, while a commonly proposed approach is through the lens of multiple resilience capacity dimensions, such approach is applied by few empirical studies (Benoit et al., 2020; Slijper et al., 2022). Using this approach, Benoit et al., (2020) focuses on sheep farms in Ireland and France while Slijper et al., (2022) considers various farm types across nine European countries. While important from a methodological point of view, these studies do not provide empirical evidence for intercropping systems, nor for changes in farm economic performance due to adaptation of a new practice.

The aims of this paper are to assess the effects of i) adopting cereal-legume intercropping on economic outcomes and, ii) production adjustments on the economic resilience of the intercropping system. The study contributes to the research gaps on economic resilience outcomes of the intercropping systems. This knowledge improves the understanding on the suitability of intercropping in combating global food insecurity and the sustainability of intercropping, as a plausible alternative to monocropping. The present study has important contributions to the existing literature. For the first time, it explores the consequences of adopting intercropping practices on farms' economic outcomes, in the context of achieving economic resilience. We assess economic outcomes via net benefit changes and risk characteristics resulting from the production adaptation from mono- to intercropping. We define economic resilience as a capacity of the alternative system to adapt the desired production practices via adjustments in the products and the production inputs, while securing its profitability (Meuwissen et al., 2019; van der Lee et al., 2022). Risk characteristics refer to probabilities of changes in the net benefit, probability of severe drop in the net benefit and net benefit sensitivity to changes in crop prices and adaptation in inputs (Slijper et al., 2022).

The analysis is conducted by using a partial budgeting model with stochastic elements (Alvåsen et al., 2017; Jerlström et al., 2022; Owusu-Sekyere et al., 2023). We use Swedish agriculture as an empirical basis for our study and model two baseline cereal monocropping scenarios and two alternative cereal-legume intercropping scenarios (one for each base scenario). In the model, net benefit changes and risk characteristics of the baseline scenarios are compared with the respective intercropping alternatives, but not between the intercropping alternatives. This is because the two intercropping alternatives are not comparable, and our focus is changes in economic outcomes when switching from mono- to intercropping systems. Estimates of net benefit changes and the respective risk characteristics including net benefit, product prices and inputs costs revealed in the analysis are further integrated in an economic resilience assessment (Benoit et al., 2020; Slijper et al., 2022) for the intercropping systems. When incorporating the risk perspective, a system is perceived resilient if the risk of achieving the desired functionality is sufficiently low (Logan et al., 2022). Resilience theory emphasizes reorganisation change, uncertainty, and the capacity of systems to persist, adapt, and transform while retaining the functionality (Meuwissen et al., 2019). Following the study setting and assuming adaptation of intercropping systems, we focus on the resilience capacity of the system to adapt the production and the use of the resources i.e., adaptability, while securing its gross margin i.e., robustness (Darnhofer, 2014; Meuwissen et al., 2019; Serfilippi and Ramnath, 2018).

Intercropping can be implemented in several forms and all of them are likely to result in heterogeneous economic outcomes. Hence, finding appropriate intercropping systems that sustain and improve the economic outcomes is among the major challenges (Lin, 2011). Barriers that hinder farmers from achieving high economic outcomes are attributed to: i) small gross margins due to low yields and market price comparing to monocropping systems (Brannan et al., 2023); ii) need for adaptations in the resource use (Huss et al., 2022); complex crop management (Himanen et al., 2016; Huss et al., 2022); and iii) low subsidies for diversified farming systems (Jensen et al., 2020; Lin, 2011). Besides, experimental studies show that the economic outcomes of intercropping practices are context specific (Jensen et al., 2020; Lagerquist et al., 2024; Wang et al., 2023). These outcomes vary across the composition of the crop mixture (Lin, 2011; Wang et al., 2023), the type of intercropping system like mixed, strip, row, and relay (Glaze-Corcoran et al., 2020; Wang et al., 2023), and the inclusion/exclusion of a system such as monocropping versus intercropping (Glaze-Corcoran et al., 2020). Outcomes also have spatial context (Lin, 2011; Weih et al., 2021), differing between low-yielding and high-yielding locations (Weih et al., 2021). More specifically, a meta-study by Huss et al. (2022) indicates that row intercropping of legume and cash crops have no impact on per-unit yield while non-legume intercrops decreased yield. In mixed cereal-legume intercropping, yields are lower than cereal monocropping, but higher than legume monocropping (Glaze-Corcoran et al., 2020). That trade-off is economically desirable since it often results in higher forage quality (Glaze-Corcoran et al., 2020). Context-dependent outcomes highlight the need for more context-specific studies on diversified cropping (Brannan et al., 2023). While capturing contextual factors is challenging, it is crucial to acknowledge the economic implications that arise from various forms of intercropping if the method is to be considered for broader use (Himanen et al., 2016).

The paper is structured as follows. Section 2 presents the methodology and Section 3 provides the results. Discussion is presented in Section 4 and followed by conclusions in Section 5.

2. Methodology

2.1. Scenarios selection

Intercropping can be implemented in a variety of forms, which allow farmers to choose an approach with desirable economic outcomes compared to monocropping (Glaze-Corcoran et al., 2020). Subsequently, this strengthens the resilience of their farms (Lin, 2011). Four production strategies organized in two separate scenarios were selected since they are appropriate for the Swedish context. The selected scenarios include spring wheat and spring faba bean (grown for food), oats and pea (grown for feed); these crops are already commonly grown in Sweden, although spring wheat currently is the less common wheat type in Sweden compared to winter wheat (Swedish Board of Agriculture, 2023). Each scenario consists of one cereal baseline and a respective cereals-legume intercropping alternative. In both scenarios, the unit of analysis was a farm field (Glaze-Corcoran et al., 2020), with a size of 3 ha, which can be easily extended to other plot sizes. For the intercropping alternatives, we assumed adaptation from monocropping to intercropping system, considering changes in the: i) intercropping system encompassing both strip intercropping and mixed intercropping, ii) composition of the crop mixture, e.g., cereal-legume, and iii) the end-use of the final products, whether for human or livestock use. Scenarios were chosen based on expert assessments (Ahmed et al., 2020; Alvåsen et al., 2017) and enable the examination of the effects of multiple intercropping solutions that are technically viable in the Swedish agriculture. The selected crop composition, intercropping system, and their respective end-use of the final products are well aligned with the common practice in Sweden.

The scenarios composition is as follows. In the first scenario, we assumed a baseline monocropping system of spring wheat, which is grown with a three-year rotation. Details on variables included in the baseline scenarios are given in Table 1. The alternative to this baseline scenario is a strip intercropping system between spring wheat and faba bean, assuming planning in wide strips over multiple rows, arranged spatially. Strip cropping is the planting of crops in parallel strips, each comprised of multiple rows (Glaze-Corcoran et al., 2020). We divided the considered 3 ha into 12 equal strips, each 417 m × 6 m (in length and width). The strip size corresponds to the common production management practice, such as working width of sowing and harvesting machines, does not require special equipment and allows for separate harvest making expensive seed separation unnecessary. The strip size ratio of the system is 1 × 1, where spring wheat is planted in 50 rows, followed by 24 rows of faba bean. The spring wheat is sown at a depth of 5 cm, with a row distance of 0.12 m, plant spacing of 0.03 m, and a sowing density of 550 germinable seeds/m^2. The faba bean is sown on a depth of 5–6 cm, in a row distance of 0.25 m, plant spacing of 0.05 m, and a sowing density of 50 germinable seeds/m^2. The sowing parameters are according to the recommended practice in Sweden. The production is used for human consumption. Detailed presentation on other characteristics of the wheat baseline scenarios and the strip intercropping system are provided in heading 2.3.1 and in Box A1 in the appendix.

In the second scenario, we assumed a baseline monocropping system of oat, which is grown with a three-year rotation. Details on variables included in the baseline scenarios are given in Table 2. Alternative option for the second baseline scenario is a mixed intercropping system, where mixtures of oats and yellow peas are grown simultaneously, in immediate proximity without spatial arrangement (Glaze-Corcoran et al., 2020) with a ratio of 70:30. The selected mixed crops are seeded and harvested together, and the final product is for forage production. Oat-pea mixtures for forage production are not uncommon and are commercially available in Sweden. (Swedish Board of Agriculture, 2007; Svenska foder, 2024). Detailed presentation on other characteristics of the oat baseline scenario and the mixed intercropping alternatives are provided in heading 2.3.1 and in Box A2 in the appendix.

