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Designing and application of a Comprehensive Farm Assessment Index: towards efficient and relevant policy analysis

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Abstract

Purpose – Sustainability indicators that allow integrated farm assessments have received increasing attention. However, limited evidence is available for the use of the same when assessing the agricultural sustainability of farming systems, especially in regions practising incessant monoculture. Therefore, this study aims to develop a holistic index to assess alternative farming systems based on a stock-and-flow framework.

Design/methodology/approach – A composite metric was developed by aggregating the economic, social and environmental indicators. The methodology involved estimation, normalisation, hierarchical weighting and progressive aggregation of indicators to form the Comprehensive Farm Assessment Index (CFAI). The CFAI was applied to assess the farming practices of 88 organic and 90 conventional farming plots across three agro-climatic zones over two cropping seasons in selected districts of Punjab, India.

Findings – Results showed statistical mean differences between the organic and conventional farming systems in terms of key production costs and income for wheat, rice and cotton crops. The normalised values

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of the selected social indicators were higher for the organic farming system. Similarly, in the environmental dimension, more biodiversity and less water contamination were found in organic farms. Except for paddy cultivation in the North–East region, the CFAI for organic farming is higher than that for conventional farming, even under the mono-cropping system with a single-crop rotation.

Originality/value – The CFAI has ubiquitous applications and can be used to assess alternate sustainable approaches and practices across crops and regions. It provides a perspective on the social viability and ecological sustainability of agriculture, which would enable contextual and effective policy analysis and implementation.

Keywords Comprehensive Farm Assessment Index, Conventional farming, Organic farming, Policy, Punjab, Stock-and-flow framework

Paper type Research paper

1. Introduction

Economic growth has been the primary objective of development, universally accepted by practitioners and policymakers, while the difficulty in the trade-off between sustainability and economic viability has increasingly been acknowledged. An economically sustainable farming system should generate sufficient earnings to recover the farm's production factors at a rate comparable to other sectors and an income allowing for an appropriate standard of living. Furthermore, it should lead to savings to cover incidents and exigencies. If the efficiency of the production factors can be improved, it stands to reason that the farming system can increase output and create higher-quality produce at lower prices. Any increase in production contributes to the country's economic growth.

The agriculture system is pivotal in providing sustainable livelihoods through employment opportunities, particularly for women, unskilled or semi-skilled workers and seasonal migrant labourers. Therefore, sustainable farming should result in social equity, self-sufficiency, preservation of traditional agrarian and indigenous wisdom and culture and support for smallholders. Thus, adequate access to housing, income, health, good working conditions, services, facilities, education and financial security should be available to farmers as part of their social inclusion. A respectful social identity with values and norms should be restored. Finally, it should help them build networks and trust collectives, furthering their social capital.

A resource-limited ecological strategy would promote the sustainable use of soil, water and air for environmental and biodiversity conservation, livestock management and improved quantity and quality of produce. Given the limited availability of primaeval fertile soils, the required growth in agricultural production must come from yield enhancement in currently cultivated soils. Therefore, efforts must be made to add maximum value with minimum resources to mitigate environmental impacts. Furthermore, concerted efforts must be diverted towards waste reduction, specifically hazardous waste and food loss across the value chain.

Indicator-based farm assessment frameworks effectively evaluate and prioritise resource allocation to the most vulnerable farming communities and regions, leading to better agricultural policies (Pannell and Glenn, 2000). Such indices are developed to capture the multiple dimensions using a comprehensive literature and system-based framework vetted by stakeholders, namely, farmers, academicians and government representatives (Von Wirén-Lehr, 2001; FAO, 2017). A single composite index that weights different principles of sustainable agriculture provides an unambiguous condensed metric that is easily comprehendible and accurately assesses adoption levels (Fongang *et al.*, 2023). A holistic evaluation using a participatory approach assists in designing contextual and effective policies (Zahm *et al.*, 2008). At the same time, the characterisation of the ecosystem, for example, taking individual farm soil samples and gauging farmer's socio-economic condition, can enable targeted interventions to address the unique needs of different farms, leading to better resource allocation (Meul *et al.*, 2008; Brennan *et al.*, 2022). The sensitivity analysis of indicators has indicated that crop production is more sensitive to the changes in input price (Zhen *et al.*, 2005). An integrated farm index has been successfully used to assess land management practices and the economic viability of smallholder farmers to guide policy (Muthuprakash and Damani, 2019; Mutyasira *et al.*, 2018). Indices have been invoked to determine environmentally sustainable farming systems as the benchmark for farm evaluation (Merante *et al.*, 2015). An objective data-driven assessment framework enables evidence-driven policy decisions that promote long-term agricultural sustainability (Ness *et al.*, 2007). The tool has been instrumental in shaping policies that address specific challenges in agriculture, like water scarcity (Berbel *et al.*, 2019), depleting soil health and chemical fertiliser hazards (Robertson and Vitousek, 2009). The index has effectively led to enhanced subsidies and support programs for organic practices (Padel and Niggli, 2009), promoting biodiversity (Firbank *et al.*, 2008) and climate-resilient practices (Rickards and Howden, 2012). The composite index approach is a dynamic tool geared to continuously evolving ecosystems (Chopin *et al.*, 2021), thus remaining relevant over time.

In agriculture, three pillars – economic, social and environmental – integrate land stewardship to create resource-conserving and equitable farming systems for future generations. Recently, studies using composite indicators to determine the sustainability of agricultural systems have gained prominence, specifically in Western literature (e.g. Food and Agricultural Organization, 2013; Häni *et al.*, 2003; King *et al.*, 2000; López-Ridaura *et al.*, 2002; Mohamed *et al.*, 2014). A few studies use a comprehensive index when assessing the agricultural sustainability of alternative farming systems, especially in regions practising incessant monoculture (Rigby *et al.*, 2001). These studies, however, lack an epistemological-based framework or have premediated criteria leading to weak methodological underpinnings. This study fills the gap in the existing literature by designing a composite quantitative and qualitative metric using the stock-and-flow framework to compare alternative farming systems and crops. A Comprehensive Farm Assessment Index (CFAI) was constructed based on the hierarchical weighting and progressive aggregation of 36 primary and 16 secondary indicators for seven dimensions measured over two cropping seasons. The field application of CFAI was followed to assess the alternate farming practices across three agro-climatic zones over two cropping seasons in selected districts of the State of Punjab.

Punjab has primarily been an agrarian economy and is currently contributing approximately 18% and 12% of the nation's wheat and rice production, respectively (Government of Punjab, 2023). Historically, the advent of the Green Revolution in the late 1960s led to increased areas under cultivation, wheat-rice cropping patterns, augmented use of fertilisers and pesticides, unabated drawing of groundwater and extensive farm mechanisation and crop protection measures, resulting in high crop productivity (World Bank, 2004). In addition, the government supported subsidies for power and minimum price for wheat and rice, incentivising farmers to adopt the hybrid seeds-chemical fertiliser-heavy irrigation technology package. Over the years, industrialised farming systems have taken their toll with deleterious effects on soil, water and air quality, resulting in decreased yields and high indebtedness. In the wake of the agrarian crisis, progressive farmers have recently transitioned to more holistic organic cultivation methods (e.g. Kaur, 2020; Singh, 2020; Tomar, 2019). However, little is known about the relative social and ecological effects of organic and conventional farming systems beyond economic considerations.

Limited studies have been conducted to assess agricultural sustainability in emerging countries that provide a holistic view of sustainability pertinent to alternate farming systems. This study contributes to the literature in several ways. First, with the need to move beyond the quantitative Farm Assessment Index (FAI), the CFAI incorporates both quantitative and qualitative aspects of farming in the indicator framework to assess alternative farming practices. In line with the definition proposed by the International Federation of Organic Agriculture Movements (IFOAM–Organics International, 2005), organic farming is a production system that sustains the health of soil, ecosystems and people. Second, the stock-and-flow framework offers a structural underpinning for selecting a comprehensive set of indicators across economic, social and ecological dimensions. Thus, expert judgment frees indicator selection from any bias that might creep in. Third, the normalisation of indicators makes it possible to use regional averages. Accordingly, the applicability of the index is ubiquitous and can be invoked for alternative sustainable approaches and practices across crops and regions. Fourth, besides collating data on indicators through an extensive questionnaire-based interview with farmers and testing of farm soil physicochemical properties, an immersive stakeholder engagement helped build consensus on the indicator classification and weights. Finally, the study provides a unique contextual insight into whether agronomically unfriendly practices, such as mono-cropping, can be sustainable. The findings are relevant as there is an urgent need to develop an evidence-based, stakeholder-engaged framework that entails an understanding of low-carbon organic farming and the drivers and actions to enable necessary policy changes.

2. Materials and methods

There are many stages in the construction process of the CFAI, in conjunction with decisions relating to the spatial distribution and selection of farmers, preparation and administration of the survey instrument and soil physicochemical analysis (Figure 1).

2.1 Developing a framework

The concept of "stock" and "flow" was constructed using the systems thinking method (Tao, 2010). This concept better captures the characteristics of a system, along with its causal forward and backward linkages, enabling a better understanding of the relative importance and reasons for the inclusion or exclusion of related indicators (Rossing *et al.*, 2007). Stock describes the system's characteristics accumulated over the long term, and flow describes the evanescent and dynamic characteristics of the system (Sterman, 2000). In addition to the number of stocks and flows, the attributes or characteristics of the system, which are usually context-specific, are also considered.

The "stock" and "flow" for wheat crop cultivation are illustrated in Figure 2. The portfolio of agricultural assets and total financial resources available to farmers determine the financial viability of economic components. The ecological aspects include groundwater and soil nutrient stocks, as well as inputs from other environmental elements such as rainfall and solar energy. Economic and social factors also contribute to increased wheat crop production. Factors of production are required to cultivate the land, which involve both economic

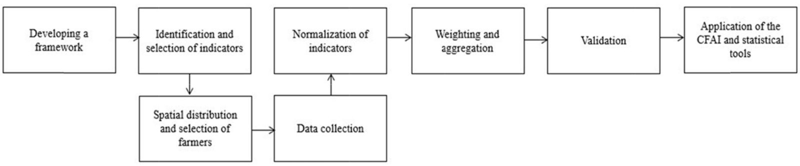

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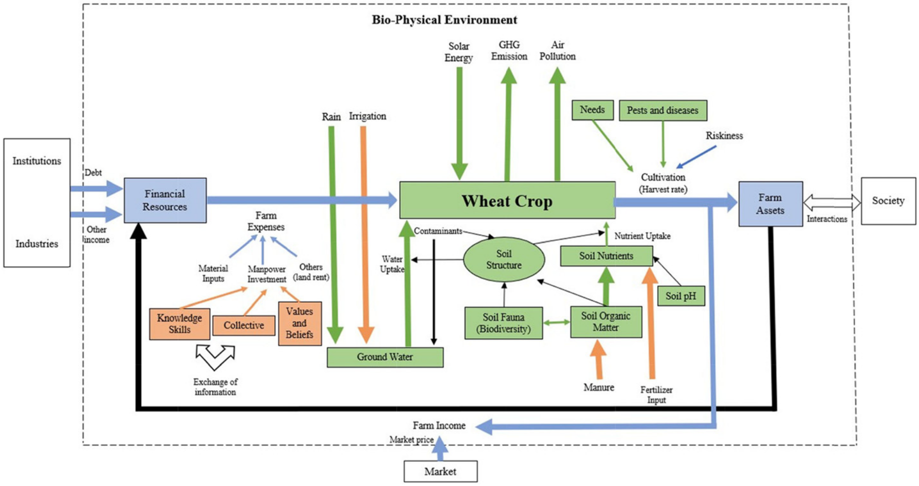
Figure 1. Methodology workflow



Notes: Rectangular boxes are stocks; ovals are other system components; solid arrows depict capital flows; thin line arrows show other dependencies; economic, social and ecological elements are in blue, peach and green, respectively
Source: Authors' own work

Figure 2. Stock and flow in wheat crop cultivation

(expenses) and social (resource) flows. Soil nutrient stocks are augmented using organic or inorganic fertiliser. Irrigation increases soil moisture levels. Other components of social capital include farmers' knowledge, skills, official and/or informal networks. The negative impact of farm inputs, such as the stockpile of soil nutrients and the water table, is reduced by flows to the growing crop. Similarly, excessive discharge of toxic fertilisers and pesticides can negatively influence the environment and society.

2.2 Indicator identification and selection

The stock-and-flow framework provides a structural basis for the process of indicator identification and selection, unlike several other frameworks where it is subjectively based on judgment. The indicator identification process began with defining the boundary settings due to the complexities of economic, social and environmental interactions. The stock-and-flow-based framework was then applied to identify a primary set of indicators, followed by selecting proxy indicators based on the scope of the field application (Muthuprakash and Damani, 2019). As advocated by Bockstaller *et al.* (2008), indicators were defined in the spatio-temporal continuum with the participation of stakeholders. Even though the indicators have standardised and extensive estimation methods, they were simplified based on the scope of the study, resource availability and data accessibility (Viglizzo *et al.*, 2006). For example, water use efficiency can be defined as yield per unit of water consumed by the crop or yield per unit of water applied to the field. A trade-off was made between the level of detailing and feasibility depending upon the end application and utility of the indicator. Contingent to the definition of indicators, an appropriate method was selected to estimate each indicator.

Several proxy variables were identified using the stock-and-flow framework and published literature to develop a set of indicators applicable for a wider application. First, all stock variables in the system and the intrinsic attributes of the system, like soil pH, were directly taken as indicators (Andrieu *et al.*, 2007). Second, indicators related to desirable outflows, like the benefit-cost ratio (BCR), were calculated directly. Third, a proxy was used for indicators related to undesirable outflows. For instance, pesticide contamination was determined by calculating the pesticide impact quotient (PIQ) using the toxicological database of pesticides and the applied dosage (Kovach *et al.*, 1992). Similarly, the Fertiliser Impact Quotient (FIQ) captures the direct and indirect impacts of fertiliser use. The usage of fertilisers causes soil pollution (ecological dimension). FIQ is calculated based on extra nutrients applied to the field. Disproportionate fertiliser use, often known as nutrient inefficiency, is an additional expense (economic dimension). Excessive fertiliser use has a negative influence on the health of farmers and neighbouring residents (social dimension). Finally, indicators from the impacts of inflow, like farm riskiness, were measured by taking total farm expenditure as the proxy because the market and institutions are outside the impact boundary (Harwood *et al.*, 1999).

Due to the qualitative nature of the social dimension, which is frequently elusive and devoid of consensus, accounting for the social aspects of a system was challenging (von Geibler *et al.*, 2006). Establishing a collection of indicators with a broader scope of application required descriptive features such as producer development, consumer impact and national impact. According to Muthuprakash and Damani (2019), the selection process is predicated on the specification of boundary conditions, followed by conceptualising the system using a stock-and-flow model. This method was then used to find and choose appropriate indicators. In defining socio-economic indicators, the term “paid-out cost” indicates the farmer’s actual spending without accounting for the cost of self-borne labour (e.g. family labour) and inputs (e.g. farmyard manure). When calculating the total cost of cultivation and total labour expense, the market value of the input and the opportunity cost of self-borne labour were computed and added to the paid-out cost and labour expense, respectively. Environmental indicators were estimated using a direct survey-based methodology. On the other hand, field indicators relied on soil samples from the field that underwent laboratory testing. The well-mediated process resulted in the selection of a comprehensive set of quantitative (19) and qualitative indicators (7), identified and selected across the economic, social and ecological dimensions (Appendix Table A1).

2.3 Spatial distribution and selection of farmers

Punjab is traditionally classified into three agro-climatic zones (World Bank, 2003). The organic and conventional farming systems across these zones – the North–East (districts of S. A.S. Nagar, Rupnagar, and Hoshiarpur), Central (Patiala District) and South–West (districts of Mansa and Bhatinda) – were assessed (Figure 3). Thus, 88 organic and 90 conventional farm plots across the three zones provided an opportunity to capture agricultural spatial variations. The two cropping seasons – Rabi 2020–2021 and Kharif 2021, were considered for analysis. The farmers primarily practice monoculture with a single-crop rotation (wheat-paddy or wheat–cotton). Accordingly, wheat, rice and cotton were the major crops of interest.

A list of organic farmers from the six districts under study was accessed through the database provided by non-profit registered trusts working with farmers to revive sustainable farming practices (the Kheti Virasat Mission and Nabha Foundation). Purposive sampling was adopted to cover the best comparative pairs of organic and conventional plots. The main criterion for selecting organic farmers was to ensure that the paired organic and conventional fields had similar farming conditions at the closest locations. In addition, organic farmers were shortlisted based on their conversion at least three years earlier, irrespective of whether they were certified.