2.2. Simulating economic outcomes

We simulated the consequences on the economic outcomes by going from the base line scenarios to the alternative scenarios using a partial budgeting model with stochastic elements. For the agricultural sector, the method has large application for estimating the economic consequences of implementing new practices or technologies, e.g. estimating the economic effects of animal welfare measures in dairy research (Ahmed et al., 2020; Alvåsen et al., 2017; Jerlström et al., 2022; Owusu-Sekyere et al., 2023), plant protection (Pemsl et al., 2004), row spacing in corn and soybean production (Lambert and Lowenberg-DeBoer, 2003). The benefit and cost changes for the two alternative intercropping strategies were analysed using the @Risk (Palisade, Ithaca, NY) application, which is an add-on application in Microsoft Excel.

Partial budgeting, building on data elicited from e.g. the literature and experts, is useful for analysing changes in the operations of the farm, especially when these operations result in incremental changes (Dhoubhadel and Stockton, 2010), and in situations where there does not exist sufficient data for econometric impact analysis. The approach is forward-oriented, investigating the economic consequences of a specific ‘what if’ question. Since in our case some data are not readily available and we have to rely on expert opinion, it is therefore imperative to use method that provide opportunity to use these unavailable data to evaluate changes in farming practices with little distortions and

Table 1
Descriptive statistics of variables used in the partial budget model and the resilience assessment for strip intercropping system.

Variables	Unit	Data	Source	Type
Land area of growing spring wheat	Ha	2.34	Authors work	Deterministic
Land area of growing faba bean	Ha	0.54	Authors work	Deterministic
Average yield of faba bean	kg/ha	2714	SBA 2023	Deterministic
Average yield of spring wheat in base scenario	kg/ha	4054	SBA 2023	Deterministic
Decreased yield of spring wheat in alternative scenario	%	36	Wang et al. (2023)	Deterministic
Potential yield of winter wheat in alternative scenario	kg/ha	7700	SBA 2023	Deterministic
Increased yield of winter wheat due to pre crop effect of faba bean	kg/ha	700	SBA 2023	Deterministic
Average seed quantity of spring wheat	kg/ha	235	CAB Västra Götaland 2023	Deterministic
Average seed quantity of faba bean	kg/ha	270	Agriwise 2017	Deterministic
Fertilizer N use for spring wheat in base scenario	kg/ha	125	CAB Västra Götaland 2023	Deterministic
Decreased fertilizer use rate in alternative scenario	%	50	Expert advice	Deterministic
Decreased fertilizer N use next year	kg/ha	15	SBA 2023	Deterministic
Decreased fertilizer P use	kg/ha	3	Expert advice	Deterministic
Decreased fertilizer Mn use	l/ha	2	Expert advice	Deterministic
Increased fertilizer K use	kg/ha	5	Expert advice	Deterministic
Working hours in baseline	hours/ha	9	Agriwise 2017	Deterministic
Increased working hour rate	%	70	Midega et al. (2014)	Deterministic
Average fuel consumption	l/ha	100	Agriwise 2017	Deterministic
Increased fuel consumption rate	%	10	Expert advice	Deterministic
Price of faba bean	SEK/kg	4	Svenskafoder	Stochastic
Price of winter wheat	SEK/kg	3	Agriwise 2023	Stochastic
Price of spring wheat	SEK/kg	4	Agriwise 2023	Stochastic
Price of spring wheat seed	SEK/kg	6	Agriwise 2023	Stochastic
Price of faba bean seed	SEK/kg	7	Agriwise 2017	Stochastic
Weed control cost for spring wheat	SEK/ha	570	CAB Västra Götaland 2023	Stochastic
Weed control cost for faba bean	SEK/ha	349	CAB Västra Götaland 2023	Stochastic
Drying cost for spring wheat	SEK/kg	0.1	CAB Västra Götaland 2023	Deterministic
Drying cost for faba bean	SEK/kg	0.2	CAB Vostro Götaland 2023	Deterministic
Price of fertilizer N	SEK/kg	10	SBA 2023	Stochastic
Price of fertilizer P	SEK/kg	22	SBA 2023	Deterministic
Price of fertilizer Mn	SEK/l	38	CAB Västra Götaland 2023	Deterministic
Price of fertilizer K	SEK/kg	10	SBA 2023	Deterministic
Price of diesel	SEK/l	15	Agriwise 2023	Stochastic
Pollination cost for faba bean	SEK/ha	49	CAB Västra Götaland 2023	Deterministic
Labor cost in crop cultivation	SEK/ha	241	Agriwise 2023	Stochastic
Discount rate	%	3	Authors work	Deterministic
PPI of cereals (except rice), leguminous crops and oil seeds in 2022	2020 = 1,002,020 = 100	194	SCB 2023	Deterministic
PPI of products of agriculture in 2016		86		
PPI of products of agriculture in 2022		134		
PPI of fertilizers and nitrogen compounds in 2022		149		
PPI of pesticides and other agrochemical products in 2022		116		
PPI of agricultural and forestry machinery in 2022		112		

Note: CAB – County Administrative Board; SBA - Swedish Board of Agriculture; SCB – Statistics Sweden.

Table 2
Descriptive statistics of variables used in the partial budget model and the resilience assessment for mixed intercropping system.

Variables	Unit	Data	Source	Type
Percentage of oat	%	70	–	Deterministic
Percentage of yellow pea	%	30	–	Deterministic
Average yield of oat in base scenario	kg/ha	4140	SCB 2022	Deterministic
Average yield of yellow pea	kg/ha	3500	SCB 2022	Deterministic
Increased yield of oat+pea mixture in intercropping	%	1	Expert advice	Deterministic
Decreased fertilizer N use rate	%	65	Expert advice	Deterministic
Decreased fertilizer P use	kg/ha	1.5	SBA 2023	Deterministic
Increased fertilizer K use	kg/ha	3	Expert advice	Deterministic
Average seed quantity of oat	kg/ha	205	Expert advice	Deterministic
Average seed quantity of yellow pea	kg/ha	300	Agriwise 2017	Deterministic
Average yield of oat in current system	kg/ha	4140	SCB 2022	Deterministic
Price of fertilizer N	SEK/kg	10	SBA 2023	Stochastic
Price of fertilizer P	SEK/kg	22	SBA 2023	Deterministic
Price of fertilizer K	SEK/kg	10	SBA 2023	Deterministic
Price of yellow pea and oat mixed forage	SEK/kg	3	Authors work	Stochastic
Price of oat fodder	SEK/kg	3	Agriwise 2023	Stochastic
Price of oat seed	SEK/kg	5	Agriwise 2023	Stochastic
Price of yellow pea seed	SEK/kg	7	Agriwise 2017	Stochastic
Weed control cost for oat in base scenario	SEK/ha	43	CAB Västra Götaland 2023	Stochastic
Herbicide cost for oat in base scenario	SEK/ha	171	CAB Västra Götaland 2023	Stochastic

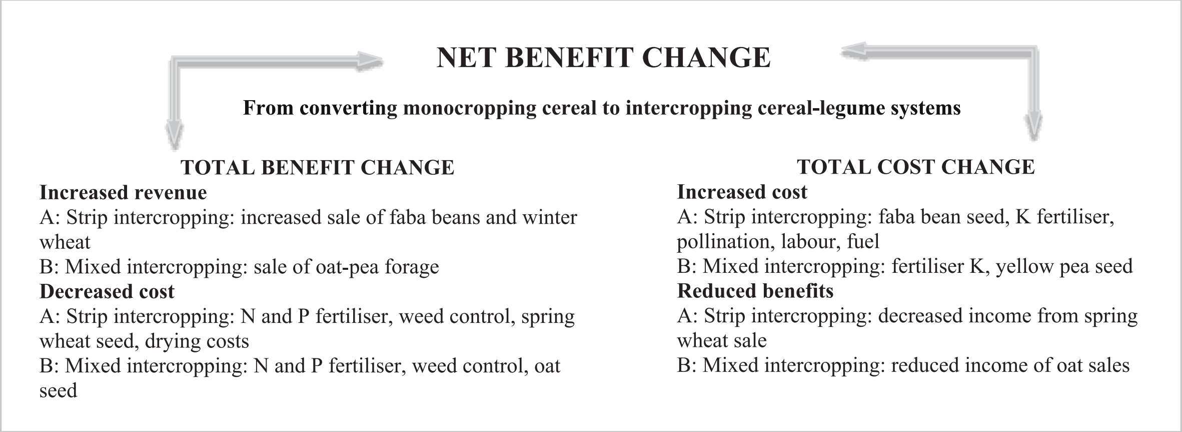
Note: CAB – County Administrative Board; SBA - Swedish Board of Agriculture; SCB – Statistics Sweden.

higher level of precision. Stochastic partial budget provides such advantages.