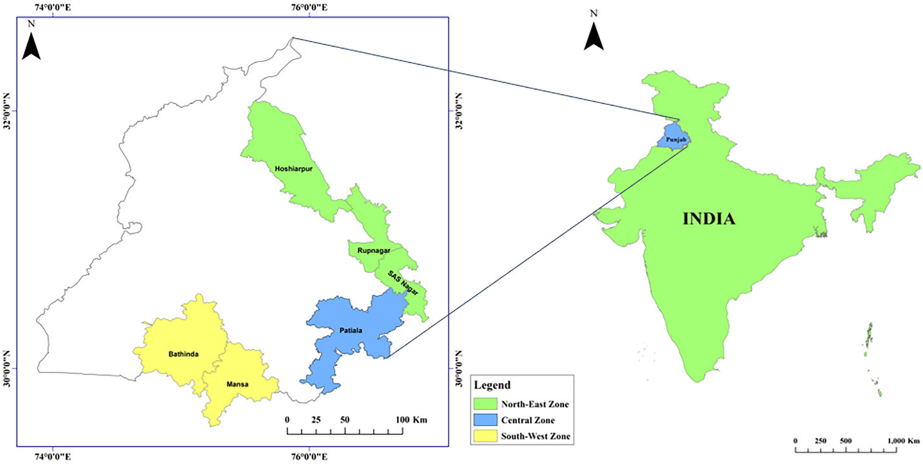


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Figure 3. Sample agro-climatic zones and districts under study

2.4 Data collection

The survey instrument used in this research was an extended version of the FAI proposed by Muthuprakash (2018). Accordingly, an extensively validated questionnaire was used to collect the quantitative details of farm inputs (actual and opportunity costs), including machinery usage, materials used and labour. Qualitative parameters were built to measure the contextual aspects of farming in the national indicator framework of sustainable agriculture (Muthuprakash and Damani, 2019; Muthuprakash *et al.*, 2020). The multidimensional nature of sustainability necessitated this diversity to obtain more reliable measures of general tendencies and to extricate these from circumstantial ones.

The questionnaire consisted of three parts. In Section 1, respondent farmers provided personal and asset details. Section 2 solicited data on constructing a quantitative CFAI. This was followed by questions on obtaining details about other sources of income the farmers had, debt position, and agricultural insurance or subsidies. Section 3 captured the general perception of on-farm management resources, social interface, extension activities, as well as their experiences, challenges and suggestions.

The respondents were informed about the research objectives at the very outset. They were also apprised of the value they were potentially bringing to the research. Furthermore, they were assured that anonymity would be observed, as stated on the questionnaire. Before administering the questionnaire-cum-interview schedule, their consent was obtained. The questionnaires were personally administered and completed in the field by trained facilitators over a period of six months.

Concerted efforts were made to collect soil samples from all the farm plots. Each sample was collected per the Government of India's soil testing manual (Department of Agriculture and Cooperation, 2011). Available nitrogen (N), phosphorus (P) and potassium (K) were estimated by Kjeldahl (1883), modified Bray (Bray and Krutz, 1945), and flame photometric methods (Jackson, 1973), respectively. The pH (1:2) was determined using a digital pH meter, while salinity was gauged by an electrical conductivity meter (ELICO-L11 62). The soil organic carbon (SOC) was assessed using Walkley and Black's rapid titration method

(Walkley and Black, 1934). The Bhumi Vigyan Vibhag, Punjab Agricultural University, Ludhiana, analysed all samples.

The average age of the respondents was 47 years, with the youngest and oldest at 23 and 72 years, respectively (Table 1). The participation of youth (< 30 years) in farming is a dismal ten per cent. The overall sample had only 2% of women farmers who were fully organic cultivators. The distribution shows that 63% of farmers are educated at a higher secondary level and above. None of the uneducated farmers were engaged in full-time organic agriculture. With an average farming experience of 25 years, 70% of farmers had been farming for 20 years or more.

Agriculture was the primary occupation of 96% of farmers, with about 45% having an alternate source of income. About 84% of farming households owned livestock, primarily buffalos and cows. More than half of the farmers were in debt. With 100% of the land irrigated, around 83% of the organic farmers cultivated their self-owned land compared to 67% of the conventional ones. The average size of organic (conventional) plots was 2.56 (11.16) acres (Table 2). The organic farmers primarily cultivated small and marginal farm plots. Among the organic farmers, 49% were certified.

2.5 Normalisation of indicators

A prerequisite for aggregation is to normalise the indicators so that they are stated in relative terms and are suitable for aggregation (OECD, 2008). The widely accepted min-max method

Table 1. Demographic profile of the farmers

Profile	No. (%)
Gender	
Male	122 (98)
Female	3 (2)
Age (*in years*)	
<30	13 (10)
30–39	27 (22)
40–49	28 (22)
50–59	29 (23)
60–69	22 (18)
>70	6 (5)
Education	
No formal education	5 (4)
Primary	6 (5)
Secondary	35 (28)
Higher-secondary	33 (26)
Graduate	30 (24)
Post-graduate	16 (13)
Farming experience (*in years*)	
<10	16 (13)
10–19	21 (17)
20–29	34 (27)
30–39	27 (22)
40–49	19 (15)
≥50	8 (6)

Note: $n = 125$
Source: Authors' own work

Table 2. Farm plot sizes

Crop	Obs.	Mean	SD	Min	Median	Max
Panel A: North–East zone (Districts of S.A.S. Nagar, Rupnagar and Hoshiarpur)						
Organic						
Wheat	30	2.87	2.50	0.50	2.00	10.00
Rice	27	3.02	2.59	0.50	2.00	10.00
Conventional						
Wheat	32	6.63	7.48	1.00	3.50	30.00
Rice	31	6.47	7.05	1.00	4.00	30.00
Panel B: Central zone (Patiala District)						
Organic						
Wheat	30	2.73	2.59	1.00	2.00	14.00
Rice	28	2.82	2.66	1.00	2.00	14.00
Conventional						
Wheat	30	19.48	17.01	4.00	15.00	70.00
Rice	30	19.48	17.01	4.00	15.00	70.00
Panel C: South–West zone (Districts of Mansa and Bathinda)						
Organic						
Wheat	31	2.10	1.49	1.00	1.50	7.00
Rice	18	2.33	1.50	1.00	2.00	7.00
Cotton	13	1.56	1.11	1.00	1.00	5.00
Conventional						
Wheat	31	15.40	13.16	1.50	15.00	64.00
Rice	23	14.11	13.05	1.50	14.00	64.00
Cotton	07	12.21	8.70	3.00	8.00	25.00
Panel D: Plot sizes (in acres)						
Organic						
Total	88	2.56	1.88	1.00	2.00	9.00
Conventional						
Total	90	11.16	8.58	1.00	9.00	36.00

Source: Authors' own work

with a pre-set reference was selected to normalise the indicators (e.g. Hajkowicz, 2006). The method retains the factual relationship between the samples with a continuous and linear function. The reference points for normalisation were identified for each indicator based on benchmarks (national or state standards), extant literature (e.g. Nambiar *et al.*, 2001; Sharma and Shardendu, 2011), or expert opinion. As proposed by Ceyhan (2010), the value of a given indicator was transformed between "0" and "1" using the following equations, where V_b and V_c are the normalised values for benefit and cost indicators, respectively, x_i is the actual indicator value, $max_i(x)$ and $min_i(x)$ are the maximum and minimum reference values for a given indicator "*i*":

$$Vb = \frac{xi - mini(x)}{maxi(x) - mini(x)} \text{ or } Vc = \frac{maxi(x) - xi}{maxi(x) - mini(x)}$$

Table 3 illustrates the reference points for the seven socio-economic indicators and three crops for Punjab. Regarding the soil parameters, reference points were set based on their

Table 3. Select reference values for socio-economic indicators for the state of Punjab

Crop	Farm expenditure (₹/acre)	Paid-out cost (₹/acre)	Gross income (₹/acre)	Net income (₹/acre)	Benefit-cost ratio	Labour expense (%)	Drudgery (₹)
Wheat	24,157	10,122	81,730	71,608	6.77	0.37	4,513
Rice	33,912	12,407	99,309	86,902	5.86	0.79	13,332
Cotton	43,222	14,474	1,07,265	92,792	4.96	1.01	21,857

Notes: Farm expenditure is the total cost of cultivation with the cost imputed for self-borne labour and inputs; paid-out cost is the total farm costs less the costs of self-borne labour and inputs; gross income is the total income from main- and by-products; net income is gross income less paid-out cost; benefit-cost ratio is gross income divided by total cultivation cost per acre; labour expense is the percentage of labour cost to operational expenses; drudgery is gross income per unit labour cost
Source: Directorate of Economics and Statistics, Government of India (2019)

scientific thresholds. The normalisation references for PIQ, FIQ, soil parameters and NPK composition are presented in Appendix 2 (Tables A2–A5).

2.6 Weighting and aggregation

Both normative and statistical methods can be adopted for weighing the indicators (OECD, 2008). The normative or opinion method of the hierarchical analytical process has been adopted to assign weights to indicators as it improves the social preference factor (Weber *et al.*, 1988) and makes it more appropriate for practical application (Gómez-Limón and Sanchez-Fernandez, 2010). Weightage was assigned using the Delphi technique by organising interactions with various study stakeholders and an expert panel for consensus on the selections and weights. The inputs on weightage were taken anonymously over multiple rounds. To ensure the robustness of the weighting process, progressive aggregation was adopted, where weighting and aggregation were performed individually at each hierarchical level (Pöyhönen and Hämäläinen, 1998). The hierarchical weighting of attributes reduces the splitting biases that might implicitly crop up when deciding the weight to be assigned to indicators (Weber *et al.*, 1988).

At the dimensional level, three separate indices – economic, social and ecological – were determined by aggregating indicators (36) and sub-indicators (16). The weightage at the highest in the hierarchy of the dimensions was rounded off to 40%, 30% and 30% for the economic, social and ecological dimensions, respectively. Thus, the CFAI of the farming system was constructed using the aggregate of indicators across all three dimensions.

2.7 Validation

This work draws from the research of Muthuprakash (2018), who validated and conducted a sensitivity analysis of the indicators comprising the FAI tool. This composite index added 13 additional qualitative indicators based on previous research. The indicators used in developing the CFAI were validated using the Delphi technique, which is widely used to validate the data, especially in tools of sustainability and agricultural assessment (Allen *et al.*, 2019). As a first step, a focused group discussion-cum-workshop was held in collaboration with Krishi Vigyan Kendra, S.A.S. Nagar (Mohali). The Delphi technique does not call the expert panel representative samples for statistical purposes, so as a second step, three experts were chosen based on their knowledge and experience in sustainable farming practices and processes. As suggested by Skulmoski *et al.* (2007), two iterations were considered sufficient because the participating experts agreed upon the indicator set and its hierarchy at the end of two rounds.

2.8 Application of the Comprehensive Farm Assessment Index and statistical tools

The spreadsheet tool devised by Muthuprakash (2018) was improvised to make it region-specific and include qualitative factors. Accordingly, the reference points used for normalisation and the weightage distribution were altered among the indicators. The data from the field visits was entered into the CFAI tool, and efforts were made to avoid data gaps and extreme entries.

The main quantitative characteristics of the sample were explored by applying descriptive statistics to the participants and their groups. Significant differences between the organic and conventional farming methods were analysed using the SPSS software (version 26). Univariate analysis was done by invoking one-way analysis of variance (ANOVA) using the general linear model to determine the differences between farming systems.

3. Results and discussion

3.1 Economic indicators

The one-way ANOVA procedure showed statistically significant mean differences between the organic and conventional farming systems in terms of key production costs and income for wheat, rice and cotton crops (Table 4). There was a statistically significant difference for wheat between organic and conventional systems for labour cost ($p = 0.003$) and gross income ($p = 0.032$) in the North–East zone, with the mean values being higher for organic farm plots. Similarly, for the Central and South–West zones, machine-related and total costs were significantly higher for organics ($p < 0.001$). On the other hand, in the South–West zone, the average gross income of organic wheat was significantly lower ($p = 0.005$).

For paddy, mean scores for material and total costs were significantly higher for organic *vis-à-vis* conventional farm plots for both the North–East and South–West. This income divergence for gross ($p = 0.002$) and net ($p = 0.018$) rice production shows a lower income realisation for organic production. A similar outcome has been reported in the South–West zone, even though it is insignificant. Although the material cost is significantly higher ($p = 0.099$) due to lower labour and machinery costs, the net income of organic cotton growers is higher at the 10% significance level.

The normalised economic indicators provide additional insights (see Appendix Figure A1). The values for wheat show that the income and nutrient use efficiency are better in the case of organic farms situated in the North–East zone. For the Central zone, the values were higher for income per acre and riskiness. Likewise, the nutrient use efficiency parameters for organic paddies were higher for the North–East and Central zones. Furthermore, the normalised values for income and riskiness were better in the Central zone. On the other hand, the organic cotton cropping in the South–West zone yields a higher income, BCR and riskiness.

3.2 Social indicators

The normalised values for most social indicators are higher for the organic farming system (Appendix Figure A2). This is irrespective of the crops sown or the agro-climatic zones. Drudgery measured as gross income per unit labour is high for both organic and chemical farms as the net receipt from the farm produce is relatively high compared to the labour involved in the production process. Furthermore, agricultural output and the employment generated were higher for the conventional farming system.

For the wheat crop, higher values are for farm resources for the North–East zone and social capital, financial resources and gender equality for the Central and South–West zones.

Table 4. Crop- and zone-wise one-way analysis of variance (ANOVA) results for farm costs and income (in xxx/acre)†

Crop	Organic mean	Conventional mean	Mean difference (organic – conventional)	df	*F*	Sig.
Panel A: North–East zone						
Wheat						
Material cost	2,02,455.19	28,681.36	1,73,773.83	62	3.761*	0.057
Labour cost	10,861.22	7,601.92	3,259.30	62	9.425***	0.003
Total cost	2,18,665.79	41,388.91	1,77,276.88	62	3.819*	0.055
Paid-out cost	1,94,456.46	36,347.62	1,58,108.83	62	3.804*	0.056
Gross income	60,060.68	41,824. 70	18,235.98	62	4.822**	0.032
Panel B: Central zone						
Machine cost	42,538.78	6,861.17	35,677.61	58	33.646***	<0.001
Total cost	65,885.28	29,232.41	36,652.87	58	13.051***	<0.001
Panel C: South–West zone						
Gross income	35,499.19	46,056.21	−10,557.02	60	8.533**	0.005
Panel A: North–East zone						
Rice						
Material cost	1,73,158.40	3,677.319	1,69,481.07	58	1.443**	0.014
Total cost	2,17,082.50	54,768.98	1,62,313.53	58	1.391**	0.027
Panel B: Central zone						
Gross income	53,678.11	59,963.13	−6285.01	56	10.097***	0.002
Net income	24,293.97	32,096.90	−7802.93	56	5.957**	0.018
Panel C: South–West zone						
Material cost	25,357.22	8,084.25	17,272.97	39	6.063**	0.018
Total cost	59,695.46	40,734.67	18,960.78	39	3.293*	0.077
Panel A: South–West zone						
Cotton						
Material cost	7,494.63	6,384.52	1,110.11	18	2.997*	0.099
Net income	36,475.35	24,881.31	11,594.03	18	2.963*	0.100

Notes: †Only significant results have been reported. The number of observations for organic (conventional) plots for wheat, rice and cotton is 33 (31), 27 (30) and 13 (7), respectively; ***, ** and *indicate significance at the 1, 5 and 10 % levels, respectively
Source: Authors' own work

For rice cultivation in the North–East zone, the values for farm and financial resources were higher for organic farmers. In the other two zones, the indicators for organics were higher for social capital and gender equality. Financial resources are important for organic farmers growing cotton, a cash crop.

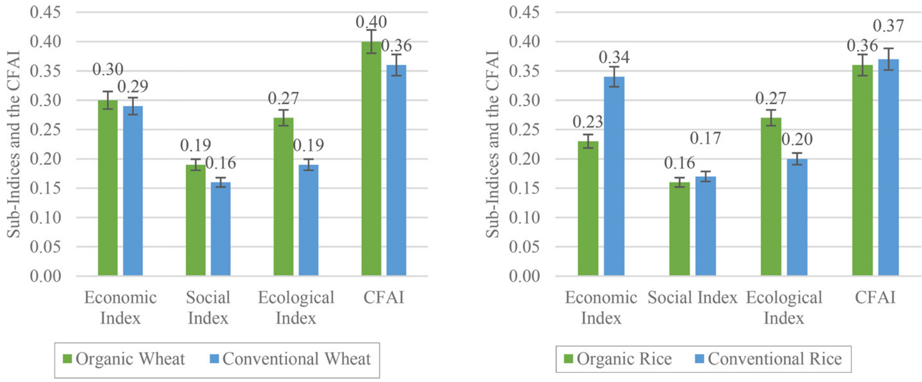
3.3 Ecological indicators

A striking observation across all zones and crops was more biodiversity and less water contamination on organic farms *vis-à-vis* conventional farms (Appendix Figure A3). Furthermore, soil contamination is lower for paddy and organic fields in the North–East and South–West zones.