2.2.1. Partial budget technique for adopting intercropping systems

Fig. 1 shows the expected benefits and costs for the intercropping systems including strip and mixed intercropping. Detailed breakdown analysis for benefit and cost changes are listed in Box A1 in appendix A.

Regarding the adoption of strip intercropping system, the increased benefits result from increased revenue and decreased costs. Increased



NET BENEFIT CHANGE

From converting monocropping cereal to intercropping cereal-legume systems

TOTAL BENEFIT CHANGE

Increased revenue

A: Strip intercropping: increased sale of faba beans and winter wheat

B: Mixed intercropping: sale of oat-pea forage

Decreased cost

A: Strip intercropping: N and P fertiliser, weed control, spring wheat seed, drying costs

B: Mixed intercropping: N and P fertiliser, weed control, oat seed

TOTAL COST CHANGE

Increased cost

A: Strip intercropping: faba bean seed, K fertiliser, pollination, labour, fuel

B: Mixed intercropping: fertiliser K, yellow pea seed

Reduced benefits

A: Strip intercropping: decreased income from spring wheat sale

B: Mixed intercropping: reduced income of oat sales

Fig. 1. Economic outcome of intercropping systems.
Note: A denotes strip-intercropping and B denotes mixed-intercropping system.

revenue stems from both the increased sale of faba beans and the projected increase in winter wheat yield for the next year, due to the nutrient offtake from the faba bean, which is called “pre-crop effect”. Decreased costs are expected due to reduced N, P and Mn fertilizer costs and weed control usage, the decreased cost of spring wheat seed (attributable to faba bean inclusion) and from reduced drying costs for faba beans. Increased costs result from additional expenses and reduced benefits. Additional costs include increased faba bean seed costs, higher K fertilizer costs, increased pollination expenses, increased labor costs (including sowing, crop management, and harvesting), and expected increases in fuel consumption. Reduced benefits are anticipated due to decreased income from decreased spring wheat sales. Descriptive statistics of variables used in the partial budget model of the strip intercropping systems, along with the unit of measurement, data sources, expected benefits, costs, and the distribution used in the analysis are presented in Table 1.

For adopting a mixed intercropping system, the increased benefits result from the increased revenue related with the increased pea and oat forage sales. As in the first alternative system, the decrease in costs is expected from fertilizer (N and P) and herbicides costs but also from the oat seed cost due to decreased share of oat in the total land use. On the other hand, costs increase for fertilizer K, and yellow pea seed. Reduced benefit is expected from reduced income of oat sales. Descriptive statistics of variables used in the partial budget model of the mixed intercropping systems, along with the unit of measurement, data sources, expected benefits, costs, and the distribution used in the analysis are presented in Table 2.

Making the partial budget analysis stochastic means attaching probabilities of occurrence to the possible values of the key factors in a deterministic budget, thereby generating the probability distribution of budget outcomes (Hardaker, Huirne and Anderson, 1997; Ahmed et al., 2020). Uncertainty is the main reason for the selection of stochastic parameters. We consider variables that cannot explicitly provide enough information for the realisation of net benefit. These variables normally stem from uncertain cost and/or price volatility. Therefore, these uncertain and volatile variables can then be mapped to create a cumulative distribution function (CDF) which enable us to create probabilities for the deterministic values. To this end, we used Monte Carlo simulations and the Tornado diagram to illustrate the sensitivity of the analysis (Palisade, 2024). A stepwise multiple regression process is applied, and the results highlights the relative importance of each stochastic parameter on the net benefit by ranking them in order of their influence, from the most to the least influential. The probability distribution of the economic outcomes and the sensitivity of the stochastic parameters on the economic outcomes are used as means for the resilience assessment. Table B1 and Table B2 in appendix B present the summary statistics of stochastic parameters considered in the strip- and the mixed intercropping system. Standard deviation depicts the stochastic parameters are stable. Both the skewness value (0) and the kurtosis of the input variables (3) indicate that data is normally distributed.

2.3. Integrating the risk parameters from the stochastic partial budget analysis into a resilience assessment

Resilience theory emphasizes reorganisation change, uncertainty, and the capacity of systems to persist, adapt, and transform while retaining the functionality, following an event (Meuwissen et al., 2019). Risk characteristics are an integrated part and could be a means toward resilience analysis and vice versa (Aven, 2019). Here, we focus on resilience capacity (Darnhofer, 2014; Meuwissen et al., 2019; Serfilippi and Ramnath, 2018) and its adaptability and robustness dimensions. Resilience capacities are mutually dependent (Slijper et al., 2022), thus a successful adaptation implies that resilient system have a capacity to adapt the use of their resources (adaptability), while still being robust to retain its gross margin, and deliver the farms functions (robustness) (Meuwissen et al., 2019; van der Lee et al., 2022).

Building on the indicator-based framework by Slijper et al. (2022), we interpret the economic resilience of intercropping systems with several risk related indicators reflecting 1) robustness and 2) adaptability dimensions.

1) Robustness is related to the short-term stability and assessed via i) resistance - change in the net benefit, where a lower decrease or eventual increase in the net benefit implies higher resistance and robustness, ii) shock - as a probability for a severe drop (at least 30%) in the net benefit (Slijper et al., 2022), implying the system is not robustness. The observed variation relates to the estimated net benefit change for the respective monocropping system. Probabilities of changes in the net benefit are derived from the stochastic budget analysis.
2) The adaptation of a system is reflected through adjustments in its crop- and input composition (Slijper et al., 2022). In our study, adaptability observes the sensitivity of the impact of selected stochastic parameters (see Table 1 and Table 2) all considered to have key role for the net change. We assess the adaptability via i) crop-diversity, analysing the effects of changing from mono- to intercropped crops, including spring wheat, oat, faba bean and yellow pea, and ii) farm intensity, analysing effects from the adaptation in the inputs: fertilizers-, crop protection-, energy- and labour costs. While Slijper et al. (2022) focuses on crop composition, our focus is the crop prices. Coefficients of their effects are derived with the Tornado analysis. The most resilient systems are those that utilize

low level of inputs (Benoit et al., 2020; Slijper et al., 2022). Greater adaptability of the alternative systems is achieved if the net benefit is less sensitive to the changes in the corresponding stochastic parameters if robustness is ensured (Logan et al., 2022). Descriptive statistics of the stochastic parameters along with the unit of measurement, data source and the distribution are presented in Table 1 (strip intercropping system) and Table 2 (mixed intercropping system).

3. Results

3.1. Economic effects of adopting strip cropping system

The deterministic results of the partial budget (Table 3) show that the main factors influencing the net benefit change incurred by adopting a strip-intercropping system. The left part of Table 3 shows the benefit change due to increased revenues and reduced costs. In terms of increased benefits, total increased benefits are 13,160 SEK because of increased faba bean sales and increased winter wheat sales in the next year. In terms of reduced cost, the largest change is decreased cost of spring wheat seed cost, which is 2180 SEK, followed by decreased fertilizer use with 1793 SEK. The subtotal for benefit change undertaking strip-intercropping is 18,166 SEK. Cost changes are listed in the right part of Table 3 that include decreased revenues and increased costs. Increased cost includes increased faba bean seed cost, increased fertilizer K cost, increased pollination cost for faba bean and increased fuel consumption, that is 7960 SEK in total. The reduced benefit is estimated at 19221 SEK due to reduced spring wheat sales. After deducting the subtotal cost change from the subtotal benefit change, net benefit change is estimated at −9015 for the considered three-hectare plot.