Among the soil health field parameters, the normalised values of SOC and nitrogen (N) are higher for organic wheat and paddy, irrespective of the location of the farm plots (Appendix Figures A4–A6). In contrast, the soil pH level was marginally higher in conventional plots in the sample zones. Concurrent with the normalised values, the SOC was higher for organic farms. Similarly, the soil phosphorus (K) content was higher in the organic plots. On several organic farms, it has been observed that using compost, manure, bio-fertiliser, crop residue and cover crop increases soil test P and K levels above sufficiency.

3.4 Composite indices

The CFAI summarises the complex multidimensional realities of alternative farming systems. In the North–East zone (Figure 4), the economic index of wheat was marginally higher for organic farms. This is because of their relatively higher income and better nutrient efficiency. However, the economic index of organic paddies has a lower score because of the exorbitant total costs, particularly material costs. The social index indicates that organic farms scored higher than chemical farms for wheat but lower for rice. The positive impact of self-reliance and the health impacts of using negligible pesticides can be observed in the index for wheat. Furthermore, farm resources with peripheral trees, livestock ownership and institutional support have positive effects. On the other hand, the colossal difference in the yield between organic and conventional paddies did undo the positive impact of the abundance of financial resources. Finally, the ecological index for wheat and paddy was higher for organic plots, especially for water contaminants and SOC. Overall, the CFAI for



Source: Authors' own work

Figure 4. CFAI for crops in the North–East zone

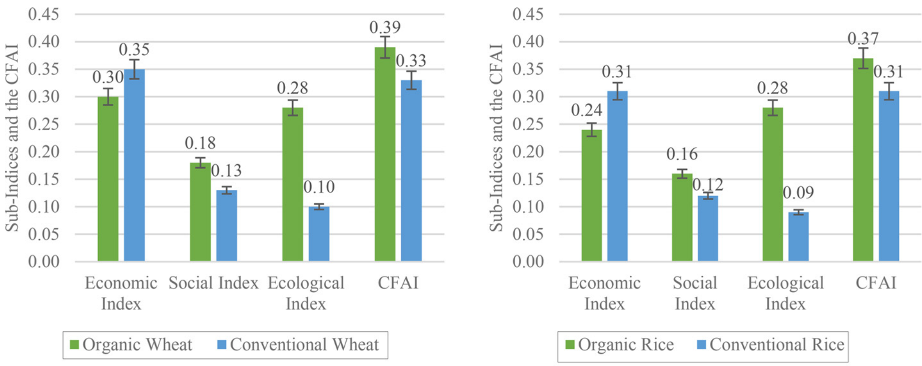
organic wheat was higher than that for paddy. Thus, farm economics focuses on income and yield maximisation, which is essential for farm management.

The economic indices for wheat and paddy are lower for organic *vis-à-vis* conventional farms in the Central zone (Figure 5). This is because of the exceedingly high cost of production, leading to poor incomes. On the other hand, the social indices for organic wheat and paddy were higher than those for conventional ones. Although the yield is similar to conventionally cultivated wheat, the self-borne cost of the total cost and positive health impacts benefit the index for organics. In the case of paddy fields, health impacts based on the potential absence of toxicity in organic cultivation had a beneficial effect on the social index. The ecological index was higher for both organic wheat and paddy, implying the adverse effects of chemical farming on the soil, water and organisms. All in all, the CFAI of organic farms was higher than that of chemical wheat and paddy farms.

The results for the indices in the South–West zone differ for cotton crops *vis-à-vis* wheat and paddy (Figure 6). The economic index of the organic production of wheat and rice is low because of the higher costs and lower incomes. On the other hand, organic cotton has a significantly positive income with associated effects on BCR and riskiness. The social index of all crops is higher because of the positive effect of financial resources, self-reliance and good health implications resulting from the lack of pesticide usage. The ecological indices were higher for organic than for conventional wheat, paddy and cotton. Thus, CFAI is higher for organic than conventional production systems.

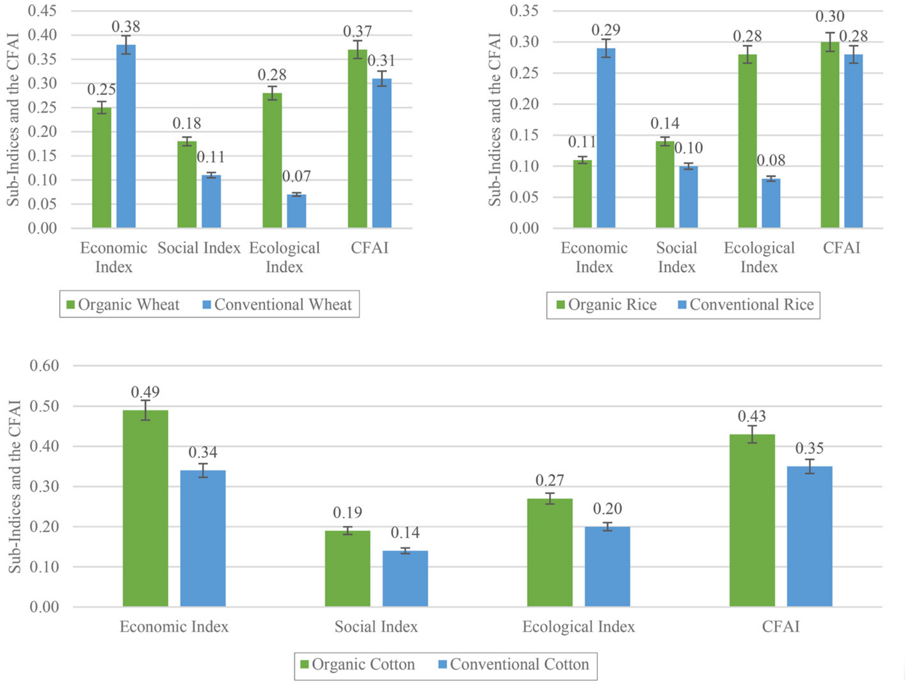
The comparative CFAI highlights that, except for paddy cultivation in the North–East region, the composite indices for organic farming are higher than those for the conventional systems (Figure 7). The highest composite value calculated (0.43) was for organic cotton, which is a cash crop, compared to food grains, wheat and rice.

Overall, the results from the CFAI application in alternate farming systems indicate that a sole focus on economic returns is not tenable. While the cost of production is a significant factor, it is only relevant in determining the economic viability of the farming system, as posited in the literature (Reganold and Wachter, 2016). Beyond economics, indicators affecting both social and ecological indices have profound implications for composite farm assessments. Organic farms scored better on both social and ecological indices. Hence, adopting organic practices under continuous wheat–rice or wheat–cotton cultivation conditions would seem sustainable, as substantiated in mono-cropping systems (e.g.



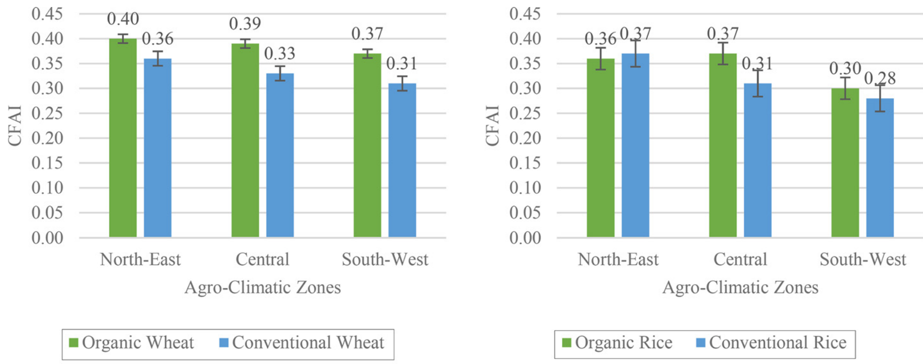
Source: Authors' own work

Figure 5. CFAI for crops in the Central zone



Source: Authors' own work

Figure 6. CFAI for crops in the South–West zone



Source: Authors' own work

Figure 7. Comparative CFAI across agro-climatic zones

Mukhovi and Jacobi, 2022; Zhang *et al.*, 2016). The pesticide and FIQs are critical factors affecting the social and ecological indices of conventional farms. Furthermore, higher self-borne costs (self-reliance) on organic farms have also affected the social index score. Input-intensive crops such as paddy have lower CFAIs and marginal differences between organic and conventional index scores (negative for organic in the North–East zone). On the other hand, organic cotton farming has benefitted farmers economically and scored better in social and environmental indices, as evidenced in the literature on developing countries (e.g. Williamson *et al.*, 2005; Eyhorn *et al.*, 2007).

4. Conclusion and recommendations

With the epistemological underpinning of a stock-and-flow-based framework, the present analysis attempts to develop a composite index to assess alternative farming systems on economic, social and ecological dimensions in the selected districts of Punjab. The field application of CFAI highlights that organic farming practices contribute to overall agricultural sustainability. This is because of the use of their own and local resources, ingenious knowledge, increased soil fertility, reduced degradation, biodiversity conservation and a forged spirit of collaborative partnership and support. In addition, the organic system is part of a diverse mixed farming system, including livestock and cultivation of peripheral trees and plants, which reduces farmers' vulnerability. Organic agriculture provides considerable health benefits by lowering pesticide exposure of farmers, workers, rural communities and consumers.

The adoption of sustainable practices is, to a considerable extent, influenced by the institutional context as well as national and state policies. With State support, Punjab was chosen as the initiation site for the green revolution technology. The state's top-down approach through investments and subsidies led to initial adoption and concomitant bumper harvests but resulted in spatial and social disparities over the years. The change from traditional sustainable methods to monocropping and unsustainable practices has adverse effects on the socio-economic conditions and environment of rural communities. Currently, organic farming is promoted and facilitated by central governmental and non-profit organisations; however, it has had marginal success in Punjab. The results strongly indicate that if organic agriculture is to provide sustainable food security and livelihood, economic sustainability must be ensured through adequate pricing and market accessibility. Primary data also revealed that promoting networks, providing training and extension services, expanding value-added food processing facilities, engaging youth and enabling women's participation to enhance social sustainability are critical factors influencing the shift to organic agriculture.

From a policy perspective, CFAI enables assessment at a disaggregated spatial level, which provides valuable information at the state level. If applied at a broader level, the index can help identify the strengths and weaknesses of each region and enable the comparison of the performance of individual and composite indicators with the benchmark average. Thus, they can support the development of strategies and effective policies. Furthermore, temporal mapping of the CFAI can enable changes to be tracked to identify trends and progress. The index can also help create awareness amongst the diverse stakeholders regarding sustainability challenges, thus sensitising them to the perils of industrial agricultural practices. This is true in that the market share of organic food remains small because consumers prefer organic food but are unwilling to pay a price premium. Finally, dissemination of the benefits of diversity by intercropping and crop rotation, even while practising agro-industrial cropping systems, can bring desirable outcomes (Lin, 2011). Furthermore, crop varieties suitable for organic farming should be propagated given the agro-climatic conditions.

The application of CFAI to assess alternate farming systems provides a sound epistemological basis and reliable estimate for decision-making. The findings of this study should, however, be interpreted with caution owing to some limitations. First, a composite indicator was applied to compare farming systems at the field level in Punjab. There is always scope to build a more intensive index that incorporates additional qualitative factors. Second, survey-based field data have the inherent problem of flawed respondent discernment and recall errors. Furthermore, collating technical specifications in farm inputs, especially self-labour or home-based inputs, can be tenuous. Third, comparing organic and conventional farming systems presents several methodological challenges and trade-offs between expeditiousness and accuracy. Although significant zone- and crop-wise disparities in farming practices were observed, the results can be better deduced using larger samples. Finally, a longitudinal research design involving more cropping seasons would allow for a more rigorous analysis.

The results suggest that the field's status is promising, with uncharted prospects. Future research can focus on invoking a farm assessment tool to study differences across spatial and temporal scales for alternate agricultural systems for different regions, landscapes (low versus highly productive), crops and livestock products. A cropping system approach that considers multiple crops in a rotation and their interactions can be effective. Women's low engagement and failure in policy intervention to create sustainable livelihoods for rural women, too, can be examined. Experimenting with multiple crops in a rotation and their interactions would provide interesting insights into different cropping system approaches to sustainability. Alternative methodological frameworks can be explored to create composite indices, including weighting, aggregation and robustness. Furthermore, because the choice of quantitative- versus qualitative-based indicators impacts the outcome, it is worth exploring other surrogate measures. This is specifically true for social indicators, which are more complex and abstract; for example, indicators capturing both social capital and well-being. The methods and means of evolving and enhancing the evaluative tool to work as a decision tool would contribute to the practical applications that benefit decision-makers. Finally, good or optimal organic management practices must be documented and disseminated to achieve environmental sustainability.

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Appendix 1

Table A1. Description of dimensions, indicators, units of measure and explanation of indicators

Dimension	Primary indicator	Estimated and proxy indicator	Measure	Unit	Estimation	Definition
Panel A: Economic index						
Financial benefits	Income per acre	Net income	QN	₹/acre	Field survey	The total value of the farm produce minus the paid-out cost for cultivation
	Benefit-Cost ratio (BCR)	BCR	QN	Dimensionless	Field survey	The ratio of the total value of farm produce to the paid-out cost of cultivation
	Riskiness	Farm cost	QN	₹/acre	Field survey	The total cost of cultivation with the cost imputed for self-borne labour and inputs
Resource efficiency	Nutrient use efficiency	Fertiliser Impact Quotient (FIQ)	QN	Dimensionless	Field survey	An estimate of nutrient balance between total nutrients applied and nutrients consumed with respect to the crop yield
	Water use efficiency	Irrigation scheduling	QL	Dimensionless	Field survey	The decision of irrigation scheduling, i.e., when (timing) to water a field to maximise irrigation efficiency and crop production
Panel B: Social index						
Producer development	Farmer knowledge	Knowledge	QL	Dimensionless	Field survey	The choice for the basis of crop selection, willingness to learn new practices and access new information, level of knowledge of best farming practices (e.g. drip, sprinkler) and its sources, source of price information, and approached institution for advice
	Social capital	Community association	QL	Dimensionless	Field survey	An association with the community or producers' group, benefits gained, and the strength and composition of the group
	Farm resources	Livestock ownership	QL	Dimensionless	Field survey	The ownership of livestock and other peripherals
	Financial resources	Paid-out cost of cultivation	QN	₹/acre	Field survey	The paid-out cost of cultivation, i.e. is the total farm costs less the costs of self-borne labour and materials;
	Self-reliance	Self-borne cost	QN	Dimensionless	Field survey	The ratio of self-borne cost to total cost of cultivation
	Drudgery	Labour cost	QN	Dimensionless	Field survey	Gross income per unit labour cost
Consumer impact Consumer impact	Health impacts from fertilisers	Fertiliser impact quotient (FIQ)	QN	Dimensionless	Field survey	An estimate of nutrient balance between total nutrients applied and nutrients consumed with respect to the crop yield
	Health impacts from pesticides	Pesticide impact quotient (PIQ)	QN	Dimensionless	Field survey and PIQ tool	An impact estimate based on the potential toxicity of active ingredients and the dosage applied

(*continued*)