Fig. 2 shows the probability distribution of net benefits for the strip spring wheat and faba bean intercropping system. The result is used as a base for assessing the robustness capacity of the resilience assessment. Given the results, there is 90% probability that the net benefit change lies between −7500 to −9500 SEK. The magnitude is an indication that adopting strip spring wheat and faba bean intercropping system appears as a shock to the economic outcome, hence does not secure the robustness capacity of the system (Slijper et al., 2022). The observed variation relates to the estimated net benefit change regarding spring wheat monocropping system.

The results of the impact (sensitivity) analysis for the strip intercropping system are shown with Tornado diagram in Fig. 3. These results are used as a base for assessing the adaptability capacity of the resilience assessment. The correlation coefficients belong to the range of [−1,1], and represent the degree of which the net benefit change is sensitive to changes in the stochastic parameters. Correlation coefficients are normalized by the standard deviation of the net benefit change and the standard deviation of stochastic parameters and represent the increase in the standard deviation of the net benefit change, due to an increase of the standard deviation of a stochastic parameter.

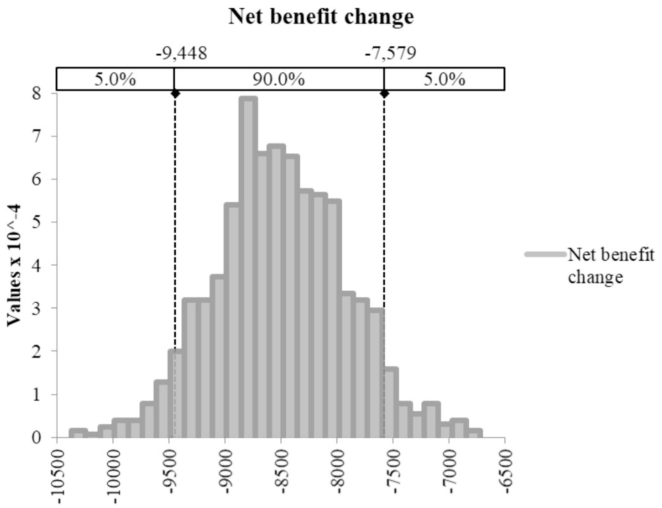


Fig. 2. Probability distribution of Net benefits for the for strip intercropping system.

For the strip intercropping alternative, the price of spring wheat and faba bean are the most influential factors in determining this outcome, hence the adaptability capacity of the system. Given the result, 1% increase in the spring wheat price decreases the net benefit by 0.86%. On the other hand, the 1% higher price of faba bean leads to a 0.46% increase in the net benefit, supporting the adaptability capacity. Prices of N fertilizer have largest impact on the variations in the net benefit, hence the adaptability capacity. Low prices of N fertilizer and high price of the faba bean seed decrease the net benefit, hence the systems' adaptability capacity. The effect of the price of spring wheat seed is positive for the net benefit, but small, 0.05% (for 1% increase in the net benefit). Weed control-, diesel consumption and labour use have small effect (0.01 to 0.03%) on the variation in the net benefit, hence supporting the adaptability capacity of the system. Scatter plots for the net benefit change and product/input variables for the strip intercropping are shown in appendix C1.

3.2. Economic effects of adopting mixed intercropping system

Results for the partial budget analysis related to changes under the scenario of adopting a mixed intercropping system are provided in Tables 4. The benefit changes including increased revenue and reduced costs are listed in the left part of the table. Increased sales of mixed

Table 3
The deterministic effects of adopting strip intercropping system on net benefit change.

Benefit change	Value (SEK)	Cost change	Value (SEK)
Increased faba bean sales	10,873	Increased faba bean seed cost	4042
Increased winter wheat sales next year	2287	Increased fertilizer K cost	97
		Increased pollination cost for faba bean	82
		Increased labour cost	3393
		Increased fuel consumption cost	346
Total increased benefit	**13,160**	**Total added cost**	**7960**
Decreased fertilizer N cost next year	179		
Decreased spring wheat seed cost	2180		
Decreased weed control cost	696		
Decreased drying cost	158		
Decreased fertilizer use current year (N,P,Mn)	1793	Reduced spring wheat sales	19,221
Total reduced cost	**5006**	**Total reduced benefit**	**19,221**
Sub-total benefit change	**18,166**	**Sub-total cost change**	**27,181**
Net benefit change	**−9015**		

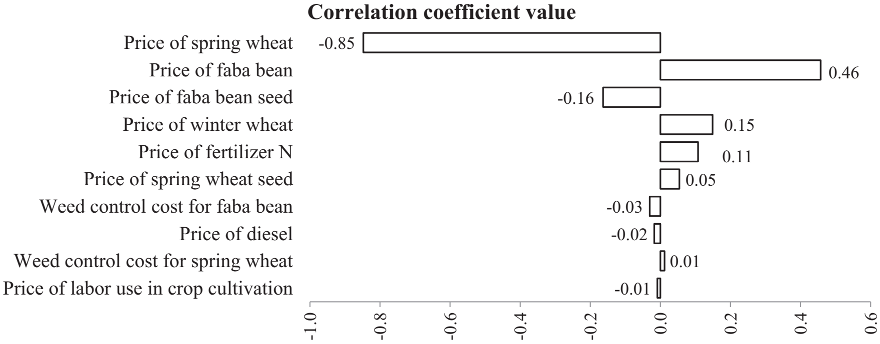


Fig. 3. Tornado plot with correlation coefficients of drivers of net benefit change for the strip intercropping system.

Table 4
The deterministic effects of adopting mixed intercropping system on net benefit change.

Benefit changes due to change	Value (SEK)	Cost change due to change	Value (SEK)
Increased yellow pea and oat mixed forage sales	19,361	Increased yellow pea seed cost Increased fertilizer K cost	2048 58
Total added benefit	**19,361**	**Total added cost**	**2106**
Decreased fertilizer cost (N, P)	1489		
Decreased oat seed cost	736		
Decreased weed control cost	129		
Decreased herbicide cost	512	Reduced oat forage sales	16,765
Total reduced cost	**2526**	**Total reduced benefit**	**16,765**
Sub-total benefit change	**21,887**	**Sub-total cost change**	**18,871**
Net benefit change	**3016**		

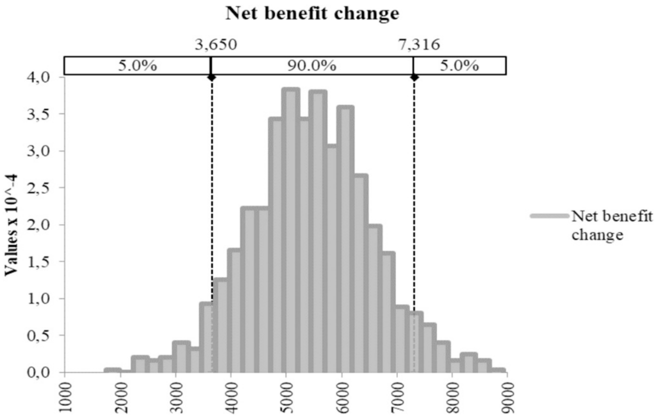


Fig. 4. Probability distribution of Net benefits for the for the mixed intercropping system.

forage of yellow pea and oat is 19,361 SEK, which is the most influential variable in determining benefit change. The total reduced cost is 2526 SEK, whereas the decreased fertilizer cost for N and P is 1149 SEK. The increase in benefit is offset by an increase in costs of 18,871 SEK due to increased yellow pea seed cost (2048 SEK), increased fertilizer K cost (58 SEK) and reduced forage sales (16,765 SEK). The net benefit change is estimated at 3016 SEK for the three-hectare plot. This means increased net benefit per hectare in the mixed intercropping system is thus estimated at 1006 SEK.

Fig. 4 shows the probability distribution of net benefits for the mixed intercropping system. For the mixed intercropping, there is 90% probability that the net benefit change lies between 3650 and 7316 SEK, meaning that the adopting mixed intercropping of oat and pea for feed production can be considered as a viable option for securing the robustness. The observed variation relates to the estimated net benefit change regarding the oat monocropping system.

Fig. 5 shows the Tornado diagram with correlation coefficients of drivers of net benefit change for the mixed intercropping system. The price of mixed fodder of oat and pea and price of the oat fodder are the most influential factors in determining the net benefit change, hence the adaptability capacity of the system. Given the result, 1% increase in the mixed fodder increases the net benefit by 0.70%. On the other hand, 1% higher price oat fodder leads to 0.67% decrease in the net benefit. While the impact of the price of the mix folder and the price of oat feed is opposite, the estimated net benefit change is positive 1005.6 SEK/ha. While the expected decrease in the use of N fertilizer, herbicides and pesticides is crucial for securing the environmental benefits of this system, the effect of their prices on the net benefit change is small (0.01–0.03%), hence supporting the adaptability of the system. The adoption of mixed intercropping system does not assume adjustments in the diesel consumption and the labour use, hence these inputs are not presented in the figure. Scatter plots for the net benefit change and product/input variables for the mixed intercropping are shown in appendix C2.

4. Discussion

Intercropping is gaining attention for its potential to enhance the sustainability and the resilience of farming systems (Brannan et al., 2023; Jensen et al., 2020; European Commission, 2022). Due to the existence of various intercropping systems (Glaze-Corcoran et al., 2020), uncertainties in economic outcomes (Huss et al., 2022), and context dependency (Brannan et al., 2023; Ha et al., 2023), adoption research that takes local specifies into consideration is needed (Ha et al., 2023). The primary challenge for the research is identifying intercropping systems that lead to the desired economic outcome and resilience in a given cultivation context (Brooker et al., 2015; van der Lee et al., 2022). In this paper, we provide novel insights into the farm-level economic outcomes and resilience consequences by looking into the shift from the conventional monocropping to different types of intercropping. In particular, the study examines the net benefits of two intercropping alternatives and identifies how key characteristics including product- and input prices can support or constrain the net benefit of the adoption and the resilience of the system. The study presents novel evidence in which economic outcomes and the resilience assessment are integrated. In this study, net changes and risk parameters of the inputs associated with the intercropping practices are discussed through the lenses of resilience capacity (Slijper et al., 2022).

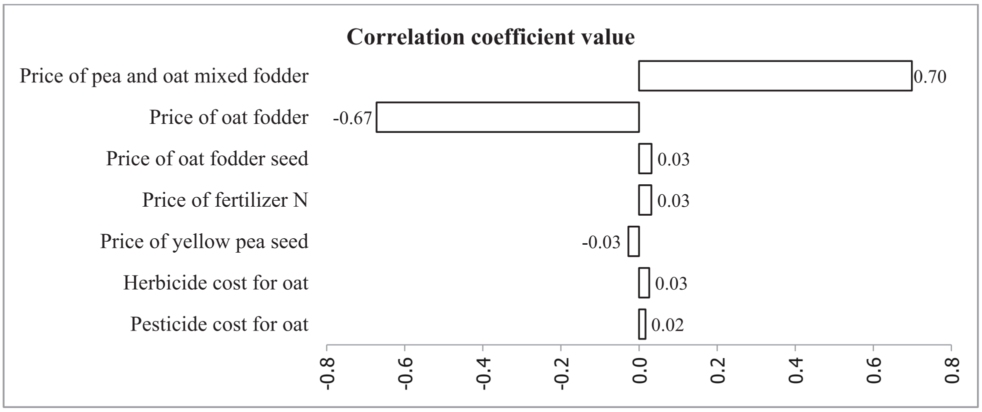


Fig. 5. Tornado plot with correlation coefficients of drivers of net benefit change for the mixed intercropping scenario.

4.1. Net benefit and resilience from adopting cereal-legume intercropping practices in Sweden

We found that given the available production management practices and market conditions, net benefits from replacing various monocropping systems with an intercropping alternative differ. Due to the negative result of the net benefit, the strip spring wheat faba bean intercropping alternative fails to secure robustness (causing shock to the system). The adoption of mixed intercropping system of oat and pea for fodder production is a feasible alternative, yielding positive result for the net benefit change and the robustness of the system.

Changes resulting from product composition, i.e., the products' prices, make the largest impact on the result. Prices of spring wheat and faba bean in the strip intercropping, prices of mixed fodder of oat and pea, and price oat fodder in the mixed intercropping are the most influential factors in determining the adaptability capacity of the intercropping systems. The impact from the spring wheat price in monocropping is negative and larger than the positive impact of wheat faba bean prices in intercropping. The result is an indication that high price of the monocropping products is a strong determinant against the adaptability capacity of the intercropping system. For the mixed intercropping alternative, the effect of the monocropped and the intercropped cultivation systems on the variations in the net benefit is opposite but similar. The net benefit for this system is positive due to the low intensity of the production, i.e., low use of the remaining inputs. Benoit et al. (2020) also showed that the most resilient systems with the lowest coefficient of variation of net income are those that combine a low level of inputs. Our findings in relation to the strip intercropping of the spring wheat and faba bean partially confirm the existing literature that monocropped crops outcompete intercropped crops on gross margins (Brannan et al., 2023).

For both intercropping systems, the intensity of the inputs use, especially the N fertilizer and the weed control are well in line with the policy principles for sustainable and resilient production (European Commission, 2020). As a part of Farm to Fork strategy (F2F), and Energy and Climate Plans, the EC proposes reducing the usage of fertilizers, chemical pesticides (European Commission, 2020), and fossil fuels (European Commission, 2023). Research providing evidence for the economic outcomes while meeting these targets is of great value for determining the barriers that hinder adoption. Our results show that while the production intensification and the impact of the production inputs, (except for the N fertilizer) on the variations in the net benefit change are low, these changes are insufficient to outbalance the economic costs of the strip intercropping system. In comparison with the remaining inputs N fertilizer price has a large contribution to the variations in the net benefits. Specifically, the low price of N fertilizes decreases the net benefit of the adoption, hence the adaptability of the strip intercropping system.

Our results support the previous findings that intercropping could play a role as an alternative system for sustainable and resilient agriculture (Martin-Guay et al., 2018), but both the net benefit and the resilience capacity resulting from intercropping alternatives are highly context specific (Brannan et al., 2023; Weih et al., 2021) and specific to the type of intercropping.

4.2. Policy implications and recommendations

Findings of this study are highly policy relevant. In Sweden, the adoption rate of intercropping is low, and farmers are reluctant to intercrop common field crops (Jensen et al., 2020). However, our findings show that field crops, especially cereal-legume mixed cropping for fodder consumption can be considered a viable practice. Intercropping adoption is driven by farmers perceived financial benefits (Ha et al., 2024) and hindered by insufficient knowledge, both for the farmers (Brannan et al., 2023; Ha et al., 2023; Ha et al., 2024) and the extension services (Brannan et al., 2023; Zimmer et al., 2016). To eliminate knowledge barriers, policymakers at various levels should use the argument about intercropping's financial benefits to enact policies facilitating the dissemination of knowledge to extension services and farmers via training programmes, demonstration projects, and production planning assistance (Ha et al., 2023; Ha et al., 2024; Zimmer et al., 2016).

Net benefit change from adopting differs across the intercropping alternatives, primarily due to prices of the products. The price of the main crop has a negative impact while the price of intercropped products has a positive impact on the net benefit change, especially for the strip intercropping. These results are an indication for the need of policies that target innovative solutions for improving the market conditions for less viable intercropped products, e.g., for establishing and expansions of markets, markets information, and supply chains coordination (Brannan et al., 2023; Mamine and Farès, 2020) to encourage uptake of more sustainable practices. Market conditions play a vital role even for the viable intercropped products. Our study shows that the net benefit of the mixed intercropping alternative is positive. However, in practice, farmers mainly intercrop to produce animal feed. Results imply that in short run, polices supporting this product are plausible for regions where such market exists.