Table A1. Continued

Dimension	Primary indicator	Estimated and proxy indicator	Measure	Unit	Estimation	Definition
National impact	Agricultural output	Yield per Acre	QN	Kilograms per acre	Field survey	The total crop produce, including intercrops
	Employment	Labour expenditure	QN	Dimensionless	Field survey	The ratio of total labour cost to the total cost of cultivation
	Gender equality	Women employment	QL	Dimensionless	Field survey	The contribution of women to agricultural operations
	Institutional strength	Institutional intervention	QL	Dimensionless	Field survey	The availability of credit sources, reasons for selecting a crop, sources of price trends and other information, and the benefit of joining a community or producers' group
Panel C: Ecological index						
Environmental	Biodiversity	Peripheral trees	QL	Dimensionless	Field survey	The decision to crop and plant peripheral trees
	Soil contamination	Fertiliser impact quotient (FIQ)	QN	Dimensionless	Field survey	The estimate of nutrient balance between total nutrients applied and nutrients consumed to the crop yield
	Water contamination	Pesticide impact quotient (PIQ)	QN	Dimensionless	Field survey and PIQ tool	An impact estimate based on the potential toxicity of active ingredients and the dosage applied
Field	Soil health (nitrogen)	Soil nitrogen	QN	Parts per million	Laboratory testing	The available nitrogen (N) in the soil
	Soil health (phosphorus)	Soil phosphorus	QN	Kilograms per hectare	Laboratory testing	The available phosphorus (P) in the soil
	Soil health (potassium)	Soil potassium	QN	Kilograms per hectare	Laboratory testing	The available potassium (K) in the soil
	Soil health (soil organic carbon)	Soil organic carbon	QN	Concentration (%)	Laboratory testing	The carbon stored insoil organic matter
	Soil health (pH)	Soil pH	QN	Dimensionless	Laboratory testing	The pH of the soil
	Soil health (salinity)	Soil salinity	QN	Decisiemens per metre	Laboratory testing	The salinity of the soil measured through electrical conductivity

Notes: QN and QL stand for quantitative and qualitative measures for indicators
Source: Compiled by the authors

Appendix 2

Table A2. Reference for pesticide impact quotient (PIQ)

Pesticide	EIQ (per unit litre)	Reference EIQ (% of threshold point)	Maximum recommended dose (kilogram per acre)	EIQ of recommended dose
Acephate	41.33	33.07	0.40	16.53
Carbendazim	55.70	33.42	0.30	16.71
Chloropyrophos	28.40	28.40	0.50	14.20
Clodinafop-propargyl (Topik)	11.90	6.00	0.25	3.00
Cypermethrin	7.70	7.70	0.50	3.85
Diafenthiuron	35.33	11.31	0.16	5.65
Sulfosulfuron (leader)	46.30	1.40	0.14	0.70

Note: EIQ stands for Environmental Impact Quotient (https://nysipm.cornell.edu/eiq/calculator-field-use-eiq/)
Source: Eshenaur *et al.* (2016)

Table A3. Reference for yield and fertiliser impact quotient (FIQ)

Crop	Average yield (kilograms per acre)	Nutrient absorption reference (kilograms per metric tonne)		
		N	P	K
Wheat	561.86	128.00	46.00	219.00
Paddy	1,200.00	20.00	11.00	30.00
Cotton	127.50	156.00	36.00	151.00

Source: Directorate of Economics and Statistics (2019) and Roy *et al.* (2006)

Table A4. Reference for soil parameters

Parameters	Reference	
	0	1
Soil organic carbon (%)	0.00	0.75
Total nitrogen (%)	0.00	0.25
Available nitrogen (kilograms per hectare)	0.00	560.00
Available phosphorous (kilograms per hectare)	0.00	24.60
Available potassium (kilograms per hectare)	0.00	280.00
pH	9.00	7.00
Salinity (mS/cm)	16.00	2.00

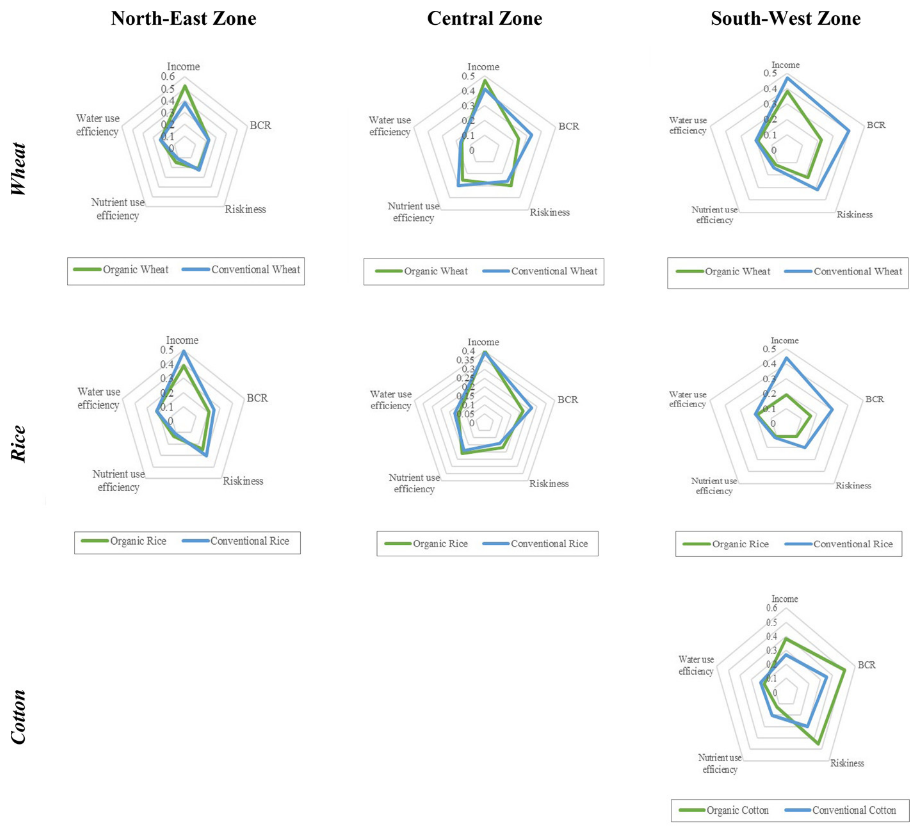
Source: Department of Agriculture and Cooperation (2011) and Hazelton and Murphy (2007)

Table A5. NPK composition standard of nutrient inputs used in FIQ

Fertiliser input	N (%)	P (%)	K (%)
10:26:26	10.00	26.00	26.00
15:15:15	15.00	15.00	15.00
18:18:10	18.00	18.00	10.00
19:19:19	19.00	19.00	19.00
20:20:00	20.00	20.00	0.00
Biosuper	0.00	0.00	0.00
Compost	0.75	0.60	1.00
Cow dung manure	0.45	0.35	0.35
DAP	21.00	23.00	0.00
FYM	0.95	0.60	1.10
Gomuthram	1.05	0.11	0.75
Green leaves	2.85	0.37	1.67
Green manuring	2.83	0.54	1.74
Jivamrut	1.96	0.17	0.28
Neem cake	5.20	1.00	1.40
Panchagavyam	2.29	2.09	2.32
Potash	0.00	0.00	50.00
Poultry manure	1.40	1.60	0.85
Single superphosphate	0.00	8.80	0.00
Urea	46.00	0.00	0.00
Vermicompost	1.06	0.61	0.44
Zinc and magnesium	0.00	0.00	0.00

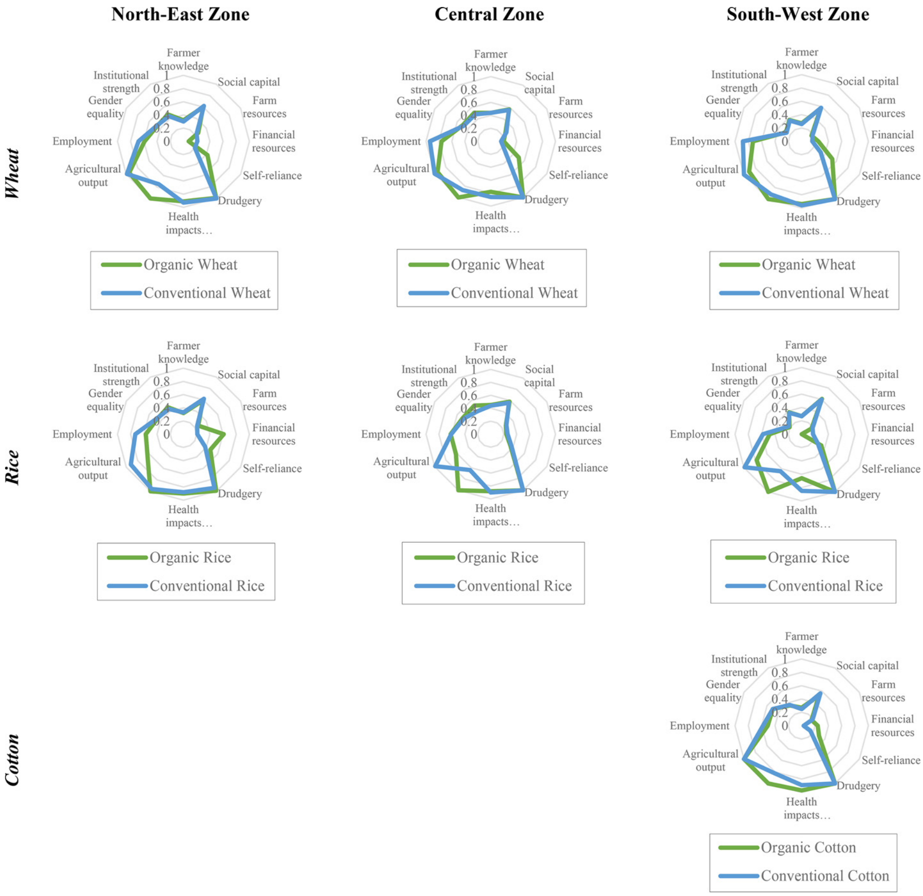
Source: Devakumar *et al.* (2014)