Intercropping is among the practices supported by the CAP eco-schemes (Regeringen, 2023). The current payment of about 125 euro/ha partially compensates for the net benefit loss for the strip intercropping. Results show that without coordination with proper market solutions, the transition from monocropping spring wheat to strip spring wheat faba bean intercropping requires higher public support. The goal of the eco-schemes' payment is to reduce nutrient leaching (Regeringen, 2023). Our results suggest that low prices of N fertilizer hinder adaptability of the strip intercropping alternative. Thus, agricultural policies need to reconsider the standards and the regulations to make sure that the net benefit from using less sustainable production methods will not hinder the intercropping adoption (Mamine and Farès, 2020).

Last but not the least, in line with the existing literature (Lin, 2011; Wang et al., 2023), economic outcomes of the intercropping alternatives depend on the composition of the crop mixture. Results of this study inform policy makers and the practitioners for the risk mitigation potential of the evaluated intercropping alternatives, thus allowing for better strategic planning. For instance, it is crucial to take into consideration the local needs for N sensitive regions and the possibilities for selling the end-use product.

To summarize, private policies targeting markets and value chains, public policies compensating negative outcomes from the intercropping adoption, knowledge diffusion, and innovative solutions for market development can be of great relevance for scaling up intercropping.

4.3. Limitations

This research has several limitations. Particularly, applying stochastic partial budget modelling means that the results are limited to selected scenarios with only two cereal-legume intercropping alternatives in Sweden and do not account for change over time. While our analysis can be easily extended to other plot sizes, it did not take into account the economic scalability of intercropping systems. This means our results did not provide insight into changes in observed economic benefits across different scales of operation. Nevertheless, the ex-ante analysis of these hypothetical scenario is crucial to inform decision making by farmers and policy makers. Moreover, due to the scenario's assumptions, the method is restricted to only two resilience capacities, namely robustness and adaptability. Future studies on economic benefits of intercropping can extend the application to other dimensions of resilience like anticipation and transformability (Manevska-Tasevska et al., 2023).

The analysis observes changes in monetary terms but not quality characteristics, for example, possible variations in the nutritional value of the outputs (Kocer and Sebahattin, 2012). Low quality mixture will not attain the expected revenue from the product sale. In addition, the analysis considers a homogenous mixture of the seeds (e.g., oat and pea seed). However, technical considerations are necessary for seed preparation and adjustments in planting to accommodate seeds of different sizes (Glaze-Corcoran et al., 2020). Extra costs may arise from sorting seeds before sowing due to differences in the weight of the seeds from two species. In this case, the seeding procedure needs to be repeated twice, resulting in increased seeding cost. Future research should consider two technological issues including proper sowing and product quality.

This study exclusively examines the economic outcomes and resilience of the alternative intercropping system. However, given the challenge of global food and nutrition insecurity future research could explore changes in nutritional value and analyse the associated trade-offs with the economic resilience outcome. Last but not the least, this application is for the Swedish crop production. The agricultural sector in Sweden operates in a Nordic climate with a limited number of crops. This limits the validity of the results to a Nordic context. Replication of the study elsewhere requires reconsidering the choice of the intercropping alternatives and their respective production management. Longitudinal studies that capture temporal variability in economic outcomes, as well as broader geographic studies, are needed to improve the generalizability of the findings.

5. Conclusions

This study investigates the consequences of adoption of intercropping practices on the farm economic outcomes in Sweden, in the context of achieving economic resilience. We model two baseline cereal- based monocropping scenarios and two corresponding cereal-legume intercropping scenarios to examine net changes and risk characteristics resulting from the adaptation from mono- to intercropping system. Estimates of net changes and the respective risk characteristics are integrated in an economic resilience assessment for the intercropping systems.

Results show that intercropping could play an essential role as an alternative system for sustainable and resilient agriculture. Our findings confirm the existing literature, demonstrating the contextual dependence of economic outcomes and resilience in intercropping systems. Given the negative result of the net benefit, the strip spring wheat faba bean intercropping alternative do not contribute to achieving robustness. Compared to oat monocropping system, the adoption of mixed oat pea intercropping system for fodder purposes yields positive result for the net benefit change and contribute to the robustness of the system. Prices of the mono- and the intercropped products of both intercropping alternatives and the use of N fertilizer for the strip intercropping alternative are the most influential factors in determining the adaptability capacity. Prices supporting the monocropping products, and the low price of N fertilizer hinder the adaptability of the intercropping system.

The study has several contributions. First the stochastic partial budget analysis applied in our study is for hypothetical technology adoption that could be understood as an ex-ante analysis to inform decision making on implementing new adaptation practices (Ahmed et al., 2020; Jerlström et al., 2022; Owusu-Sekyere et al., 2023). The stochastic component attaches probabilities of occurrence to the possible values of the key factors in an economic outcome, thereby generating the probability distribution of possible economic outcomes (Hardaker et al., 1997). In these ways, our approach is different from that of Benoit et al. (2020) and Slijper et al. (2022), which provide empirical evidence for existing farming systems. Second, this paper is the first attempt that uses stochastic partial budget analysis to interpret economic outcomes through the lenses of resilience capacities. Thus, the paper provides novel results on economic resilience of adopting intercropping practices in a Nordic context. Third, the economic outcomes in this study were simulated (Ahmed et al., 2020; Alvåsen et al., 2017), adding to the existing related literature where most intercropping studies are conducted at experimental fields (Jensen et al., 2020; Wang et al., 2023). Last but not the least, the study informs Swedish extension services and policymakers on effective intercropping practices and policy design for economic outcomes and resilience.

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CRediT authorship contribution statement

Gordana Manevska-Tasevska: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Vivian Wei Huang:** Writing – review & editing, Visualization, Supervision, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Zhen Chen:** Writing – review & editing, Formal analysis, Data curation. **Ortrud Jäck:** Writing – review & editing, Data curation, Conceptualization. **Nasir Adam:** Writing – review & editing, Visualization, Formal analysis. **Thi Thanh Mai Ha:** Writing – review & editing, Validation, Conceptualization. **Martin Weih:** Writing – review & editing, Funding acquisition, Data curation, Conceptualization. **Helena Hansson:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Box A1

Partial Budgeting Technique for adopting strip intercropping system. Detailed breakdown analysis for benefit and cost changes

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Increased benefits

Increased revenue

- Increased legume sales: Increased legume sale (SEK) = yield of faba bean (kg/ha) × share of land - faba bean (ha) × price of faba bean (SEK/kg)
- Increased cereal sales next year: Increased winter wheat sale next year (SEK) = (share of land - faba bean (ha) × increased yield of winter wheat in next year (kg/ha) × price of winter wheat (SEK/kg)) / (1 + discount rate)

Decreased cost

- Decreased fertilizer N use next year: Decreased fertilizer N use next year (SEK) = (share of land-faba bean (ha) × decreased fertilizer N use (kg/ha) × price of fertilizer N (SEK/kg)) / (1 + discount rate)
- Decreased spring wheat seed cost: Decreased spring wheat seed cost = share of land - faba bean (ha) × seed quantity of spring wheat (kg/ha) × price of spring wheat seed (SEK/kg)
- Decreased weed control cost: Decreased weed control cost (SEK) = weed control cost for spring wheat (SEK/ha) × total land area (ha) - (share of land - faba bean (ha) × weed control cost for faba bean (SEK/ha) + share of land - spring wheat (ha) × weed control cost for spring wheat (SEK/ha))
- Decreased drying fees: Drying cost for faba bean (SEK) = yield of spring wheat in baseline (kg/ha) × land area (ha) × drying cost for spring wheat (SEK/kg) - yield of faba bean (kg) × share of land - faba bean (ha) × drying cost of faba bean (SEK/kg) - yield of spring wheat (kg/ha) × share of land - spring wheat (ha) × drying cost of spring wheat (SEK/kg)
- Decreased fertilizer use (N, P, Mn): fertilizer use cost (SEK) = (decreased fertilizer P use (kg/h) × total land area(ha) × price of fertilizer P (SEK/kg) + decreased fertilizer N use × share of land - faba bean (ha) × price of fertilizer N (SEK/kg) + decreased fertilizer Mn use (l/ha) × share of land - faba bean (ha) × price of Mn (SEK/l)

Increased costs

Increased cost

- Increased legume seed cost: Increased seed cost (SEK) = seed quantity of faba bean (kg/ha) × share of land - faba bean (ha) × price of legume seed (SEK/kg)
- Increased fertilizer K cost: Increased fertilizer K cost (SEK) = Increased fertilizer K use (kg/ha) × total land area (ha) × price of fertilizer K (SEK/kg)
- Increased pollination cost: Increased pollination cost (SEK) = pollination cost per ha (SEK/ha) × share of land - faba bean (ha)
- Increased labor cost (including sowing, crop management and harvest): Increased labor cost (SEK) = working hours in baseline (hour) × labor cost in crop cultivation (SEK/h) × increased percentage of labor use (%)
- Increased fuel consumption: Increased fuel consumption (SEK) = average fuel consumption (l/ha) × total land area (ha) × price of diesel (SEK/l) × increased rate (%)

Decreased benefit

- Reduced income of wheat sales: Decreased wheat sale (SEK) = yield of spring wheat in monocropping (kg/ha) × total land area (ha) × price of spring wheat (SEK/kg) - yield of spring wheat in intercropping (kg/ha) × share of land - spring wheat (ha)) × price of spring wheat (SEK/kg)

Box A2

Partial Budgeting Technique for adopting mixed intercropping system. Detailed breakdown analysis for benefit and cost changes

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Increased benefits

Increased revenue

- Increased pea and oat forage sales: Increased pea and oat forage sale (SEK) = yield of pea and oat forage (kg/ha) * total land (ha) * forage price (SEK/kg)

Decreased cost

- Decreased fertilizer use: fertilizer use cost (SEK) = Decreased fertilizer N rate (kg/h) * total land (ha) * price of fertilizer N (SEK/kg) + Decreased fertilizer P rate (kg/ha) * total land (ha) * price of fertilizer P

(*continued on next page*)

Box A2 (*continued*)

- Decreased oat seed cost: Increased oat seed cost (SEK) = oat seed rate (kg/ha) * decreased share of oat (%) * total land (ha) * price of oat seed (SEK/kg)
- Decreased weed control cost: Decreased pesticide cost (SEK) = decreased pesticide use (kg/ha) * total land (ha) * price of pesticide (SEK/kg)
- Decreased herbicide cost: Decreased herbicide cost (SEK) = decreased herbicide use (kg/ha) * total land (ha) * price of herbicide (SEK/kg)

Increased costs

Increased cost

- Increased yellow pea seed cost: Increased seed cost (SEK) = legume seed rate (kg/ha) * share of mixed - pea (%) * total land (ha) * price of pea seed (SEK/kg)
- Increased fertilizer K cost: Increased fertilizer K cost (SEK) = Increased fertilizer K rate (kg/ha) * total land (ha) * price of fertilizer K (SEK/kg)

Decreased benefit

- Reduced income of oat sales: Decreased oat sale (SEK) = yield of oat (kg/ha) * total land (ha) * oat fodder price (SEK/kg)

Appendix B

Table B1
Summary statistics for product and input variables (stochastic parameters) considered for the strip intercropping system.

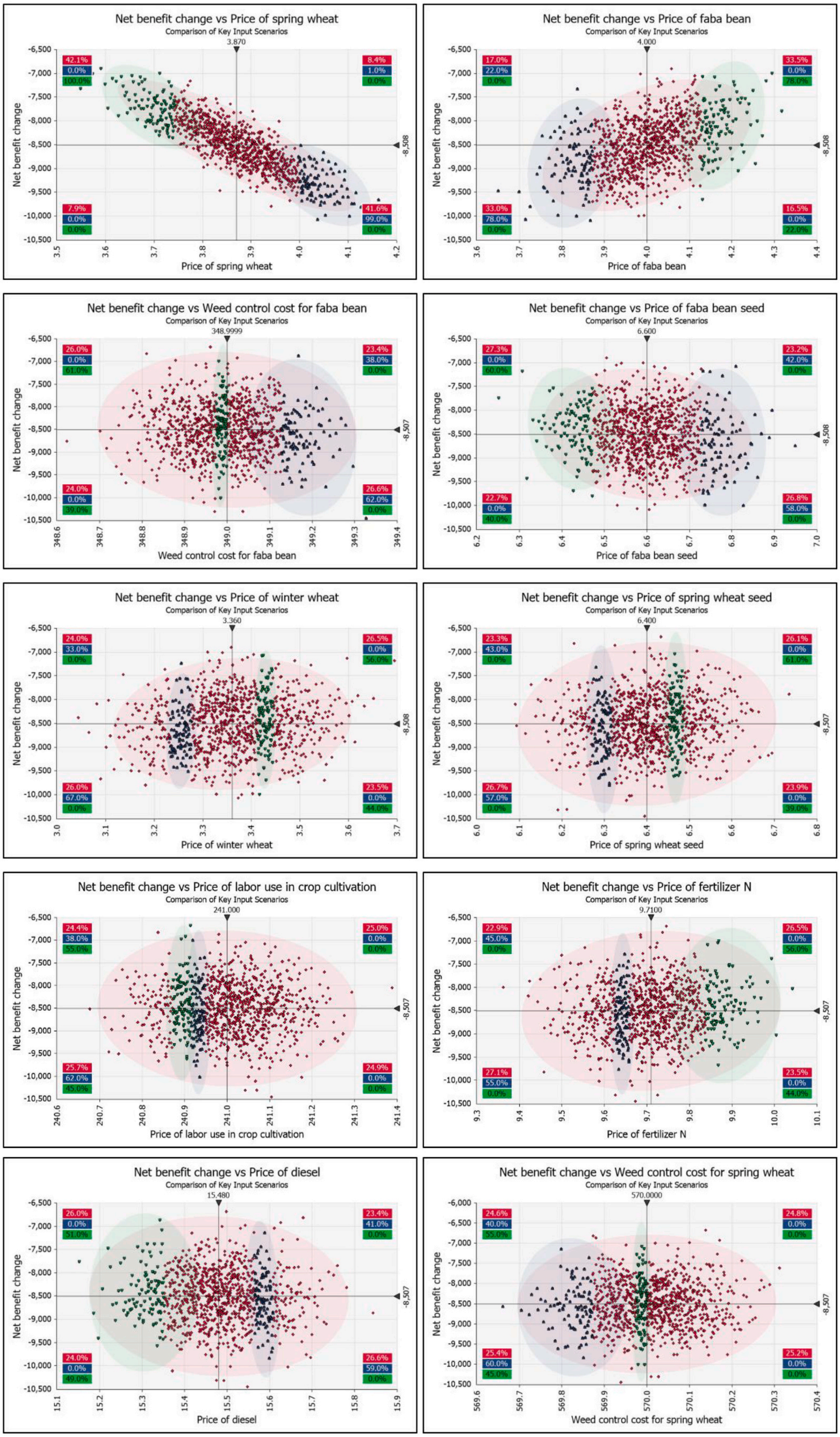
Variables	**Median**	**Min**	**Max**	**5%**	**95%**	**St.dev**	**Skewnes**	**Kurtosis**
Price of spring wheat	3.87	3.50	4.22	3.71	4.03	0.10	−0.01	3.06
Price of oat fodder	4.00	3.64	4.34	3.84	4.16	0.10	−0.01	3.03
Price of spring wheat seed	6.40	6.08	6.72	6.23	6.56	0.10	−0.00	2.95
Price of faba bean seed	6.60	6.22	6.93	6.43	6.76	0.10	−0.02	3.05
Price of fertilizer N	9.71	9.37	10.03	9.54	9.87	0.10	−0.00	2.99
Price of diesel	15.48	15.16	15.81	15.31	15.64	0.10	0.00	2.97

Table B2
Summary statistics for product and input variables (stochastic parameters) considered in mixed intercropping system.