Appendix 3



Notes: BCR stands for benefit-cost ratio; Assigned value between ‘0’ and ‘1’ using min-max normalisation; (a) North-East Zone; (b) Central Zone; (c) South-West Zone
Source: Authors’ own work

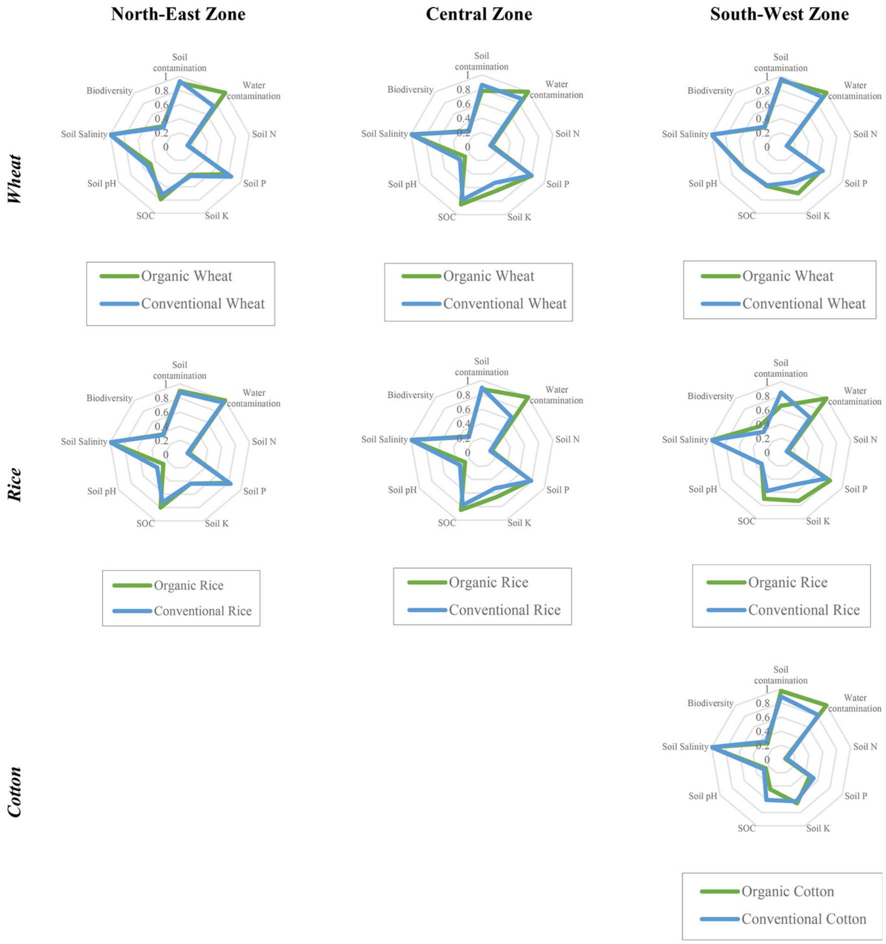
Figure A1. Economic indicator values



Notes: Assigned value between '0' and '1' using min-max normalisation; (a) north-east zone; (b) central zone; (c) south-west zone

Source: Authors' own work

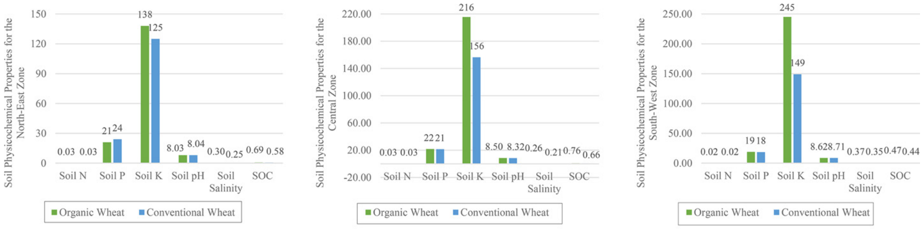
Figure A2. Social indicator values



Notes: soil N, P, and K stand for nitrogen, phosphorus, and potassium, respectively; SOC is the soil organic carbon: Assigned value between ‘0’ and ‘1’ using min-max normalisation; (a) north-east zone; (b) central zone; (c) south-west zone
Source: Authors’ own work

Figure A3. Ecological indicator values

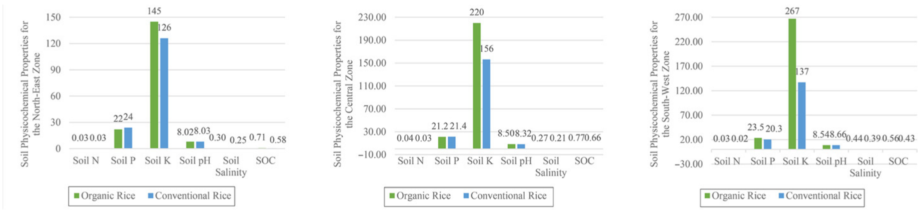
Appendix 4



Notes: Soil N, P, and K stand for nitrogen, phosphorus, and potassium, respectively; SOC is the soil organic carbon

Source: Depicted by the Authors based on the Soil Test Reports from Bhumi Vigyan Vibhag (Soil Testing Laboratory), Punjab Agricultural University, Ludhiana, Punjab

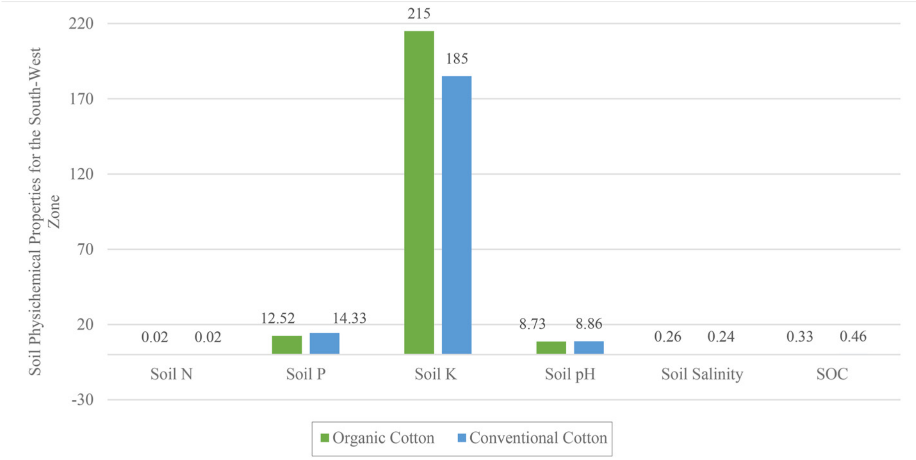
Figure A4. Soil physicochemical properties of wheat (based on field soil sample analysis)



Notes: Soil N, P, and K stand for nitrogen, phosphorus, and potassium, respectively; SOC is the soil organic carbon

Source: Depicted by the Authors based on the Soil Test Reports from Bhumi Vigyan Vibhag (Soil Testing Laboratory), Punjab Agricultural University, Ludhiana

Figure A5. Soil physicochemical properties of rice (based on field soil sample analysis)



Notes: Soil N, P, and K stand for nitrogen, phosphorus, and potassium, respectively; SOC is the soil organic carbon

Source: Depicted by the Authors based on the Soil Test Reports from Bhumi Vigyan Vibhag (Soil Testing Laboratory), Punjab Agricultural University, Ludhiana

Figure A6. Soil physicochemical properties of cotton (based on field soil sample analysis)

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