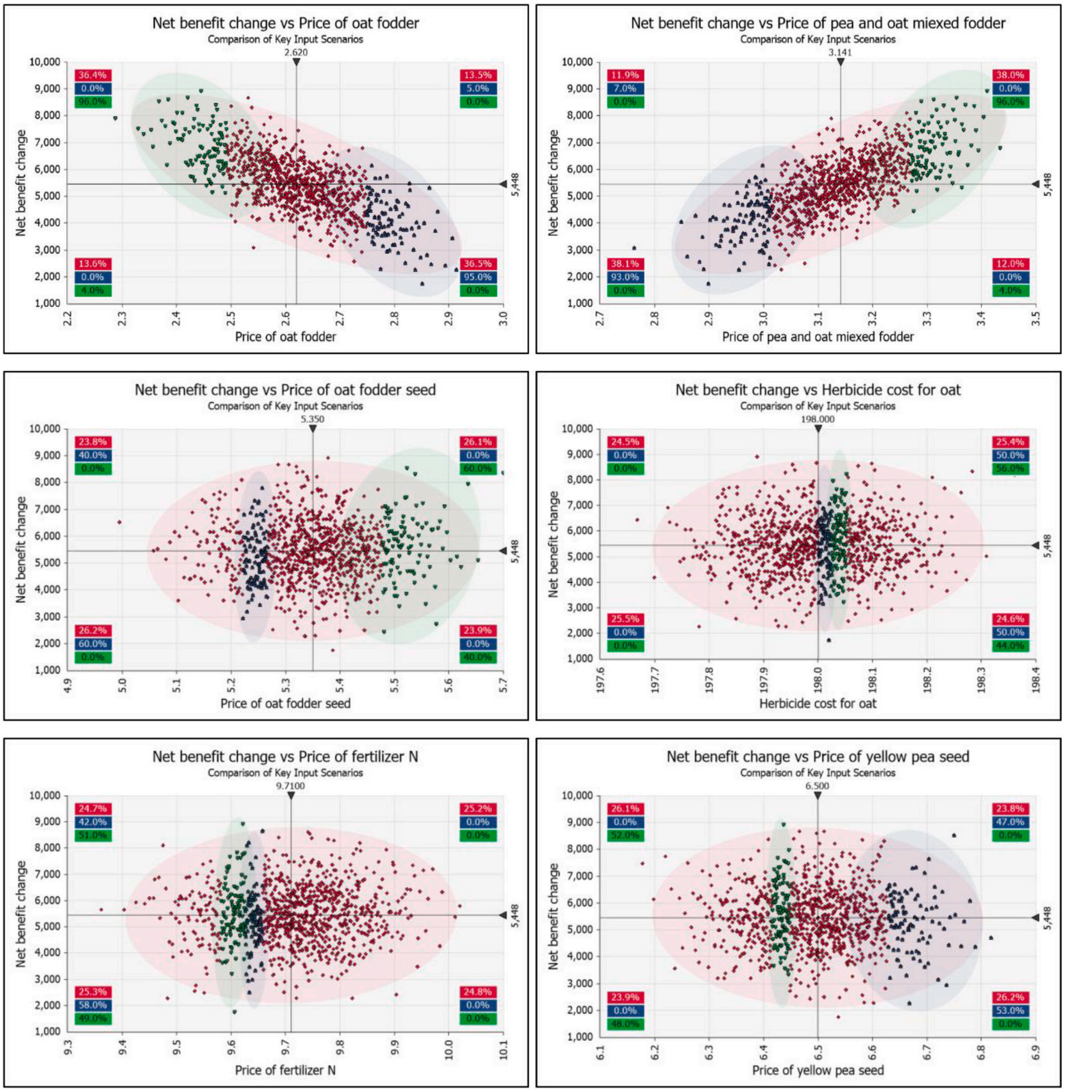
Variables	Median	Min	Max	5%	95%	Std. Dev	Skewness	Kurtosis
Price of pea and oat mixed fodder	2.82	2.82	3.48	2.98	3.06	0.10	0.00	2.98
Price of oat fodder	2.30	2.30	2.99	2.46	2.78	0.10	0.02	3.02
Price of yellow pea seed	6.18	6.18	6.83	6.33	6.66	0.10	−0.01	3.00
Price of oat fodder seed	4.97	4.98	5.69	5.19	5.51	0.10	0.01	3.04
Price of fertilizer N	9.38	9.38	10.06	9.54	9.87	0.10	0.01	2.99
Price of diesel	15.17	15.17	15.81	15.31	15.64	0.10	0.00	2.95
Herbicide cost of oat	197.67	197.67	198.37	197.84	198.16	0.10	0.01	3.03
Pesticide cost for oat	49.64	49.65	50.34	49.83	50.23	0.10	−0.01	3.03

Appendix C

C.1. Scatter plots for the net benefit change and product/input variables for the strip intercropping


Net benefit change vs Price of spring wheat
Comparison of Key Input Scenarios
3.870
-8,508
42.1%
0.0%
100.0%
8.4%
1.0%
0.0%
7.9%
0.0%
0.0%
41.6%
99.0%
0.0%
Net benefit change
-6,500
-7,000
-7,500
-8,000
-8,500
-9,000
-9,500
-10,000
-10,500
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
Price of spring wheat
Net benefit change vs Price of faba bean
Comparison of Key Input Scenarios
4.000
-8,508
17.0%
22.0%
0.0%
33.5%
0.0%
78.0%
33.0%
78.0%
0.0%
16.5%
0.0%
22.0%
Net benefit change
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
Price of faba bean
Net benefit change vs Weed control cost for faba bean
Comparison of Key Input Scenarios
348.9999
-8,507
26.0%
0.0%
61.0%
23.4%
38.0%
0.0%
24.0%
0.0%
39.0%
26.6%
62.0%
0.0%
Net benefit change
348.6
348.7
348.8
348.9
349.0
349.1
349.2
349.3
349.4
Weed control cost for faba bean
Net benefit change vs Price of faba bean seed
Comparison of Key Input Scenarios
6.600
-8,508
27.3%
0.0%
60.0%
23.2%
42.0%
0.0%
22.7%
0.0%
40.0%
26.8%
58.0%
0.0%
Net benefit change
6.2
6.3
6.4
6.5
6.6
6.7
6.8
6.9
7.0
Price of faba bean seed
Net benefit change vs Price of winter wheat
Comparison of Key Input Scenarios
3.360
-8,508
24.0%
33.0%
0.0%
26.5%
0.0%
56.0%
26.0%
67.0%
0.0%
23.5%
0.0%
44.0%
Net benefit change
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
Price of winter wheat
Net benefit change vs Price of spring wheat seed
Comparison of Key Input Scenarios
6.400
-8,507
23.3%
43.0%
0.0%
26.1%
0.0%
61.0%
26.7%
57.0%
0.0%
23.9%
0.0%
39.0%
Net benefit change
6.0
6.1
6.2
6.3
6.4
6.5
6.6
6.7
6.8
Price of spring wheat seed
Net benefit change vs Price of labor use in crop cultivation
Comparison of Key Input Scenarios
241.000
-8,507
24.4%
38.0%
55.0%
25.0%
0.0%
0.0%
25.7%
62.0%
45.0%
24.9%
0.0%
0.0%
Net benefit change
240.6
240.7
240.8
240.9
241.0
241.1
241.2
241.3
241.4
Price of labor use in crop cultivation
Net benefit change vs Price of fertilizer N
Comparison of Key Input Scenarios
9.7100
-8,507
22.9%
45.0%
0.0%
26.5%
0.0%
56.0%
27.1%
55.0%
0.0%
23.5%
0.0%
44.0%
Net benefit change
9.3
9.4
9.5
9.6
9.7
9.8
9.9
10.0
10.1
Price of fertilizer N
Net benefit change vs Price of diesel
Comparison of Key Input Scenarios
15.480
-8,507
26.0%
0.0%
51.0%
23.4%
41.0%
0.0%
24.0%
0.0%
49.0%
26.6%
59.0%
0.0%
Net benefit change
15.1
15.2
15.3
15.4
15.5
15.6
15.7
15.8
15.9
Price of diesel
Net benefit change vs Weed control cost for spring wheat
Comparison of Key Input Scenarios
570.0000
-8,507
24.6%
40.0%
55.0%
24.8%
0.0%
0.0%
25.4%
60.0%
45.0%
25.2%
0.0%
0.0%
Net benefit change
-6,000
-6,500
-7,000
-7,500
-8,000
-8,500
-9,000
-9,500
-10,000
-10,500
569.6
569.7
569.8
569.9
570.0
570.1
570.2
570.3
570.4
Weed control cost for spring wheat

C.2. Scatter plots for the net benefit change and product/input variables for the mixed Intercropping



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